No. 141, Original

In the

SUPREME COURT OF THE UNITED STATES

STATE OF TEXAS,

Plaintiff,

v.

STATE OF NEW MEXICO and
STATE OF COLORADO,

Defendants.

OFFICE OF THE SPECIAL MASTER

APPENDIX OF EVIDENCE
IN SUPPORT OF STATE OF TEXAS'S NOTICE OF MOTION AND MOTION FOR PARTIAL SUMMARY JUDGMENT; MEMORANDUM OF POINTS AND AUTHORITIES IN SUPPORT THEREOF
FEDERAL RULE OF CIVIL PROCEDURE 56

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APPENDIX OF EVIDENCE

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1	Declaration of Robert Brandes, P.E., Ph.D., and Attachments 1-3	TX_MSJ_000001	TX_MSJ_000016
2	**Attachment 1:** Resume	TX_MSJ_000017	TX_MSJ_000021
3	**Attachment 2:** National Resources Committee, Regional Planning: Part VI-The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico, and Texas 1936-1937, published in February 1938 (JIR)	TX_MSJ_000022	TX_MSJ_000600
4	**Attachment 3:** 2001 Report of the Rio Grande Compact Commission	TX_MSJ_000601	TX_MSJ_000656
5	Declaration of William R. Hutchison, Ph.D., P.E., P.G., and Attachments 1-4	TX_MSJ_000657	TX_MSJ_000669
6	**Attachment 1:** Resume	TX_MSJ_000670	TX_MSJ_000688
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8	**Attachment 3:** Groundwater Modeling Experience Outside of Texas	TX_MSJ_000691	TX_MSJ_000692
9	**Attachment 4:** DataAnn sheet of Excel file named Ferguson Rebuttal_revised 9-15-20	TX_MSJ_000693	TX_MSJ_000695
10	Declaration of Staffan W. Schorr and Attachment 1	TX_MSJ_000696	TX_MSJ_000699
11	**Attachment 1:** Resume	TX_MSJ_000700	TX_MSJ_000703
12	Declaration of Theresa C. Barfield and Exhibits 1-2	TX_MSJ_000704	TX_MSJ_000705
13	**Exhibit 1:** State of New Mexico's Objections and Witness Designations to the United States' Notice of Rule 30(b)(6) Deposition and to State of Texas's Cross-Notice, 9/10/2020	TX_MSJ_000706	TX_MSJ_000728
14	**Exhibit 2:** State of New Mexico's Objections and Supplemental Responses to the State of Texas's First Set of Requests for Admission to the State of New Mexico	TX_MSJ_000729	TX_MSJ_000756

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16	Deposition Excerpts of John D'Antonio, 6/25/2020	TX_MSJ_000789	TX_MSJ_000812
17	Exhibit 3 to John D'Antonio Deposition 6/25/2020: Active Water Resources Management in the Lower Rio Grande (8/19/2005)	TX_MSJ_000813	TX_MSJ_000833
18	Deposition Excerpts of John D'Antonio, 6/26/2020	TX_MSJ_000834	TX_MSJ_000853
19	Deposition Excerpts of John D'Antonio, 8/14/2020	TX_MSJ_000854	TX_MSJ_000887
20	Deposition Excerpts of Peggy Barroll, 2/5/2020	TX_MSJ_000888	TX_MSJ_000925
21	Deposition Excerpts of Peggy Barroll, 2/6/2020	TX_MSJ_000926	TX_MSJ_000943
22	Deposition Excerpts of Peggy Barroll, 8/7/2020	TX_MSJ_000944	TX_MSJ_000959
23	Deposition Excerpts of Peggy Barroll, Rule 30(b)(6), 10/21/2020	TX_MSJ_000960	TX_MSJ_000988
24	Deposition Excerpts of Gary Esslinger, 8/18/2020	TX_MSJ_000989	TX_MSJ_001022
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26	Deposition Excerpts of Jorge Garcia, 2/6/2019	TX_MSJ_001051	TX_MSJ_001074
27	Deposition Excerpts of Estevan Lopez, 7/6/2020	TX_MSJ_001075	TX_MSJ_001097
28	Deposition Excerpts of Estevan Lopez, 7/7/2020	TX_MSJ_001098	TX_MSJ_001122
29	Deposition Excerpts of Estevan Lopez, Rule 30(b)(6), 9/18/2020	TX_MSJ_001123	TX_MSJ_001176
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32	Deposition Excerpts of Ryan Serrano, 4/17/2019	TX_MSJ_001267	TX_MSJ_001288
33	Deposition Excerpts of Herman Settemeyer, 7/30/2020	TX_MSJ_001289	TX_MSJ_001312
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35	Deposition Excerpts of Cheryl Thacker, 9/18/2020	TX_MSJ_001344	TX_MSJ_001393
36	Exhibit 1 to Deposition of Cheryl Thacker, 9/18/2020: Well Metering Requirements (Effective March 2006)	TX_MSJ_001394	TX_MSJ_001423
37	Deposition Excerpts of Adrienne Widmer, 2/5/2019	TX_MSJ_001424	TX_MSJ_001453
38	Exhibit 58 to Deposition of Adrienne Widmer, 2/5/2019: City of Las Cruces 40-Year Water Development Plan (April 2017)	TX_MSJ_001454	TX_MSJ_001531
39	Deposition Excerpts of Lee Wilson, 7/23/2020	TX_MSJ_001532	TX_MSJ_001550
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41	Figure 1: The Rio Grande basin	TX_MSJ_001574	TX_MSJ_001574
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46	Figure 6: Table 90 of the JIR	TX_MSJ_001579	TX_MSJ_001579
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50	Figure 10: Schematic of Rio Grande Groundwater System Interaction Prior to Development of Groundwater Pumping in Ricon and Mesilla basins	TX_MSJ_001583	TX_MSJ_001583
51	Figure 11: Schematic of Rio Grande and Groundwater System Interaction After Development of Groundwater Pumping in Rincon and Mesilla basins	TX_MSJ_001584	TX_MSJ_001584
52	Declaration of Scott Miltenberger, Ph.D., and Attachments 1-2 **Attachment 1:** Resume **Attachment 2:** Library of Documents Referenced in Scott A. Miltenberger Declaration (*Documents in the Library are hyperlinked in footnotes*)	TX_MSJ_001585	TX_MSJ_006491

Dated: November 5, 2020

Respectfully submitted,

s/ Stuart L. Somach

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Tab 1

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In the

SUPREME COURT OF THE UNITED STATES

STATE OF TEXAS,

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v.

STATE OF NEW MEXICO and
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Defendants.

OFFICE OF THE SPECIAL MASTER

DECLARATION OF ROBERT J. BRANDES, P.E., Ph.D IN SUPPORT OF THE STATE OF TEXAS'S MOTION FOR PARTIAL SUMMARY JUDGMENT; MEMORANDUM OF POINTS AND AUTHORITIES IN SUPPORT THEREOF FEDERAL RULE OF CIVIL PROCEDURE 56

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November 5, 2020

I, Robert J. Brandes, declare as follows:

BACKGROUND AND EXPERIENCE

1. My name is Robert J. Brandes, P.E., Ph.D. I am over the age of 18, have personal knowledge of the facts set forth in this Declaration, and if called as a witness could and would testify competently under oath to such facts.

2. I have been engaged in consulting engineering practice since the late 1960s specializing in water resources and related engineering and environmental disciplines. Today, I own and operate my consulting business Robert J. Brandes Consulting in Austin, Texas. My street address is 6000 Maurys Trail, Austin, Texas 78730.

3. I have been retained by the State of Texas to provide consulting services on hydrologic and water resources issues presented in this case.

4. A true and correct copy of my professional curriculum vitae is attached hereto as Attachment 1 and is incorporated as though fully set forth herein.

5. My education includes a Bachelor of Science degree in Civil Engineering from the University of Texas at Austin (1967), a Master of Science degree in Civil Engineering from the University of Texas at Austin (1968), and a Ph.D. in Water Resources from the from the University of Texas at Austin (1972).

6. I am licensed in Texas as a Professional Engineer, No. 39120.

7. I specialize in water resources and related engineering and environmental disciplines. I have represented numerous private, commercial, and governmental entities, providing various planning, analysis, permitting, design, and operational services for a wide range of water projects. I have directed and conducted numerous studies and investigations dealing with surface and groundwater hydrology and hydraulics; water resources planning and development; water availability modeling (WAMs), water rights permitting and related issues;

municipal, industrial and agricultural water supply; reservoir system operations; rural and urban flooding and stormwater management; water quality; irrigation system analyses; project site development engineering; and environmental impact assessments. My experience encompasses a wide variety of problems involving rivers and streams, lakes and reservoirs, groundwater aquifers, wetlands, and bays and estuaries, and I am especially familiar with the development and application of computerized simulation techniques for analyzing water-related phenomena in these systems.

8. I have prepared and presented testimony and served as an expert witness in various judicial proceedings in state and federal courts and in administrative and regulatory hearings conducted by the State Office of Administrative Hearings and natural resources agencies in Texas, as well as the Texas Legislature.

9. I have authored or co-authored numerous technical documents and project reports, and have presented many technical papers and lectures pertaining to water resources and water rights at professional society meetings, water conferences and short courses.

10. In the last four years, I have testified as an expert witness in two cases.

11. The Rio Grande is an interstate and international river, approximately 1,800 miles long, originating in southern Colorado. *See* National Resources Committee, Regional Planning: Part VI-The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico and Texas 1936-1937, published in February 1938 (JIR) at 7 (Volume I). The JIR reflects an investigation by federal agencies at the request of the Rio Grande Compact Commissioners with input from Colorado, New Mexico, and Texas representatives. The primary purpose of the joint investigation was to compile factual data essential to support an apportionment of the waters of the Rio Grande above Ft. Quitman. JIR at vi-vii. A true and correct copy of the JIR is attached hereto as Attachment 2.

12. The Rio Grande winds southward approximately 400 miles across New Mexico, and crosses into Texas near the city of El Paso, where it defines the 1,250-mile international boundary between the United States and Mexico as it traverses to the Gulf of Mexico. The entire Rio Grande basin is depicted on the map below entitled **Figure 1**.

FIGURE 1: The Rio Grande basin

13. Along its entire course, the Rio Grande provides a source of surface water that is used extensively to meet the needs of municipalities, industries, and agricultural irrigators, as well as to support various environmental uses. Numerous dams and reservoirs exist along the river primarily for water supply and flood control purposes; consequently, flows in much of the river are substantially controlled and regulated.

14. With respect to the usage of water, the river is divided into two distinct sections at Fort Quitman. The Upper Rio Grande basin (the area above Fort Quitman, Texas) is comprised of parts of Colorado and New Mexico, and a very small part of Texas. The Upper Rio Grande basin itself is divided into three sections: (1) the San Luis section in

Colorado, (2) the Middle section in New Mexico, and (3) the Elephant Butte-Fort Quitman section in New Mexico, Texas, and Mexico. JIR at 7. This case is centered primarily upon issues involving the Elephant Butte-Fort Quitman section of the Upper Rio Grande basin. Figure 2 depicts the Upper Rio Grande basin.

<u>FIGURE 2: The Upper Rio Grande basin</u>

15. A different naming system for the full Upper Rio Grande basin geographic area (upstream of Ft. Quitman, Texas) is used locally. The San Luis section in Colorado is referred to as the "Upper Rio Grande," the middle section in New Mexico is referred to as the "Middle Rio Grande," and the Elephant Butte-Fort Quitman section in New Mexico, Texas, and Mexico is referred to as the "Lower Rio Grande." This local naming system is used in my Declaration and in Texas's Memorandum of Points and Authorities in support of its Motion for Partial Summary Adjudication. Correspondingly, this case is primarily centered upon issues involving the Lower Rio Grande, as the term is used in this local naming system.

16. The Project was authorized pursuant to the Rio Grande Reclamation Project Act of 1905 as a federal project that provides water from the Rio Grande primarily for agricultural irrigation along the Rio Grande in southern New Mexico and in the El Paso Valley of Texas. Elements of the Project also provide hydropower, flood control, and water for municipal users. It included construction of Elephant Butte Dam and Reservoir ("Elephant Butte Reservoir" or "Reservoir") on the Rio Grande near Truth or Consequences, New Mexico, to provide stored water for Project users.

17. The states of Colorado, New Mexico, and Texas agreed to the Rio Grande Compact in 1938 (1938 Compact or Compact). As a result of the negotiations to formalize the 1938 Compact, depletions were frozen at pre-1938 conditions. Two delivery schedules, or indices, were adopted: one for Colorado to New Mexico, and one for New Mexico to Elephant Butte Reservoir. These schedules were derived from streamflow data and analyses developed primarily by the JIR – an effort to provide the needed data to resolve the impasse over the apportionment of the Rio Grande waters above Fort Quitman.

18. The total water supply available for diversion by Elephant Butte Irrigation District (EBID), El Paso County Water Improvement District No. 1 (EP#1), and Mexico included storage in and releases from Elephant Butte Reservoir and return flows generated within EBID and EP#1. New Mexico's post-Compact development has depleted that water supply by capturing returns flows that otherwise would have been available.

19. By 1938, and later, releases from Elephant Butte Reservoir comprised effectively all of the Rio Grande surface water supply in the Lower Rio Grande. In addition to releases from the Reservoir, small amounts of seasonal arroyo discharges contribute to available water in the Rio Grande. These arroyo flows were included in the total volume of water that was to be made available downstream of the Reservoir.

20. Mining of a groundwater basin means that more water is being pumped from the groundwater basin than can be replaced, causing groundwater levels to decline and, in the context of this case, has caused further depletion of the volume of water available to Texas. Groundwater pumping in New Mexico continues unabated today.

21. Colorado, New Mexico and Texas adopted the Compact in 1938 to ensure, among other things, a prescribed delivery of water from the Rio Grande in Elephant Butte Reservoir. The Project is dependent on the Compact for its water supply. The Project, in turn, is the means by which the water apportioned to Texas by the Compact is stored in Elephant Butte Reservoir, and subsequently delivered to Texas (subject to deliveries to EBID, pursuant to its contract with the United States, and to Mexico, pursuant to the 1906 Treaty). The relationship between the Compact and the Project is critical to the ability to effectively supply water from the Rio Grande to users in Texas, EBID, and Mexico. Both the Project and the Compact were conceived and implemented prior to the significant development of groundwater in the Rincon and Mesilla basins of New Mexico, which began in the early 1950s.

22. Today, the Project includes Elephant Butte Dam and Reservoir, Caballo Dam and Reservoir located immediately below Elephant Butte Dam, a hydropower plant at Elephant Butte Dam, three diversion dams on the Rio Grande in New Mexico (Percha, Leasburg, and Mesilla), two diversion dams on the Rio Grande in Texas (American and International, both owned and operated by the International Boundary and Water Commission), and an extensive system of canals, laterals, waste ways, and drainage ways that support irrigation operations in EBID and EP#1. The major dams and reservoirs and the diversion dams included in the Project are identified on the map of the region in **Figure 5**.

FIGURE 5: Map of Rio Grande Project Area

23. There are 159,650 acres authorized within the Project, with 90,640 acres within EBID in New Mexico and 69,010 acres within EP#1 in Texas. These acreages translate to approximately a 57/43 split for the distribution of irrigable acres between EBID and EP#1 (collectively "Districts").

24. Releases of Project water stored in Elephant Butte and Caballo Reservoirs are made at the start of the irrigation season (typically February) to Project users in New Mexico and Texas, and to Mexico. The Districts request releases of stored water during the irrigation season in response to irrigation demands. As a practical matter, however, diversions by the Districts and Mexico consist of varying amounts of reservoir storage, return flows from upstream irrigation operations, and occasional arroyo inflows. Return flows are a key part of Project operations, and interference with return flows removes a critical component of deliveries to Project users. Project return flows consist of excess irrigation tailwater and

groundwater seepage from irrigated fields that are collected in drains that convey these return flows to the Rio Grande. The proportion of return flows in the river increases in the downstream direction relative to stored water from the reservoirs, and the water diverted by Project users in the lower Mesilla basin and in the El Paso Valley of Texas includes diversion of significant quantities of return flows.

25. **Figure 6** is Table 90 of the JIR. It shows the percentage of net diversions for each valley for reservoir releases, arroyo flow, and drain flow for the period prior to the Compact. The net diversions in the Rincon portion of EBID contained 0.3 percent drain flow and seepage (return flows) and net diversions in the Mesilla portion of EBID contained 7.4 percent, while the net diversions into the Franklin canal in EP#1 contained 35.1 percent return flows and the net diversions into the Tornillo canal in EP#1 contained 57.7 percent return flows and only 38.2 percent of reservoir releases.

TABLE 90.—*Estimated percentages of reservoir water, arroyo inflow, and drainage in net diversions and disposal of reservoir releases, Elephant Butte-Fort Quitman section, 1930–36*

Division or item	Mean disposal of reservoir water 1930–36 (percentage distribution)	Mean percentage content, 1930–36, in net diversions, of—			
		Unused reservoir releases [1]	Arroyo inflow	Drain flow and seepage	Total
Rincon	8.5	97.5	2.2	[2] 0.3	100.0
Mesilla	46.4	89.8	2.8	7.4	100.0
El Paso	18.4	58.4			
Upper El Paso (Franklin canal)		61.5	3.4	35.1	100.0
Lower El Paso (Tornillo canal)		38.2	4.1	57.7	100.0
Rio Grande Project	73.3	79.8	3.0	17.2	100.0
Hudspeth	2.2	33.9	6.1	60.0	100.0
Juarez (Mexico)	11.4	49.5	5.4	45.1	100.0
Upper Juarez		58.3	3.1	38.6	100.0
Lower Juarez		24.4	11.8	63.8	100.0
Riverbed losses	9.2				
Passing Fort Quitman	3.9	17.2	14.8	68.0	100.0
Total	100.0				

[1] Distinguished from returned drainage originally from the reservoir.
[2] Invisible accretion to river.

Estimates based on detail study of all available data, 1930–36, on river flow, reservoir releases, diversions, wastes, drain flow, and arroyo inflow.

FIGURE 6: Table 90 of the JIR

26. After diversion by EP#1, Project water is delivered to the city of El Paso for municipal use under agreements with EP#1 and its constituents that assign their Project water

allotments for specific land parcels to the city. Excess canal flows and return flows from Project lands within EP#1 also provide a supplemental water supply for approximately 18,000 acres of land within the Hudspeth County Conservation and Reclamation District No. 1 (HCCRD) below EP#1 down to Fort Quitman, Texas.

27. Within the Project area from Elephant Butte Reservoir downstream to Fort Quitman, Texas, the Rio Grande covers approximately 210 river miles. Project water was to be allocated between irrigators in southern New Mexico and in the El Paso Valley of Texas in proportion to the irrigated acreage of Project lands within each state.

28. A water budget is an accounting for a defined time period of the inflows into, and the outflows from, a defined control area. Often, performing a water budget with known volumes of inflows and outflows for a specific time period can lead to the quantification of one or more unknown variables for that same time period. Performing multiple water budgets for a specific control area for different time periods can provide information regarding how certain phenomena may have changed. Even a visual depiction of the water budget for a control area showing the generalized movement of water into, within, and out of the area under different conditions and circumstances can be informative and help to understand how the Project water supply system was originally conceived to work and how it has changed with the development of groundwater in New Mexico.

29. I have utilized conceptual water budgets to illustrate the effect of groundwater depletions in the Project area within the Rincon and Mesilla basins of New Mexico where significant groundwater development began in the early 1950s. Prior to the development of extensive groundwater pumping in the Rincon and Mesilla basins, groundwater levels generally were relatively high and fluctuated in response to the seasonal application of irrigation water from the Rio Grande on Project lands. In the early days of the Project, this

phenomenon created a serious problem. Soon after the Project began delivering water to the irrigators, groundwater levels rose in New Mexico to and above ground level, thereby waterlogging and making useless land previously capable of growing crops. The solution was to construct a complex system of drains that would capture excess groundwater created by irrigation and return it to the river. This "return flow" became a significant source of irrigation water for downstream irrigators, particularly in Texas, a fact recognized and catalogued in the JIR. With the construction of the drains, irrigation water not consumed by crops and other vegetation or by evaporation, percolated down through the soil into the groundwater system, which typically flowed toward and into drains specifically designed for collecting groundwater and for conveying groundwater and excess irrigation tailwater away from fields and to the Rio Grande. This condition is illustrated in a general fashion by the diagram in Figure 10.

FIGURE 10: Schematic of Rio Grande and Groundwater System Interaction Prior to Development of Groundwater Pumping in Rincon and Mesilla basins

30. As shown in Figure 10, Project water is diverted from the Rio Grande into an irrigation system canal and then distributed to individual irrigated fields, where it is either consumptively used by the growing crops or evaporated into the atmosphere. Any excess irrigation water is either discharged directly to the drain as tailwater or percolated through the subsurface into the groundwater system. The bottom of the drain is below the upper level of

the groundwater; thus, groundwater is induced to flow toward and into the drain. Similarly, the bottom of the river channel is below the level of the groundwater, with water shown flowing in both directions depending on the relative heights of the water in the river and the groundwater from location to location. The irrigation tailwater and groundwater that is collected in the drain flows to the river and is referred to as return flow. The return flow from the drain that is discharged into the Rio Grande provides an important supply of Project water for users located downstream, namely users in the lower Mesilla basin and in the El Paso Valley of Texas. This important source of water for Project users was contemplated in the early development of Project operations and in the negotiations among the states leading up to the adoption of the 1938 Compact.

31. For example, the JIR investigation determined that approximately 35 percent of the total supply of Project water delivered to Texas in the El Paso Valley was from upstream return flows, with the majority of the balance originating as releases from Caballo Reservoir. Conversely, since water for Project users in New Mexico was diverted from the Rio Grande farther upstream, i.e., above the river outfalls of most drains, less than seven percent of New Mexico's total deliveries originated from return flows.

32. With the extensive development of groundwater in the Rincon and Mesilla basins of New Mexico that began during the early 1950s – particularly in the relatively shallow aquifers with generally high groundwater levels such as those along the Rio Grande – groundwater levels began to fluctuate and decline in some areas. This in turn caused discharges of groundwater into the drains, and directly into the river, to be reduced. Eventually, with enough groundwater pumping, the groundwater gradient in many areas reversed, with significant reductions in the groundwater inflows to the drains and into the river. This condition is illustrated by the diagram in Figure 11.

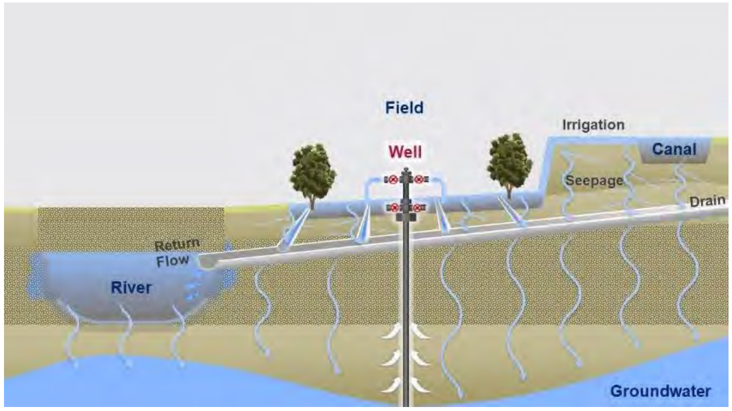

FIGURE 11: Schematic of Rio Grande and Groundwater System Interaction After Development of Groundwater Pumping in Rincon and Mesilla basins

33. As shown in Figure 11, the level of the groundwater is below the bottom of the river channel and the drain, and water flowing in the river and in the drain moves toward and into the groundwater system, rather than the other way around, as it was prior to the initiation of groundwater pumping. The discharge of return flow from the drain into the river is substantially curtailed, if not reduced to zero, thereby also reducing the flow in the river.

34. The phenomenon of reduced river flows caused by groundwater withdrawals is an underlying component of what is referred to as streamflow depletions, and these streamflow depletions have increased along the Rio Grande within the Rincon and Mesilla basins since significant groundwater development began in the early 1950s. One of the obvious impacts of these increased streamflow depletions has been to alter the Project water budget by reducing flows in the Rio Grande that otherwise would ultimately reach water users in the lower Mesilla basin and in the El Paso Valley in Texas. In essence, the release of a specific quantity of water from Caballo Reservoir now contributes less to the surface water supply for these users because of the losses of flow due to the increased seepage from the Rio Grande and interior drainage ways, thus altering the previously existing Project water budget.

35. In the early 1980s, the BOR developed the D1 and D2 allocation curves for the Project based on 1951-1978 operating data, and under normal supply conditions for the Project, these curves provided for 122 percent of the annual Caballo Reservoir release to be diverted from the Rio Grande for Project users. This additional 22 percent was almost entirely from return flows discharged into the Rio Grande from drains. This is shown on Figure 10 (Schematic of Rio Grande and Groundwater System Interaction Prior to Development of Groundwater Pumping in Rincon and Mesilla basins), discussed above. These D1 and D2 allocation curves reflect conditions that are different from the flow regime that existed at the time of the Compact. The D1 and D2 allocation curves were based upon the depleted flow conditions influenced by the extensive groundwater pumping in New Mexico during the 1951-1978 period.

36. I have reviewed, and am familiar with the contents of, the 2001 Report of the Rio Grande Compact Commission. A true and correct copy of the 2001 Report of the Rio Grande Compact Commission is attached hereto as Attachment 3. Within that report, beginning at page 3, is the Report of the Engineer Advisors to the Rio Grande Compact Commissioners, dated February 22, 2002 (2/22/02 EA Report). The 2/22/02 EA Report demonstrates that there is nothing in all the figures that the Compact Commission collects that addresses the 57/43 split. This is because that is an allocation issue and not a Compact issue. If it were a Compact issue, it would have been accounted for as such. Section 2.1 of the Memorandum of Understanding between the Rio Grande Compact Commission and the BOR, included in the 2001 Report of the Rio Grande Compact Commission, confirms that the Compact accounting data includes “deliveries by New Mexico to Texas at Elephant Butte.” 2001 Report of the Rio Grande Compact Commission, at 19.

37. Regarding the 57/43 split, referable to Project allocations, the Project delivers the *water available to it* at the points of diversion on the river. The volume of Project water that was split 57/43 in 1938 for the Project to make the allocation to EBID and EP#1 pursuant to the contracts with the United States reflected the acreages of irrigated land in the two Districts at that time and the generally gaining condition of the river below Caballo Reservoir as influenced by relatively high groundwater levels in the absence of significant pumping. This changed beginning in the 1950s with the extensive development of groundwater in New Mexico and the subsequent lowering of groundwater levels along the Rio Grande that altered the condition of the river from a generally gaining stream to a generally losing stream. The implications of this change are obvious - river flow losses mean greater depletions and less Project water for downstream users. The Project has no control over New Mexico's depletions and can only allocate the amount of water remaining after the New Mexico groundwater pumping depletes Project water in the river, including Reservoir releases.

38. I declare under penalty of perjury that the foregoing is true and correct. Executed this 4th day of November 2020 at Austin, Texas.

Robert J. Brandes

Robert J. Brandes, P.E., Ph.D.

INTENTIONALLY

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Tab 2

Professional Resume

ROBERT J. BRANDES

PERSONAL DATA	Birthplace:	East Bernard, Texas
	Home Address:	6000 Maurys Trail Austin, Texas 78730

EDUCATION

Pre-Engineering Curriculum, Southwestern University, 1962-1964
B. S., Civil Engineering, The University of Texas at Austin, 1967
M. S., Civil Engineering, The University of Texas at Austin, 1968
Ph.D., Water Resources, The University of Texas at Austin, 1972

HONORS

Tau Beta Pi, Chi Epsilon, Sigma Xi

REGISTRATION

Professional Engineer, State of Texas, No. 39120

EXPERIENCE

Dr. Brandes has been engaged in consulting engineering practice in Texas since the late 1960s, specializing in water resources and related engineering and environmental disciplines. He has represented numerous private, commercial, and governmental entities, providing various planning, analysis, permitting, design, and operational services for a wide range of water projects. He has directed and conducted numerous studies and investigations dealing with surface and ground water hydrology and hydraulics; water resources planning and development; water availability modeling (WAMs), water rights permitting and related issues; municipal, industrial and agricultural water supply; reservoir system operations; rural and urban flooding and stormwater management; water quality; irrigation system analyses; project site development; and environmental impact assessments. His experience encompasses a wide variety of problems involving rivers and streams, lakes and reservoirs, ground water aquifers, wetlands, and bays and estuaries, and he is especially familiar with the development and application of computerized simulation techniques for analyzing water-related phenomena in these systems. Dr. Brandes has prepared and presented testimony and served as an expert witness in judicial proceedings in state and federal courts and in administrative and regulatory hearings conducted by the State Office of Administrative Hearings and Texas natural resources agencies, as well as the Texas Legislature.

PUBLICATIONS

Dr. Brandes has authored or co-authored numerous technical documents and project reports, and he has presented many technical papers and lectures pertaining to water resources and water rights at professional society meetings, water conferences and short courses.

COMMITTEES

Dr. Brandes has served on several committees appointed by Texas state agencies and professional associations dealing with water rights, wastewater reuse, water supply planning, and environmental flow issues. He was chairman of the Science Advisory Committee for the Legislative-appointed Study Commission on Water for Environmental Flows and the Science Advisory Committee for the Governor-appointed Environmental Flows Advisory Committee, and he was vice-chair for the Senate Bill 3 Texas Environmental Flows Science Advisory Committee. He currently is a director and past president of the Texas Water Conservation Association and has served as flood response committee chairman, surface water committee co-chair, water availability modeling committee co-chair, and finance committee member.

PROFESSIONAL AFFILIATIONS

American Society of Civil Engineers
American Water Resources Association
Texas Water Conservation Association
Texas Society of Professional Engineers
American Academy Water Resources Engineers

PROFESSIONAL
HISTORY

2008 to Present	Principal and Owner; Robert J. Brandes Consulting; Austin, Texas.
2008 to 2015	Senior Consultant; Atkins (formerly PBS&J); Austin, Texas.
2005 to 2008	Principal; TRC/R. J. Brandes Company, Consulting in Water Resources; Austin, Texas.
1994 to 2018	Principal and Director; Crespo Consulting Services, Inc.; Austin, Texas.
1992 to 2005	Principal and Director; Terra Dynamics, Inc.; Austin, Texas.
1984 to 2005	Principal and Owner; R. J. Brandes Company, Consulting in Water Resources; Austin, Texas.
1975 to 1984	Associate and Vice President; Camp Dresser & McKee Inc.; Austin, Texas.
1971 to 1980	Associate, Senior and Principal Engineers and VP; Water Resources Engineers; Austin, Texas.
1970 to 1971	Special Consultant; F. Barry Haskett Investments/Aquarius, Inc.; New York, NY and Zurich, SUI
1968 to 1971	Associate; Frank D. Masch & Associates; Austin, Texas.
1967 to 1970	Research Engineer/Scientist; The Univ. of Texas at Austin, Depart. of Civil Engr.; Austin, Texas.

REPRESENTATIVE PROJECT
ASSIGNMENTS

- Currently under contract with the Texas Commission on Environmental Quality to update the hydrologic data base for the State's water availability model of the Texas and Mexico portions of the Rio Grande Basin.

- For Riverbend Water Resources District, developed naturalized flows for extension of the hydrologic data base for Run 3 and Run 8 versions of the water availability model for the Sulphur River Basin and modified existing water availability models to represent current water rights conditions.

- Directed and performed water availability and project operation studies for the Unappropriated Flows Permit sponsored by the Lower Colorado River Authority, including development and evaluation of alternative project configurations and components, applying water availability models, investigating numerous environmental flow scenarios, working with state regulatory and resource agencies as part of water rights permitting, and coordinating work with client, other project team members, and various environmental groups.

- Directed and performed reservoir water availability and firm yield studies, conceptual dam and spillway design, and project mitigation planning and analyses for the proposed Lake Ralph Hall on the North Sulphur River in Fannin County, Texas, for the Upper Trinity Regional Water District, including preparation of supporting documents for the water rights permit application, coordination of permitting activities with the TCEQ, and presentation of expert testimony in the SOAH permit hearing.

- Directed and performed water availability and project operation studies for the Excess Flow Optimization Project sponsored by the Tarrant Regional Water District, including development and evaluation of alternative project configurations and components, applying water availability models, investigating numerous environmental flow scenarios, preparation of water rights permit application, working with TCEQ as part of water rights permitting, updating District's accounting plan to reflect new permits and amendments, and coordinating work with client and other project team members.

- Served as a special consultant to the State of Texas and the International Boundary and Water Commission through the Texas Water Development Board and the Texas Natural Resource Conservation Commission regarding water deficits incurred by Mexico under the 1944 Treaty between the United States and Mexico and participated in negotiations between the two countries.

- Directed and performed long-range water supply planning for the Lower Colorado River Authority, including analysis of future municipal, industrial and power water demands, identification and evaluation of numerous supply alternatives, and consideration of alternative means for satisfying environmental flow requirements.

- Performed water supply studies for Dow Chemical Company in Brazoria County, Texas, including analysis of DOW's historical and projected water demands and supplies, modification and application of the TCEQ's Brazos Basin water availability model for evaluations of DOW's existing and proposed water supply system, investigated reservoir storage and river pumping requirements to meet specific levels of water demands considering river salinity effects, and provided expert testimony in SOAH permit hearings.

- For City of San Angelo, Texas, provided consulting assistance with several water rights amendments, including water availability analyses, preparation of applications, processing of amendments through TCEQ, expert testimony, and preparation and maintenance of accounting plan for all of the City's water rights.

- Developed naturalized streamflows for the Sulphur, Sabine, Colorado, San Bernard, and Rio Grande River Basins and for the Brazos-Colorado and Nueces-Rio Grande Coastal Basins for the Texas Commission on Environmental Quality as part of the Senate Bill 1 water availability modeling program and direction application of the Texas A&M Water Rights Analysis Package to develop water availability models (WAMs) and simulate water availability for existing water rights under different flow conditions, assumed water rights cancellation, and various levels of wastewater reuse.

- For Lake Chapman water users, performed firm yield analyses of the reservoir and developed an accounting plan to provide an equitable distribution and use of inflows to and storage in the reservoir and to allow equal access to the available water supply from the reservoir among water rights holders and users.

- Directed and performed surface water availability studies for the Lower Colorado River Authority/San Antonio Water System joint Water Supply Project, including development and evaluation of alternative project configurations and components, developing and applying various water availability models to test alternatives, and coordinating work with LCRA/SAWS and project team members and making public presentations.

- Provided hydrologic and water rights permitting support for amendment of Tarrant Regional Water District's permits for diversion of upper Trinity Basin return flows from the Trinity River into Richland-Chambers Reservoir and Cedar Creek Reservoir in order to develop additional firm supply for TRWD customers.

- For the City of Irving, performed assessment of existing water rights and applications for water supplies from Lake Hugo and Kiamichi Creek in Oklahoma, developed and applied water availability model for Kiamichi Basin to assess Lake Hugo firm yield and reliability of water supplies from reservoir under different operating plans, and prepared documentation of findings and study results.

- Performed hydrology, water quality and water supply system operations studies for the Texas Attorney General's Office to support potential Federal litigation regarding the use and ownership of water from the Rio Grande Project in Texas and New Mexico, including the development of a quantity and quality routing models of Project operations.

- For a public power company, evaluated availability and reliability of cooling water supplies for potential power plant projects in the Colorado and Guadalupe River Basins, including application of basin water availability models and simulation of off-channel reservoir operations under different water demand conditions.

- For the Lavaca-Navidad River Authority, examined increased water supplies for industrial users through joint operation of Lake Texana in the Lavaca River Basin with other surface water rights in adjacent basins, including conceptual design and analysis of an off-channel reservoir and development of operating procedures.

- Served as special consultant to the Lower Colorado River Authority with negotiations with the City of Austin to develop a joint settlement agreement regarding future use of water rights and available water supplies, including return flows, from the Colorado River for the next 100 years.

- Served as special consultant to the Lower Colorado River Authority with negotiations with the South Texas Nuclear Project to develop a joint settlement agreement regarding future use of water rights and a dependable supply of water from the Colorado River for the life of the project.

- Served as a special consultant to the International Boundary and Water Commission to provide assistance with review of water conservation plans and other strategies proposed by Mexico to alleviate its water deficit under the 1944 Treaty between the United States and Mexico.

- For the Lower Colorado River Authority, performed water availability analyses and modeling to assess water supplies and strategies in support of regional water supply planning undertaken pursuant to Senate Bill 1 of the 75th Texas Legislature for the Lower Colorado Regional Planning Study (Region K).

- Performed water supply systems operations analyses and water rights/environmental permitting for the proposed Brownsville Weir and Reservoir Project on the Lower Rio Grande, including computer simulations of the hydrologic behavior and performance of the proposed project considering daily historical sequences of streamflows; preparation of an environmental assessment; state water rights and federal 404 permitting support; and meetings and negotiations with regulatory agencies, protestants, and Mexican representatives.

- Directed and performed water availability studies as part of a multidisciplinary team of consultants for the Lower Guadalupe Water Supply Study that was jointly sponsored by the San Antonio River Authority, San Antonio Water System and Guadalupe-Blanco River Authority, including evaluation of alternative project scenarios, applying water availability models, coordinating work project team, and making public presentations.

- Investigated existing and projected surface water supplies and demands for municipal, industrial and irrigation users in the lower and middle Rio Grande Basin, including reservoir simulations and yield analyses under alternative reservoir operating plans and storage allocations, and evaluated Mexican Rio Grande water deficits under the 1944 Treaty, as part of the eight-county Rio Grande Regional Water Planning Study (Region M).

- Represented the State of Texas as a consultant and expert for the State Attorney General's Office regarding State ownership of land in the Texas Panhandle along the Canadian River in a dispute over oil and gas royalties and definition of State property boundary.

- For the City of San Antonio, evaluated alternative scenarios for maintaining springflow conditions required for preservation of endangered species at Comal and San Marcos Springs, analyzed stream channel and spring run hydraulics at Comal Springs, and presented expert witness testimony in Federal District Court.

- Provided consulting assistance to a private water right holder with determining losses and operating procedures associated with adding new diversion points on the Rio Grande in Maverick and Webb Counties for diverting approximately 8,000 acre-feet/year of water for municipal use that was previously authorized for irrigation use near Presidio, Texas upstream of Lake Amistad and assisted with TCEQ permitting activities.

- Inventoried surface and ground water supply sources and facilities on the 21,000-acre Indio-Faith Ranch on the Rio Grande in Maverick and Dimmitt counties in South Texas and developed recommendations and a plan for joint use of the available water supplies and water facilities by two entities owning different parts of the ranch.

- Investigated flooding in Big Fossil Creek watershed caused by upstream development in city of Saginaw and provided expert witness support and testimony for plaintiffs in Tarrant County, Texas law suit.

- Analyzed domestic and agricultural water demands for 112,000-acre Comanche Ranch in Maverick County, Texas, developed water supply plans and facility designs for providing Rio Grande water to meet ranch water demands, and assisted with implementation of various water supply strategies and facilities.

- Analyzed potential downstream flooding caused by warehouse and drainage projects implemented by City of Fredericksburg, represented City in law suits, and developed mitigation measures used in settlement proceeding.

- Evaluated the impacts of upstream artificial recharge projects in the Edwards Aquifer recharge zone on the yield and operations of City of Corpus Christi's reservoirs in the Nueces River Basin, including examination of bay and estuary inflows and system operation with other sources of water supply.

- Analyzed future water supply availability for the Lower Neches Valley Authority considering existing municipal, industrial and irrigation water rights in the Neches River Basin and Federal hydropower water requirements at Sam Rayburn Reservoir, including application of the Neches water availability model.

- Served as special consultant to the Texas Natural Resource Conservation Commission for the evaluation and analyses of various water rights and water resources management models as part of technical advisory team to select a general modeling approach pursuant to the requirements of Senate Bill 1 of the 75th Texas Legislature.

- Analyzed the feasibility (yield and cost) of constructing and operating off-channel reservoir projects for developing new municipal water supplies at various locations throughout the San Antonio and Guadalupe River Basins as part of the South Central Texas Regional Water Planning Study (Region L).

- Investigated causes of flooding of Republic Bank Towers in Dallas, Texas during severe rainfall event for plaintiffs in law suit in Dallas County District Court, including definition of contributing drainage areas, analysis of street inflows to lower level parking areas, and presentation of expert deposition testimony.

- Performed hydrology, hydraulics, drainage and flood control studies and investigations for the City of Fredericksburg as part of a TWDB-sponsored regional flood prevention plan for the City and surrounding area, including drafting of stormwater ordinances, preparation of a drainage criteria manual, and facilities design.

- Performed hydrologic and water rights investigations for the Dallas County Park Cities Municipal Utility District to evaluate the ability of Lake Grapevine in the upper Trinity River Basin to provide a firm water supply under various operating rules and demand scenarios involving other existing water right holders.

- Analyzed surface water issues related to a Medina Lake water rights amendment for the Bexar-Medina-Atascosa Counties Water Control and Improvement District, including analysis of release requirements for instream uses below the lake, evaluation of reservoir yield and operations, and examination of reservoir water quality impacts.

- Analyzed stream flooding and erosion using HEC-2 backwater program and sediment transport methods for the City of Austin on lower Walnut Creek to evaluate the potential erosion impacts of the City's treated wastewater effluent on an adjacent property owner and presentation of expert witness testimony for defendant in Travis County District Court.

- Performed hydrologic and hydraulic investigations involving floodplain reclamation, hydraulic design of flood control facilities, and runoff and flooding simulations for a 2,000-acre residential and commercial development on the West Fork of the Trinity River in Tarrant County, Texas, including Section 404 permitting support.

- Performed hydrology and hydraulic studies of the potential impacts of sand and gravel dredging operations proposed by Sand Supply, Inc. on or near the Brazos River in Fort Bend County, Texas, and the Colorado River in Fayette County, Texas, including assistance with acquisition of permits from the Texas Parks and Wildlife Department, the Texas Natural Resource Conservation Commission and the U. S. Army Corps of Engineers.

- Performed hydrologic and hydraulic studies of runoff control and wastewater retention facilities for confined animal feeding operations (feedlots and dairies) and simulation of combined runoff storage and irrigation operations for effective disposal of contaminated waters under state and federal laws and rules, including analyses for facilities in Erath and Maverick Counties, Texas.

- Performed water quality impact analyses and nonpoint source pollution studies for the Brownsville Public Utilities Board pertaining to a proposed raw water pipeline diversion from a series of existing storage lakes and resacas, including field data collection and water quality sampling, runoff and pollutant transport modeling for a 50-year historical period, and projections of water quality conditions with and without the project.

Tab 3

REGIONAL PLANNING

PART VI—THE RIO GRANDE JOINT INVESTIGATION

IN THE

UPPER RIO GRANDE BASIN

IN

COLORADO, NEW MEXICO, AND TEXAS

1936-1937

PUBLISHED IN TWO VOLUMES

VOL. I. TEXT

VOL. II. MAPS

NATIONAL RESOURCES COMMITTEE

FEBRUARY 1938

NITED STATES GOVERNMENT PRINTING OFFICE WASHINGTON : 1938

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NATIONAL RESOURCES COMMITTEE

INTERIOR BUILDING

WASHINGTON

December 23, 1937.

The PRESIDENT,
The White House,
Washington, D. C.

MY DEAR MR. PRESIDENT:

We have the honor to transmit herewith the Report of the Rio Grande Joint Investigation, which constitutes Part VI of the series on regional planning activities and progress.

The Rio Grande Investigation was undertaken at the request of the States of Colorado, New Mexico, and Texas with the National Resources Committee serving as a channel for the organization of surveys and studies by appropriate Federal and State bureaus. It is a notable example of cooperative endeavor financed partly through an allocation from the Public Works Administration but with substantial contributions from the three States and some four or five Federal agencies.

Sincerely yours,

HAROLD L. ICKES,
Secretary of the Interior, Chairman.

HARRY H. WOODRING,
Secretary of War.
HENRY A. WALLACE,
Secretary of Agriculture.
DANIEL C. ROPER,
Secretary of Commerce.
FRANCES PERKINS,
Secretary of Labor.

HARRY L. HOPKINS,
Works Progress Administrator.
FREDERIC A. DELANO.
CHARLES E. MERRIAM.
HENRY S. DENNISON,
BEARDSLEY RUML.

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CONSULTING BOARD, RIO GRANDE JOINT INVESTIGATION

HARLAN H. BARROWS, *Chairman*

FRANK ADAMS

November 30, 1937.

Mr. FREDERIC A. DELANO,
Chairman, Advisory Committee,
National Resources Committee,
Washington, D. C.

DEAR MR. DELANO:

We submit herewith the report of the Rio Grande Joint Investigation, and recommend that it be published.

The report is of national as well as regional importance. Primarily, it forms the factual base on which a reasonable plan for the future development of the water resources of the Upper Rio Grande Basin may be constructed. In addition, it illustrates a new and pioneering method for the preparation of water plans in interstate drainage basins of the United States.

The cooperating State and Federal agencies are to be congratulated upon their skill and initiative in organizing a large-scale investigation without administrative precedent. The members of the consulting board have displayed rare ability in planning and guiding the work.

From these efforts may come a satisfactory solution of the present critical Rio Grande problems, and the experience on which plans for other interstate drainages may be undertaken.

Respectfully submitted.

ABEL WOLMAN
Chairman, Water Resources Committee
Chief Engineer, Maryland State Department of Health

BUSHROD W. ALLIN,
Special Representative,
Office of Land Use Coordination,
Department of Agriculture.

MILTON S. EISENHOWER,
Coordinator of Land Use Planning,
Department of Agriculture.

N. C. GROVER,
Chief Hydraulic Engineer,
U. S. Geological Survey.

EDWARD HYATT,
State Engineer of California.

ROGER B. MCWHORTER,
Chief Engineer,
Federal Power Commission.

JOHN C. PAGE, *Commissioner,*
Bureau of Reclamation.

THORNDIKE SAVILLE,
Dean, College of Engineering,
New York University

JULIAN L. SCHLEY,
Chief of Engineers,
U. S. Corps of Engineers.

R. E. TARBETT,
Senior Sanitary Engineer,
U. S. Public Health Service.

SHERMAN M. WOODWARD,
Chief Water Control Planning Engineer,
Tennessee Valley Authority.

August 10, 1937.

Mr. Abel Wolman,
Chairman, Water Resources Committee.

Dear Mr. Wolman: There is transmitted herewith the report of the Rio Grande joint investigation, conducted under the authority of the National Resources Committee through its Water Resources Committee. The investigation was undertaken at the request of the Rio Grande compact commissioners of Colorado, New Mexico, and Texas. It was carried out in cooperation with the United States Geological Survey, the Bureau of Reclamation, the Bureau of Agricultural Engineering, and the Bureau of Plant Industry, with material assistance from the Bureau of Indian Affairs, the Resettlement Administration, and Soil Conservation Service. Various other organizations, Federal, State, and local, helped by providing services, materials, records, office or laboratory space, and the like. The requisite funds were provided by the three States and several Federal agencies.

The basin of the Rio Grande above Fort Quitman, Tex., presents in clear relief the nature and magnitude of the physical, legal, economic, and social conditions and relationships involved in the use of the land and water resources of a large interstate drainage area in Western United States. It also furnishes an example of some of the involvements likely to arise when an important river is international as well as interstate in character.

For three-quarters of a century the Western States have been creating and perfecting, gradually but definitely, the legal principles and the social institutions needed where irrigation is the chief basis of economic life. Although much remains to be accomplished, none of the Western States lacks authority for adequate control and administration of intrastate waters, whether surface waters or underground waters. On the other hand, the authority of a State to control and administer interstate waters is limited. If the claims of two or more States to such waters are in conflict, the States may settle the controversy through negotiation of an interstate compact or may have recourse to the Supreme Court of the United States for adjudication of the differences at issue. The weight of public opinion favors the interstate compact. Moreover, the Supreme Court repeatedly has taken a friendly attitude toward the compact mode of action.

In the case of the upper Rio Grande, lack of adequate factual data proved to be an insurmountable obstacle to success by the compact method, notwithstanding earnest efforts by the interested States to reach an agreement. Finally, a suit was begun in the Supreme Court of the United States with a view to adjusting differences between the users of Rio Grande waters in New Mexico and Texas. This action was taken, however, prior to the initiation of the cooperative fact-finding investigation.

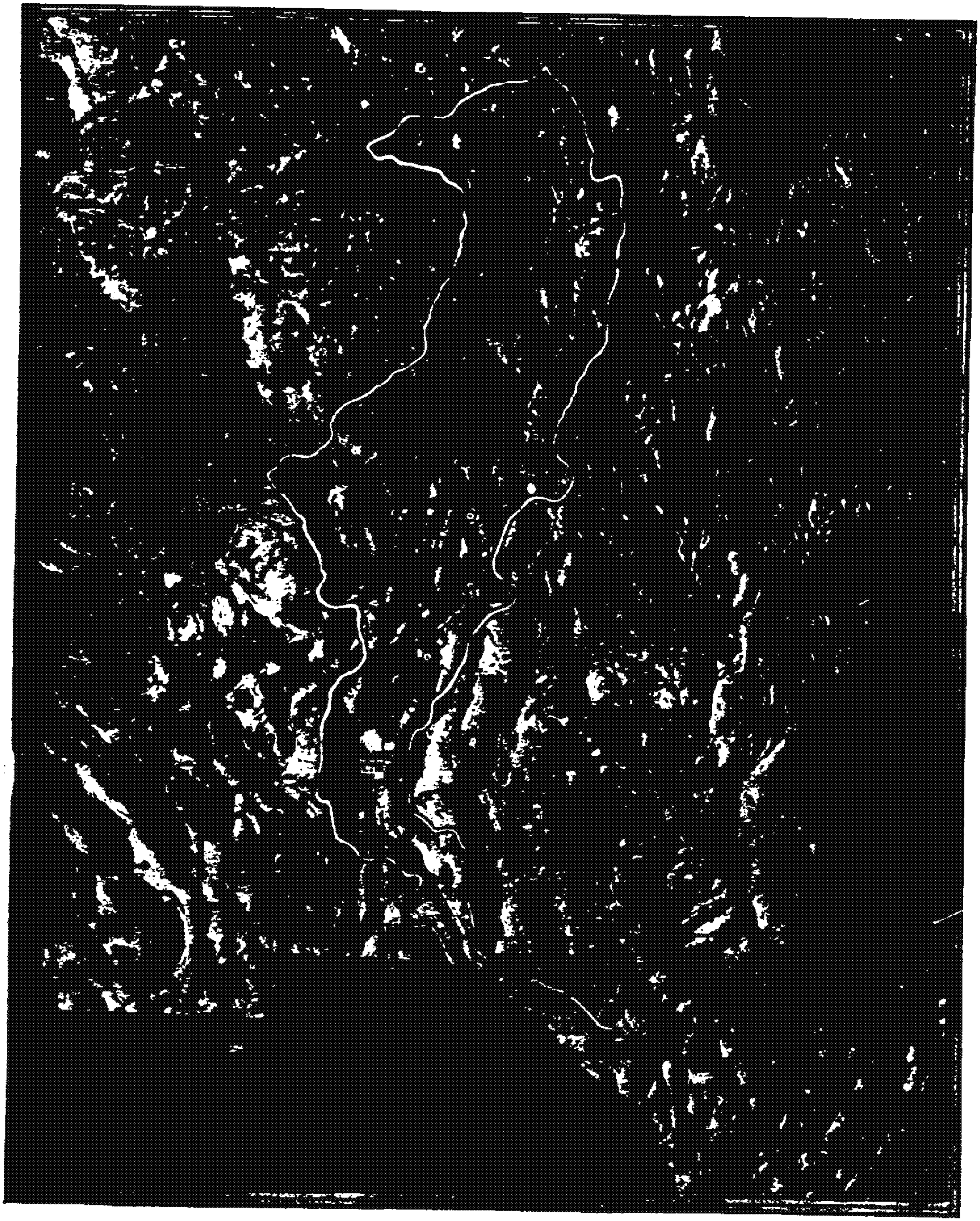
The Rio Grande joint investigation constituted a unique approach to the underlying problems of a grave controversy over an interstate river. For the first time the States engaged in such a controvery joined with one another and with the Federal Government in an endeavor to find a satisfactory basis for the allocation of the waters of a river through the assembly of the factual data essential to such an allocation. The cordial willingness with which the official representatives of Colorado, New Mexico, and Texas entered into the undertaking exemplified constructive statesmanship. The precedent they established should facilitate negotiations relating to other interstate streams. Each of these States is vitally concerned with its own welfare, yet in the Rio Grande joint investigation each recognized its obligation to its sister States; each accepted the principle that an equitable adjustment of conflicting interests in the waters of the river is imperative.

The consulting board which has been responsible to the Water Resources Committee for the organization and conduct of the investigation is grateful to all who took part in it. The participating agencies cooperated superbly, and the field organization worked enthusiastically, apparently sensing in the enterprise a great opportunity and a great challenge. Especially appreciative are we of the high ability and fine judgment displayed by the engineer in charge, Mr. Harlowe M. Stafford. We also commend the splendid services of the associate engineer, Mr. Fred C. Scobey.

It is our conviction that the report transmitted herewith furnishes a sound factual basis for an apportionment of the waters of the river above Fort Quitman that would be fair and just to each of the States and to its water users dependent on the river. It is our conviction also that the report furnishes a sound basis for the development of a plan by which the water that may be made available by salvage, storage, importation, and other means would render full service and for the formulation of a program looking to construction of the requisite works in an orderly, balanced manner. We commend the report to the careful consideration not only of the Water Resources Committee and the National Resources Committee, but also of the States, whose further cooperation will be necessary to reach an agreement with respect to the problems of the river, and of the administration and the Congress, whose assistance will be needed in providing the physical works involved in a workable solution of those problems.

Very sincerely yours,

FRANK ADAMS,
HARLAN H. BARROWS,
Chairman, Consulting Board,
Rio Grande Joint Investigation.



VIII

Upper Rio Grande Basin.

THE RIO GRANDE JOINT INVESTIGATION IN THE UPPER RIO GRANDE BASIN

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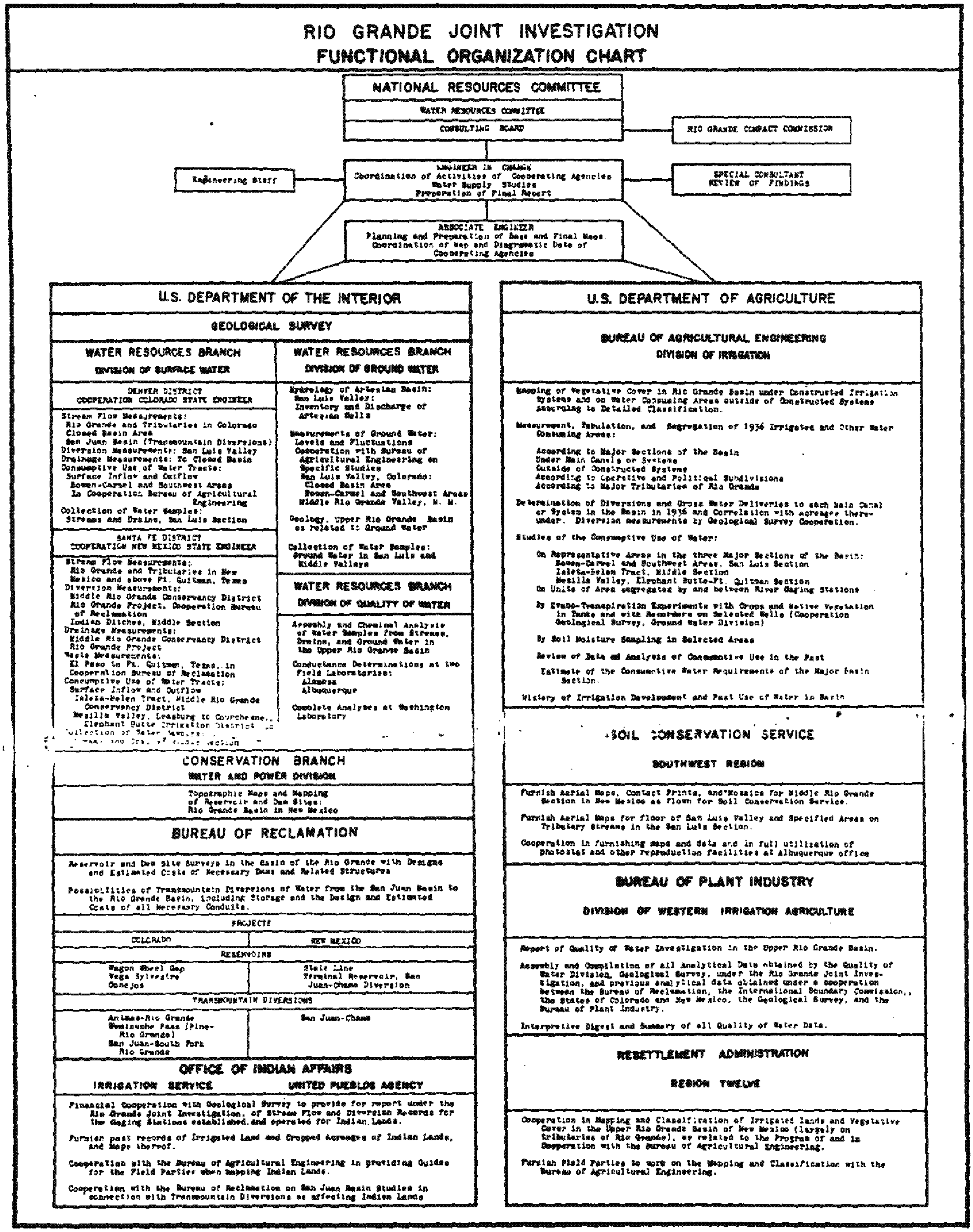
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Engineering Staff
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Water Supply Studies
Preparation of Final Report
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REVIEW OF FINDINGS
ASSOCIATE ENGINEER
Planning and Preparation of Base and Final Maps
Coordination of Map and Diagrammatic Data of Cooperating Agencies
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DENVER DISTRICT
COOPERATION COLORADO STATE ENGINEER
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COOPERATION NEW MEXICO STATE ENGINEER
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Weminuche Pass (Pine-Rio Grande)
San Juan-South Fork Rio Grande
San Juan-Chama
OFFICE OF INDIAN AFFAIRS
IRRIGATION SERVICE
UNITED PUEBLOS AGENCY
Financial Cooperation with Geological Survey to provide for report under the Rio Grande Joint Investigation, of Stream Flow and Diversion Records for the Gaging Stations established and operated for Indian Lands.
Furnish past records of Irrigated Land and Cropped Acreages of Indian Lands, and Maps thereof.
Cooperation with the Bureau of Agricultural Engineering in providing Guides for the Field Parties when mapping Indian Lands.
Cooperation with the Bureau of Reclamation on San Juan Basin Studies in connection with Transmountain Diversions as affecting Indian Lands
U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF AGRICULTURAL ENGINEERING
DIVISION OF IRRIGATION
Mapping of Vegetative Cover in Rio Grande Basin under Constructed Irrigation Systems and on Water Consuming Areas outside of Constructed Systems according to Detailed Classification.
Measurement, Tabulation, and Segregation of 1936 Irrigated and Other Water Consuming Areas:
According to Major Sections of the Basin
Under Main Canals or Systems
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Determination of Diversions and Gross Water Deliveries to each Main Canal or System in the Basin in 1936 and Correlation with acreages thereunder. Diversion measurements by Geological Survey Cooperation.
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By Soil Moisture Sampling in Selected Areas
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Estimate of the Consumptive Water Requirements of the Major Basin Section.
History of Irrigation Development and Past Use of Water in Basin
SOIL CONSERVATION SERVICE
SOUTHWEST REGION
Furnish Aerial Maps, Contact Prints, and Mosaics for Middle Rio Grande Section in New Mexico as flown for Soil Conservation Service.
Furnish Aerial Maps for floor of San Luis Valley and Specified Areas on Tributary Streams in the San Luis Section.
Cooperation in furnishing maps and data and in full utilization of photostat and other reproduction facilities at Albuquerque office
BUREAU OF PLANT INDUSTRY
DIVISION OF WESTERN IRRIGATION AGRICULTURE
Report of Quality of Water Investigation in the Upper Rio Grande Basin.
Assembly and Compilation of all Analytical Data obtained by the Quality of Water Division, Geological Survey, under the Rio Grande Joint Investigation, and previous analytical data obtained under a cooperation between the Bureau of Reclamation, the International Boundary Commission, the States of Colorado and New Mexico, the Geological Survey, and the Bureau of Plant Industry.
Interpretive Digest and Summary of all Quality of Water Data.
RESETTLEMENT ADMINISTRATION
REGION TWELVE
Cooperation in Mapping and Classification of Irrigated lands and Vegetative Cover in the Upper Rio Grande Basin of New Mexico (largely on tributaries of Rio Grande), as related to the Program of and in Cooperation with the Bureau of Agricultural Engineering.
Furnish Field Parties to work on the Mapping and Classification with the Bureau of Agricultural Engineering.

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GENERAL REPORT OF THE RIO GRANDE JOINT INVESTIGATION

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PART I

SECTION 1.—INTRODUCTION AND SUMMARY

The Upper Rio Grande Basin

This investigation is concerned with the water problems of the portion of the Rio Grande drainage area which lies above Fort Quitman, Tex., situated about 80 miles southeast of El Paso. Known generally as the Upper Rio Grande Basin, it comprises about 34,000 square miles. The total drainage area of the Rio Grande is about 175,000 square miles.

Rio Grande is an interstate and an international stream. It rises in Colorado and flows southward for more than 400 miles across New Mexico. After leaving New Mexico, it forms the boundary between Texas and the Republic of Mexico for about 1,250 miles to its mouth. The total length of the river is about 1,800 miles.

With respect to usage of water and the problems concerned with that usage, the river is divided into two distinct sections at Fort Quitman, or at the narrow gorge a few miles below. Above this nearly all the water of the river is being consumed by irrigation in Colorado, New Mexico, Texas, and Mexico. Below, in the lower basin, the river develops its flow mainly from tributaries in Mexico.

In the Upper Rio Grande Basin, including parts of Colorado and New Mexico, and a very small part of Texas, more than 99 percent of the water supply comes from Colorado and New Mexico in about equal amounts.

In accordance with natural divisions, the upper basin comprises three principal areas: the San Luis section in Colorado, the Middle section in New Mexico, and the Elephant Butte-Fort Quitman section in New Mexico, Texas, and Mexico. These are indicated on the general map, plate 1.

The San Luis section comprises the basin of Rio Grande in Colorado, the principal agricultural area of which is the San Luis Valley. This is a broad plain of smooth topography, surrounded by mountains except on the south near the Colorado-New Mexico State line, where the river has cut an outlet for the southern portion of the valley. The northern portion is not thus drained and is known as the Closed Basin. The valley floor ranges in altitude from 7,440 to 8,000 feet and the surrounding mountains from 10,000 to more than 14,000 feet.

The Middle section comprises the basin of Rio Grande in New Mexico above San Marcial. Below the Colorado-New Mexico State line, Rio Grande flows through a canyon for about 70 miles to Embudo. The "Middle Valley" comprises the long narrow territory adjacent to the river from Embudo south to San Marcial, a distance of about 200 miles. It is a succession of narrow valleys separated by rock canyons or merely short "narrows." Of these subvalleys, Santo Domingo, Albuquerque, Belen, and the northern two-thirds of Socorro constitute the area of the Middle Rio Grande Conservancy District. Altitudes in the Middle Valley range from 5,590 feet in Espanola, the uppermost subvalley, to 4,450 feet at San Marcial, at the lower end of Socorro Valley.

The Elephant Butte Reservoir of the Rio Grande Project, United States Bureau of Reclamation, occupies the immediate river valley from San Marcial narrows to Elephant Butte, a distance of about 40 miles. What is here designated as the Elephant Butte-Fort Quitman section includes the reservoir area and the wide plains and long strips of land adjacent to the river from Elephant Butte to Fort Quitman, some 210 miles, of which 130 miles are above El Paso. Like the Middle section, Elephant Butte-Fort Quitman section is a succession of valleys separated by canyons and narrows. Of these valleys, Rincon, Mesilla, and the northern half of El Paso Valley on the Texas side of the river comprise the area of the Rio Grande project. Included in the southern half of El Paso Valley, on the Texas side, is the area of the Hudspeth County Conservation and Reclamation District. The El Paso Valley area southwest of the river is in Mexico. Altitudes in the Elephant Butte-Fort Quitman section range from 4,200 feet at Elephant Butte to 3,710 at El Paso and 3,400 at Fort Quitman.

Historical Background

The valley lands of the Upper Rio Grande Basin are devoted almost entirely to agriculture. Because of scant precipitation throughout all valleys of the basin, irrigation is required for the successful growing of crops. Irrigation along the Rio Grande goes back to an unknown date when it was initiated by Pueblo Indians or their ancestors.

Recorded history of the Rio Grande Valley begins with its discovery by Coronado in 1540. Later, in the seventeenth and eighteenth centuries, Spanish colonization in the Middle and Elephant Butte-Fort Quitman sections was accompanied by an expansion of irrigation.

Irrigation by white men in San Luis Valley was begun in the early 1850's, but it was not until about 1880 that extensive development occurred. Then, in the decade 1880–90, accelerated activity resulted in most of the large canal systems and other irrigation works that exist there today.

In the early 1890's water shortages began to occur along the Rio Grande in Mesilla and El Paso Valleys and people near Juárez, across the river from El Paso, complained to the Mexican Government. The latter filed a claim for damages against the United States, alleging that the water shortages were due to increasing diversions from the river in Colorado and New Mexico. The United States Department of State then instituted an investigation of the situation through the International Boundary Commission, and the outcome was the "embargo" of 1896 and the Mexican Treaty of 1906. The "embargo" was an order by the Secretary of the Interior of the United States which prevented further irrigation development of any magnitude in the Rio Grande Basin in Colorado and New Mexico through suspension of all applications for rights-of-way across public lands in those States for use of Rio Grande water. With some modification in 1907, this embargo remained in effect until May 1925, when it was lifted. Under the terms of the Mexican Treaty, the United States guaranteed to Mexico, in return for relinquishment of all claims for damages, an annual delivery in perpetuity in the Rio Grande at the head of the Mexican Canal near El Paso, of 60,000 acre-feet of water.

Both to insure fulfillment of the Mexican Treaty and to develop a reclamation project in the Elephant Butte-Fort Quitman section. the United States provided for construction of the Elephant Butte Reservoir by the Bureau of Reclamation. This reservoir, with an original capacity of 2,639,000 acre-feet, together with other initial works for the Rio Grande Project, was completed in 1916.

The embargo was opposed in Colorado, since even by 1896 the irrigated lands in San Luis Valley used all the available natural flow of Rio Grande and its tributaries in that valley. Storage appeared necessary not only for further development but even to maintain existing developments. But storage of any magnitude was impossible under the embargo. The effort of Colorado to secure permission to build reservoirs thus began early, and has continued to date.

About 1918, active interest developed in reclamation in the Middle Valley. Much land there had become badly seeped and it was affirmed that over a period of many years there had occurred a serious decline and failure of the irrigated acreage. This was attributed not only to a decrease in the flow of the river and to a shortage of water for irrigation but also to resultant deposition of silt, aggradation of the river bed, and elevation of the water table under the valley floor. It was affirmed that the decrease in river flow was due to depletions in San Luis Valley.

The Rio Grande Compact

With the interstate situation becoming increasingly aggravated, it was suggested that a commission be named to study the water supply and to draft a compact between the States affected, under which an equitable allocation of the waters of the upper Rio Grande would be made. Accordingly the legislatures of Colorado and New Mexico enacted statutes in 1923 under which the respective Governors appointed commissioners. The President named a commissioner to represent the United States. Later, a commissioner for Texas was designated by the Governor of that State.

Negotiations looking to a compact were started, but they proceeded slowly, pending the outcome of engineering investigations instituted by Colorado and by New Mexico. Finally, after an extended session of the commission in January 1929, a compact was concluded which became effective upon its ratification, later that year, by the legislatures of the three States and by the Congress. This compact does not, however, set up an allocation of Rio Grande waters. It is, moreover, a temporary measure. Its principal articles provide, in effect, that during the period of the compact neither Colorado nor New Mexico will cause or suffer the water supply in Rio Grande to be impaired by new or increased diversions or storage unless and until such depletion is offset by increase of drainage return; that the three States will maintain certain gaging stations and exchange the records therefrom; and that before the expiration of the compact a commission shall be constituted to conclude a permanent compact providing for the equitable apportionment of the water of Rio Grande among the States. It sets up the desirability of a drain to the river from the "closed basin" in Colorado and of a reservoir on Rio Grande at or near the Colorado-New Mexico State line, as features in the economic development and conservation of the waters of the basin and as helpful factors in reaching an accord among the States. In it the conviction is expressed that the United States should construct the Closed Basin drain and the State Line reservoir without cost to the States by reason of its obligation under the Mexican Treaty, in fulfillment of which it has, in effect, made an annual draft of 60,000 acre-feet on Colorado, New Mexico, and Texas.

The original expiration date of this compact was June 1, 1935, and before that time the commission met to conclude, if possible, a permanent compact. Although many proposals were made, no agreement was reached; further basic data on the supply and use of water were needed. As a result, the effective period of the temporary compact was extended to June 1, 1937. Recommendation for its further extension to October 1, 937, was made by the Rio Grande Compact Commission sitting in Santa Fe March 4, 1937.

Previous Investigations

Reference has been made to previous engineering investigations of the supply and use of water in the Upper Rio Grande Basin. With controversies over the use of the water increasing with passing years, many investigations naturally have been undertaken and a mass of data and information has been accumulated. Unfortunately, few of these investigations have been reported in printed form. In many instances, the investigations were made to determine only the water situation for particular localities and the results were reported in typewritten form to some local, State, or Federal agency. In the bibliography accompanying this report as Appendix C there is a selected list of published and unpublished reports that have been made. Some previous investigations of basin-wide significance are noted in the following paragraphs.

In 1896 the International Boundary Commission caused an investigation to be made of the water supply and irrigation development in the Rio Grande Basin above Fort Quitman, Tex. The report of this investigation, best known as the Follett report, after W. W. ollett, who made it, covers comprehensively and in etail the stream flow, irrigated areas, canal systems, ditches, and diversions for every section of the basin from San Luis Valley to El Paso. This is published in United States Senate Document 229, Fifty-fifth Congress, second session.

In 1904 an investigation of the geology and water resources of the San Luis Valley was made by C. E. Siebenthal of the United States Geological Survey; the results were published as Water Supply Paper No. 240.

In 1910 James A. French, engineer for the Bureau of Reclamation, undertook an investigation to establish the facts concerning the "past, present, and contemplated irrigation near the headwaters of the Rio Grande in Colorado and to determine the effects of such developments on the normal flow of the Rio Grande below the Colorado-New Mexico State line." In the same year, H. W. Yeo, also an engineer with the Bureau of Reclamation, was assigned to a detailed investigation of the extent of irrigation in the Rio Grande Valley of New Mexico. The reports of these investigations were submitted to the Bureau of Reclamation.

In 1912 and 1913 Jay D. Stannard of the Bureau of Reclamation and D. G. Miller of the Drainage Investigations, Department of Agriculture, made an investigation and reported on "Drainage and Water Development in San Luis Valley, Colo."

In 1919 Engineers Harold Conkling and E. B. Debler reported to the Bureau of Reclamation on an extensive investigation made to determine the water supply, irrigation development, and possibilities of future development in San Luis Valley, in the Middle Rio Grande Valley, and under the Rio Grande Project.

In 1924 Debler made an investigation and report to the Bureau of Reclamation on the water supply and requirements of the Rio Grande Project.

Under a cooperative agreement between the Middle Rio Grande Conservancy District and the Bureau of Reclamation, Engineers Debler and Elder carried on an extensive investigation in the Middle Valley from 1926 to 1928. The primary purpose was to determine the probable effect upon the water supply for the Rio Grande project of the construction and operation of the proposed works of the Middle Rio Grande Conservancy District. A preliminary report was made in December 1927, and the final report in 1932.

The report of J. L. Burkholder, chief engineer of the Middle Rio Grande Conservancy District, covering the district's investigations and the final plan for flood control, drainage, and irrigation within its limits was published in 1929.

Beginning soon after provision was made in 1923 by Colorado and New Mexico for the appointment of their representatives on the Rio Grande Compact Commission and continuing over much of the period to date, investigations have been carried on under the direction of the Colorado and New Mexico State Engineers. The primary purpose has been the compilation of information and data needed by the commissioners in endeavoring to work out a compact between the States. The investigations of New Mexico covered the San Luis section, as well as the Middle section, and much of the data and results is included in reports, unpublished, of C. R. Hedke, 1924 and 1925; E. P. Osgood, 1928; R. G. Hosea, 1928; and H. W. Yeo, 1928 and 1931. In addition to the San Luis section, the investigations of Colorado included a study of the use of water, drainage, and wastes in the Elephant Butte-Fort Quitman section. The data and results of the work of Colorado are largely covered in unpublished reports to the State Engineer by R. I. Meeker from 1924 to 1928, and by R. J. Tipton from 1924 to 1935.

In 1935 a committee of consulting engineers, O. V. P. Stout, F. H. Fowler, and E. B. Debler, made an investigation and report to the Federal Emergency Administration of Public Works on the probable water yield, cost, and feasibility of the "sump drain", a project to conduct to the Rio Grande the recoverable waters of the sump area in the Closed Basin of San Luis Valley.

The Present Investigation

Origin and History

During the last few years there has been much activity in the Upper Rio Grande Basin in the promotion of water utilization projects for which Federal funds have been sought. In 1935, the irrigation and drainage works of the Middle Rio Grande Conservancy District, including El Vado Reservoir on Rio Chama, a tributary of Rio Grande, were completed and put in operation. District bonds for this construction were purchased by the Reconstruction Finance Corporation. The Rio Grande Project is a Federal project and a conflict of Federal interests developed. Moreover, with the available water resources of the Upper Rio Grande Basin apparently fully appropriated, the approval of any new projects involving additional drafts upon these resources seemed to point inevitably to further conflict of Federal interests and to violation of the Rio Grande compact.

Appreciating this situation and spurred by the need for prompt action to avoid uncoordinated development of water utilization projects, the National Resources Committee appointed a board to review the situation and to recommend an appropriate procedure. Pursuant to recommendations of this Board and as an immediate result of them, the President issued the following executive memorandum:

> THE WHITE HOUSE,
> *Washington, September 23, 1935.*
>
> *To Federal agencies concerned with projects or allotments for water use in the Upper Rio Grande Valley above El Paso:*
>
> From information secured by the National Resources Committee, it appears that in view of the practically complete present appropriation of reliable water supply in the basin of the Rio Grande above El Paso, Federal investments in this region which promote increased use of water tend to impair the security of extensive prior investments of Federal funds, to violate the terms of an interstate compact to which the Federal Government is a party, and to promote social insecurity in the region.
>
> Please instruct appropriate officials of your agency in Colorado and New Mexico, as well as in Washington or in other supervisory offices, not to approve any application for a project involving the use of Rio Grande waters without securing from the National Resources Committee a prompt opinion on it from all relevant points of view.
>
> (Signed) FRANKLIN D. ROOSEVELT.

Following out a further recommendation of the Board of Review, the National Resources Committee proposed a conference with the Rio Grande compact commissioners and other representatives of Colorado, New Mexico, and Texas to see if there might be any way in which the National Resources Committee and the three States could cooperate in gathering the facts that might be helpful in arriving at a solution of the interstate water problem on the Rio Grande above Fort Quitman. This conference was held at Santa Fe, December 2–3, 1935, and resulted in the adoption of the following resolution by the Rio Grande Compa Commission:

> *Whereas*, The Rio Grande Compact Commission was created for the purpose, among others, of making equitable division of the waters of the Rio Grande above Fort Quitman, Tex., between the States of Colorado, New Mexico, and Texas, and
>
> *Whereas*, The National Resources Committee has expressed its willingness to cooperate, if practicable, with the Rio Grande Compact Commission in the collection of relevant basic data,
>
> *Now, therefore, be it resolved*, That the National Resources Committee, through its Water Resources Committee, be requested, in consultation with the members of the Rio Grande Compact Commission, to arrange immediately for such investigation (1) of the water resources of the Rio Grande Basin above Fort Quitman, (2) of the past, present and prospective uses and consumption of water in such Basin in the United States, and (3) of opportunities for conserving and augmenting such water resources by all feasible means, as will assist the Rio Grande Compact Commission in reaching a satisfactory basis for the equitable apportionment of the waters of the Rio Grande Basin in the United States above Fort Quitman, as contemplated by such Rio Grande compact.
>
> In making this request the Rio Grande Compact Commission, and its individual members, declare it to be their desire to cooperate and assist in such investigation in all ways within their power, and it further declares that, through its individual members, it will seek to obtain the allotment of State funds, or services, or both, for the purposes of the investigation in such amounts as will equitably distribute the costs thereof between the Federal Government and the member States of Colorado, New Mexico, and Texas.
>
> It is understood that the cooperative investigation requested herein shall be limited to the collection, correlation, and presentation of factual data, and shall not include recommendations, except upon request of the Rio Grande Compact Commission, based upon the unanimous agreement of its members.
>
> It is further understood that the said investigation shall be in harmony with the spirit and intent of the Rio Grande compact, and nothing herein contained shall be taken to be a modification or alteration of the terms thereof.

Pursuant to this resolution, funds were allocated by the Federal Emergency Administration of Public Works to the National Resources Committee for the purpose of the investigation, on condition that certain additional funds would be contributed by the three States and by certain other Federal agencies. At a second Santa Fe conference early in February 1936 the agreements for contribution of funds were sucessfully consummated and plans for the investigation were agreed upon. Field work was started in April and continued throughout 1936. In connection with completion of studies of storage and transmountain diversions, field work continued through July 1937.

Purpose and Scope

The prime purpose of the Rio Grande joint investigation was to determine the basic facts needed in arriving at an accord among the States of Colorado, New Mexico, and Texas on an equitable allocation and use of Rio Grande waters in the future development of the upper basin. In general, the essential facts sought are those relating to the available water supply, the water uses and requirements, and the possibilities of additional water supplies by storage, importations and salvage of present losses and wastes.

With respect to the supply of water, the investigation has included measurements and records of stream flow at all essential points on the Rio Grande and its tributaries, and on San Juan Basin streams as pertaining to possible transmountain diversions to the Rio Grande Basin. Many new gaging stations have been established.

As relating both to water supply and use, the investigation has included measurements of ground water levels and fluctuations in San Luis Valley and throughout the Middle Valley, an inventory of the number and discharge of wells in the artesian basin of San Luis Valley, and a program of sampling and analysis of surface and underground waters throughout the basin to determine their chemical quality.

The investigation to determine water uses and requirements has included measurements and records of canal diversions in three principal areas—San Luis Valley, Middle Rio Grande Conservancy District, and Rio Grande Project; measurements of drainage and waste in selected areas; complete mapping, classification and determination in detail of acreages, according to canal systems and geographic and political subdivisions, of the vegetative cover on all irrigated lands and other water-consuming areas throughout the basin; the preparation of base maps, both general and in detailed units, covering all requisite geographic, artificial and hydrographic features for the entire upper basin; measurements of the consumptive use of water by crops and native or nonbeneficial vegetation by means of experimental studies, including soil moisture determinations, observation of ground water fluctuations, and the growing of plants in metal tanks, and by complete measurements of all inflow and outflow of water on selected representative areas in the San Luis, Middle, and Elephant Butte-Fort Quitman sections; a study of the consumptive use of water based on past records; and a review of the history of irrigation development in the upper basin.

As to the possibility of additional water supplies by salvage of present losses and wastes, determination of the data needed resulted largely from the investigations outlined in preceding paragraphs. With respect to additional supplies by storage and importation, the investigation has included the survey, examination, analysis, and preliminary design of four major storage projects and of four separate projects for diversion of San Juan Basin waters to the Rio Grande Basin. The storage projects include the Wagon Wheel Gap and Vega-Sylvestre on the upper Rio Grande, one or more sites on the Conejos River, the principal Rio Grande tributary in Colorado, and the State Line site on the Rio Grande near the Colorado-New Mexico State line. The transmountain diversion projects include the Animas-Rio Grande, Weminuche Pass, and San Juan-South Fork Rio Grande in Colorado, and the San Juan-Chama in Colorado and New Mexico. With reference to the diversion projects, the investigation has included a study of their effect on San Juan Basin development, and a survey of initial, terminal, and other storage opportunities on the conduit lines.

To accomplish this investigation efficiently, expeditiously, and impartially within the period available, it was proposed by the consulting board of the National Resources Committee and approved by the State representatives that the work should be assigned to and divided among three major Federal agencies by cooperative agreements between the National Resources Committee and those agencies. It was agreed further that the consulting board and an engineer in charge with headquarters at Santa Fe, N. Mex., should be responsible to the National Resources Committee for the general coordination and conduct of the work and for the final report of the investigation.

In accordance with the cooperative agreements, the Geological Survey has carried out the measurements of stream flow, drainage, waste, and diversions, the studies of ground water, and the sampling and analyses in the quality of water investigation; the Bureau of Agricultural Engineering has carried on the mapping and classification of vegetative cover, the compilation and segregation of irrigated acreages and other water-consuming areas, the study of consumptive use of water, and review of the history of irrigation development; and the Bureau of Reclamation has been responsible for the investigation and report on storage and transmountain diversion projects.

Supplementary cooperative agreements were also effected for contributions of money or services, or both, between the National Resources Committee and the Bureau of Plant Industry, the Soil Conservation Service, the Resettlement Administration, and the Office of Indian Affairs, between the Geological Survey and the States of Colorado and New Mexico; and between the Bureau of Agricultural Engineering and these States. The cooperation of the Soil Conservation Service and the Resettlement Administration has been largely in the nature of mapping and the provision of maps and data which tied in closely with the work of the Bureau of Agricultural Engineering; that of the Office of Indian Affairs has been associated with the investigations of both the Geological Survey and the Bureau of Agricultural Engineering; that of the Bureau of Plant Industry has comprised the assembly and compilation of all analytical data of the quality of water investigation, together with preparation of the summary and interpretive digest of those data. Informal cooperation has been extended by many other Federal, State, and local agencies throughout the Upper Rio Grande Basin. The reports of the data obtained and studies made by the Geological Survey, the Bureau of Agricultural Engineering, the Bureau of Plant Industry, and the Bureau of Reclamation under the Rio Grande Joint Investigation are incorporated in parts II, III, IV, and V, respectively, of this report.

The Problem

The essential water problem of the Upper Rio Grande Basin is the division of the water supply between the San Luis section of Colorado, the Middle section of New Mexico, and the Elephant Butte-Fort Quitman section of New Mexico and Texas, with due consideration to past and present uses and requirements and to future development. Elements involved are also the salvage of recoverable wastes and, to the extent feasible, the importation of water from outside the Rio Grande Basin.

As stated by Colorado, its major problem is the provision of storage capacity sufficient to regulate stream flow so that the supply of water may parallel and meet the irrigation demand of the San Luis Valley lands that are now irrigated and for which irrigation works were largely constructed prior to 1890. Its contention has been that the required major reservoir development to equalize the water supply will not result in any substantial increased depletion of Rio Grande flow at the State line; that in conjunction with drainage development it may, indeed, bring about an increase in that flow.

The major problem of the Middle and Elephant Butte-Fort Quitman sections is the maintenance of an adequate water supply for irrigation of the lands of the Middle Rio Grande Conservancy District in the Middle section and of the Rio Grande Project and Hudspeth County Conservation and Reclamation District in the Elephant Butte-Fort Quitman section. With respect to the latter section, there is the further problem of maintaining satisfactory control of salinity in the irrigated areas. Texas and New Mexico have vigorously resisted any major reservoir development in Colorado, on the ground that it would deplete the stream flow to an extent that would seriously jeopardize the water supply in New Mexico and Texas. Moreover, since the Middle Rio Grande Conservancy District began operations, Texas has contended that the use of water in the Middle district constitutes a menace to the water supply of the Rio Grande Project, which, it is asserted, will become more serious with complete development in the Middle district. In fact, on October 24, 1935, a suit was initiated in the United States Supreme Court by the State of Texas for the districts in the Rio Grande Project to enjoin the Middle Rio Grande Conservancy District and the State of New Mexico from alleged depletion of the water supply of the Rio Grande Project in violation of the Rio Grande compact.

The solution of these problems requires a comprehensive and adequate basis of fundamental facts—facts which definitely establish the available and potential water supplies, the present uses of water, and the requirements for it. With these facts in hand, reliable estimates should be possible of future changes in the water supply due to such developments as storage in Colorado, the proposed transmountain diversions from the basin of the San Juan, and the ultimate irrigation in the Middle Rio Grande conservancy district.

This report presents a basis of facts which it is hoped may prove adequate for the solution of these problems, to the end that the water resources of the Upper Rio Grande Basin may be put to maximum beneficial use and that all conflict of Federal, State, and local interests may be permanently dispelled.

Summary of Findings

Water Supply

Average annual precipitation in the Upper Rio Grande Basin ranges from less than 7 inches to 40 inches or more. The highest precipitation occurs in the Sangre de Cristo and San Juan ranges and the lowest in the central areas of the subvalleys of Rio Grande. With only 7 to 10 inches in these valleys, irrigation is essential for successful agriculture.

Mean annual lake-surface evaporation ranges from about 3 feet at an altitude of 9,500 feet on Rio Grande above San Luis Valley to about 6 feet at an altitude of 4,200 feet at Elephant Butte Reservoir.

Run-off in Rio Grande in the upper basin has been measured at five principal gaging stations for a period of 40 to 45 years. These stations are Del Norte and Lobatos, respectively above and below San Luis Valley, Otowi Bridge and San Marcial, respectively above and below the Middle valley, and El Paso. The mean annual run-off at these stations, together with the run-off of maximum and minimum years in percent of the mean, is shown in table 1.

TABLE 1.—*Annual run-off in Rio Grande at 5 principal gaging stations in the upper basin*

Gaging station	Mean annual run-off, 1890–1935, acre-feet	Annual run-off in percent of mean	
		Maximum year	Minimum year
Del Norte	707,000	165	35
Lobatos	550,000	261	18
Otowi Bridge	1,250,000	203	28
San Marcial	1,128,000	221	18
El Paso [1]	744,000	270	

[1] Regulated by Elephant Butte storage after 1915.

Means of monthly run-off at the Del Norte and Otowi Bridge stations show that 70 percent of the annual run-off occurs between April and July, inclusive.

The total mean annual water production from run-off, 1890–1935, in the upper basin, is estimated at 3,060,000 acre-feet on the basis of all available stream-flow records. Of this total, 1,570,000 acre-feet originate in Colorado and 1,470,000 acre-feet in New Mexico. The production in the two States accounts for more than 99 percent of the total for the basin. Of the Colorado production, about 12 percent originates in the Closed Basin.

Depletion in San Luis Valley.—As shown by table 1, the mean annual run-off, 1890–1935, of Rio Grande at Lobatos was 550,000 acre-feet. Over a long period of years ending about 1927, there occurred a more or less steady increase in the depletion of stream flow to the southwest area in San Luis Valley; since 1927, there appears to have been little change in the depletion. Practically the entire flow of Rio Grande leaving San Luis Valley comes from the southwest area. Taking the average depletion, 1927–35, as representing present conditions in San Luis Valley, it is estimated that the mean annual flow under these conditions of Rio Grande at Lobatos, 1890–1935, would have been 448,000 acre-feet, or 102,000 acre-feet less than the mean of the recorded flow.

Middle Valley depletion.—Accurate determination of past stream-flow depletion in the Middle Valley is not possible because of the lack of adequate records of tributary inflow and uncertainty with respect to it. An approximation has been derived, based on such data as are available in order to furnish a reasonable basis for analyses of the effect upon the Elephant Butte-Fort Quitman section of present and given future conditions of irrigation development in the San Luis and Middle sections. The mean annual stream-flow depletion, 1890–1935, Otowi Bridge to San Marcial, is estimated to have been 586,000 acre-feet. The corresponding mean annual tributary inflow derived as a residual in the method of estimating depletion is 359,000 acre-feet. Corrected for present development in San Luis Valley, the derived values for mean annual Middle Valley depletion and San Marcial flow are 580,000 and 1,030,000 acre-feet, respectively.

Return flow.—Return flow to Rio Grande in San Luis Valley has, in 3 years, 1934, 1935, and 1936, averaged 17 percent of the total Rio Grande diversions, or 36 percent of those diversions which contribute return flow to the river (excluding diversions to its closed basin). A return of 44 percent of diversions was indicated on the Conejos River by the data available for 1936. Return flow in the subdivisions of the Middle Rio Grande Conservancy District in the Middle Valley and the Rio Grande Project in the Elephant Butte-Fort Quitman section reaches the river above, and is available to, the next division downstream, except for return from the lowest divisions, Socorro in the Conservancy District and the Tornillo unit in Rio Grande Project. Return flow in the Conservancy District, as indicated by the total measured discharge of interior drains in 1936, was 28 percent of the gross diversions. Data were not available on net diversions. On the Rio Grande Project, return flow, represented by the total of measured drain flow averaged for the years 1930–36, was 50 percent of the average of total net diversions in the same period.

Ground water.—There has been little utilization of ground water as a basic source of supply for irrigation in the Upper Rio Grande Basin. The extensive control of ground water for the practice of subirrigation in certain San Luis Valley areas is, perhaps, an exception to this statement. The sources of recharge both to the shallow and artesian ground water basins of San Luis Valley are stream flow (chiefly as it crosses the alluvial fans bordering the valley), irrigation diversions, and precipitation on the valley floor. Depths to water in San Luis Valley, as shown by July 1936 measurements, were less than 5 feet over approximately 70 percent of the Closed Basin and over most of the Bowen-Carmel district and the general area east to the river. These ground water conditions, especially in the central and eastern portions of the Closed Basin, are favorable to the disposal of large quantities of ground water by evaporation and transpiration. A reconnaissance in 1936 of irrigation plants pumping from the shallow ground-water basin in San Luis Valley showed 176, and from discharges reported by owners or operators, the total output of all the plants operating continuously was estimated at 660 acre-feet per day. The number and total annual discharge of artesian wells in San Luis Valley were estimated from a 1936 inventory at 6,074 and 119,000 acre-feet, respectively. There is also an annual discharge from artesian springs of about 47,000 acre-feet.

The sources of ground water in the Middle Valley are underflow from the mesas on either side and seepage from the river, canals, and irrigated lands. In most areas, seepage from irrigated lands is the principal source, and the water in interior drains is largely derived therefrom. On the other hand, the river is, without doubt, the source of most of the water in the riverside drains. Meager data indicate a total annual underflow from the mesas of between 50,000 and 100,000 acre-feet. Depths to ground water in the Middle Rio Grande Conservancy District in 1936, compared to those in 1927 before drainage construction, show an average lowering of the water table over the entire district of 3 feet. October 1936 measurements showed depths to water of less than 3 feet in 4 percent of the total valley area; depths of between 3 and 4 feet in 11 percent of the area; between 4 and 6 feet in 46 percent; between 6 and 8 feet in 28 percent; and more than 8 feet in 11 percent.

Average depths to ground water in Mesilla Valley of the Elephant Butte-Fort Quitman section, as shown by observations in January of each year, have been between 9 and 10 feet throughout the period 1925 to date.

Quality of water.—Investigation of the quality of water in the upper basin shows, in general, a progressive increase in salt concentrations in the downstream direction in streams, drains, and subsoil. On Rio Grande the data indicate a range in average concentration from 0.1 ton per acre-foot at Del Norte to 2.75 tons per acre-foot at Fort Quitman. The latter is equivalent to about 2,000 parts per million. In terms of electrical conductance ($K \times 10^5$ at 25° C.) the indicated average is 296. The average total quantity of salts carried annually ranges from 50,000 tons at Del Norte to 650,000 tons at Leasburg, at the head of Mesilla Valley on the Rio Grande Project. Below Leasburg the tonnage carried decreases to about 470,000 at Fort Quitman, indicating the annual loss of about 180,000 tons between those two stations. Changes in the downstream direction in composition of the constituent parts of the dissolved solids are to higher percentages of sodium and chloride and lower percentages of the other four major constituents—calcium, magnesium, bicarbonate, and sulphate. In terms of conductance the average salinity of irrigation water at El Paso and at Tornillo Heading, the lowest of the Rio Grande Project, is 127 and 212, respectively. Rough averages of the conductances of drain water, as indicated by the 1936 data, are 450 in the upper El Paso Valley and 500 or more in the lower, Tornillo unit. Control of salt in the soil solution of the root zone of plants and limitation to a noninjurious concentration by an increase in the amount of irrigation water applied is indicated for the lower unit of the Rio Grande Project.

Water Uses and Requirements

The use of water for irrigation constitutes practically the entire use in the upper basin. Use by cities, towns, and villages is relatively minor and that for water power negligible.

The complete survey in 1936 of irrigated and other water-consuming areas in the basin covered 2,093,000 acres. A segregation of the mapped areas, by water-use classifications and basin sections, is shown in table 2.

Based on the 1936 acreage data, on a review of studies of consumptive use and stream-flow depletion by previous investigators and on the results of research and field work in 1936, estimates have been prepared of the present consumptive requirements in the various subbasins of the upper basin. These estimates, summarized in table 3, take into account precipitation on the consumptive areas and indicate a total consumption in the basin, exclusive of tributary areas in the Middle and Elephant Butte-Fort Quitman sections, of 3,860,000 acre-feet. By including the tributary areas and reducing the estimates to give stream-flow depletion (by correcting for precipitation) a comparison of the results with the water production in the upper basin affords estimates of water surpluses or deficiencies as shown by table 4. For a year of normal water production there is an indicated basin surplus of 177,000 acre-feet. The average annual flow of Rio Grande at Fort Quitman for the 13-year period of record is 211,000 acre-feet. Similar comparisons show a basin surplus of more than a million and a half acre-feet in the maximum year and a deficiency slightly greater than this amount in the minimum year.

TABLE 2.—*Irrigated and other water consuming areas in the Upper Rio Grande Basin, 1936*

[Unit 1,000 acres]

Basin unit	Agricultural and other lands artificially given water			Other water consuming areas nonirrigated			Total area mapped
	Irrigated	Temporarily out of cropping	Cities, towns, and villages	Native vegetation	Water and river bed surfaces	Bare lands, roads, rights-of-way, etc.	
San Luis section—Colorado:							
Closed basin	278	9	1	404	4	37	733
Southwest area	270	7	4	176	7	18	482
Southeast area	52	3	1	157	3	15	231
Total	600	19	6	737	14	70	1,446
Middle section—New Mexico:							
Above Otowi Bridge	6	......	......	4	2	1	13
Middle Rio Grande conservancy district	59	3	6	91	22	7	188
Middle Rio Grande conservancy district to San Marcial	1	......	......	13	3	......	17
Tributary areas	87	10	4	34	12	3	150
Total	153	13	10	142	39	11	368
Elephant Butte-Fort Quitman section—New Mexico and Texas:							
San Marcial to Rincon	1	......	1	29	5	1	[1] 37
Rio Grande project	154	11	2	30	8	5	210
Hudspeth County	14	2	......	6	......	......	22
Tributary areas	2	1	......	4	3	......	10
Total	171	14	3	69	16	6	279
Upper Rio Grande Basin	924	46	19	948	69	87	2,093

[1] Does not include 16,700 acres of water surface in Elephant Butte Reservoir.

TABLE 3.—*Estimates of consumptive water requirements in Upper Rio Grande Basin* [1]

Item	San Luis section	Main stem of Rio Grande in Middle section	Main stem of Rio Grande in Elephant Butte-Fort Quitman section
Irrigated lands:			
Area in 1,000 acre units	600	66	169
Consumption in 1,000 acre-feet units	1,043	172	469
Acre-feet per acre	1.7	2.6	2.8
Native vegetation:			
Area in 1,000 acre units	737	107	66
Consumption in 1,000 acre-feet units	1,056	387	267
Acre-feet per acre	1.4	3.6	4.0
Miscellaneous: [2]			
Area in 1,000 acre units	109	45	[3] 51
Consumption in 1,000 acre-feet units	135	147	190
Acre-feet per acre	1.2	3.3	3.7
Totals:			
Area in 1,000 acre units	1,446	218	286
Consumption in 1,000 acre-feet units	2,234	706	925
Acre-feet per acre	1.5	3.2	3.2

[1] Includes consumption of precipitation.
[2] Cities, towns, and villages; lands temporarily out of cropping; water surfaces and exposed beds; bare land, roads, rights-of-way, etc.
[3] Excludes area of city of El Paso.

TABLE 4.—*Water supply and stream-flow depletion in Upper Rio Grande Basin for a normal year and present use of water*

Item	San Luis section	Middle section	Elephant Butte-Fort Quitman section	Upper Rio Grande Basin
Irrigated and water-consuming acreage, 1936	[1] 1,047,000	367,000	336,000	1,750,000
Stream-flow depletion in acre-feet	[2] 1,047,000	768,000	885,000	2,700,000
Water production—total natural run-off in acre-feet	[3] 1,379,000	1,333,000	165,000	2,877,000
Surplus or deficiency	332,000	565,000	−720,000	177,000

[1] Excludes closed basin area except that irrigated from Rio Grande.
[2] Excludes closed basin consumption except by area served from Rio Grande.
[3] Excludes water production of closed basin.

Diversion requirements.—Based on all available relevant data and on studies of consumptive use, stream-flow depletion, return-flow, wastes, salinity, and present irrigated and other water-consuming acreages, estimates of the diversion requirements, or demands upon the stream flow of the major units of the upper basin have been developed as shown in table 5. These are the demands for full development as represented by the irrigated areas shown. The estimates of stream-flow depletion in each unit, from which the demands were derived, are indicated. The demand for the Rio Grande Project and for fulfillment of the Mexican treaty obligation includes a 60-percent increase in the diversion requirement for the Tornillo unit of Rio Grande Project. This is an estimated allowance for salinity control. It is experimental and may be modified as experience dictates.

The total annual stream-flow depletion by cities, towns, and villages in the upper basin, excluding El Paso, is estimated to be 21,000 acre-feet. The annual draft on deep wells supplying the municipal and industrial requirements of El Paso is about 14,000 acre-feet.

Storage, Importation, and Salvage of Water.

The present storage capacity of reservoirs in the upper basin is 2,872,000 acre-feet. Of this, 309,000 acre-feet is in Colorado and 2,563,000 acre-feet in New Mexico. Of the Colorado storage, 131,000 acre-feet capacity is in the upper Rio Grande drainage above San Luis Valley. Some 2,274,000 acre-feet or 89 percent of the New Mexico storage capacity is accounted for by Elephant Butte Reservoir.

TABLE 5.—*Estimated diversion demands upon stream flow, major units of Upper Rio Grande Basin*

Basin unit	Demand upon stream flow acre-feet	Source and required location of supply	Irrigated acreage for full development, maximum in any one year	Estimated stream-flow depletion upon which demand is based, acre-feet
Rio Grande area of San Luis Valley.	650,000	Rio Grande at Del Norte gage.	350,000	455,000
Conejos area of San Luis Valley.	230,000	Conejos River at Mogote gage and San Antonio River at mouth.	80,000	150,000
Middle Valley, Otowi Bridge to San Marcial:				550,000
Middle Rio Grande Conservancy District.	580,000	Rio Grande at Otowi Bridge and divertible tributary inflow below.[1]	100,000	
Conservancy district to San Marcial.[2]	80,000	Rio Grande at San Antonio and tributary inflow below.	1,000	
Rio Grande project and Mexican area.[3]	953,000	Rio Grande at San Marcial.	----------	[4] 180,000
	773,000	Elephant Butte Reservoir.	[5] 145,000	[5] 441,000

[1] Tributary inflow from Cochiti to San Felipe has a portion of Jemez flow. Mean annual usable inflow estimated at about [illegible]0,000 acre-feet, or [illegible] percent of total tributary inflow to Middle Valley.
[2] This area is largely native vegetation, swamp, and overflow lands.
[3] Hudspeth district not included as its water supply is derived from and entirely dependent upon residual flow drainage return, and waste from Rio Grande Project.
[4] Estimated reservoir evaporation and seepage.
[5] For Rio Grande project only.

Storage projects that have been proposed for the basin and data resulting from their investigations in 1936–37 are listed in table 6. Although primarily for irrigation, incidental benefit in the control of floods is indicated for the larger reservoirs.

Possible sources of additional water supplies for the upper basin are importations from the San Juan drainage of the Colorado River Basin and salvage of present wastes and losses. Data developed by the Rio Grande Joint Investigation with respect to possible transmountain diversions from the upper San Juan Basin are summarized in table 7. Existing developments in the San Juan Basin as far down as Shiprock would not be impaired by any of these diversions. In the event of more extensive future development of San Juan areas than now anticipated, some compensating storage on San Juan River or a tributary may be required.

Of the upper basin water consumption shown by table 3, 44 percent is accounted for by the irrigated areas and 44 percent by the areas of native vegetation. In other words, there is a nonbeneficial consumption of water by native vegetation equal in amount to the consumption by the irrigated lands. Reduced to terms of stream-flow depletion, native vegetation takes an average annual toll from the basin of more than 1,000,000 acre-feet of water. The data are not developed to determine what portion of this amount might be economically recovered, principally by proper drainage construction, but it is undoubtedly a fraction which would signify a substantial saving of water. There is still a great amount of undrained land in the basin. The estimated mean annual yield of the sump drain, a trunk drain proposed to collect the waters in the sump area of the Closed Basin, San Luis Valley, and discharge them to Rio Grande, is about 40,000 acre-feet. Chemical analyses of tributary stream flow, drainage, and ground water of the sump area indicate that the salt concentration of the sump-drain water might be as much as 1.5 tons per acre-foot initially, with a possible reduction, in time, to 1 ton or less, per acre-foot.

Availability and Use of Water under Given Conditions

Using the data developed by this investigation with respect to water supply, its uses and requirements, and opportunities for its storage, importation, and salvage, analyses were made to determine the effect upon, and conditions of water supply and use in, the San Luis, Middle, and Elephant Butte-Fort. Quitman sections, under 11 different given combinations or conditions of storage development and draft. The salient features of the various conditions are outlined in table 8, which gives a summary of the analyses by showing for each

TABLE 6.—*Storage projects under investigation, 1936-37, Upper Rio Grande Basin*

Project	State	Stream	Type of dam	Reservoir capacity	Estimated mean annual run-off to reservoir	Estimated cost in dollars: Total	Per acre-foot of capacity
				Acre-feet	*Acre-feet*		
Wagon Wheel Gap	Colorado	Rio Grande	Concrete arch	1,000,000	472,000	[1]11,900,000	[1]11.40
Vega Sylvestre [2]	do	do	Earth and rock	240,000	344,000	4,826,000	20.10
Conejos No. 1[2]	do	Conejos	do	100,000	256,000	3,700,000	37.00
Conejos Granite Site	do	do	do	100,000	256,000	{3,655,000 {2,601,000	36.55 5.75
Upper Conejos No. [illegible]	do	do	Compacted embankment	22,000	49,000	[illegible]08,000	19.00
[illegible]	do	[illegible]	do	30,000		[illegible]	[2]24.87
State Line—[illegible] Mountain Site	New Mexico and Colorado	Rio Grande	Concrete arch	[illegible]52,000			

[1] Exclusive of railroad relocation and power installation.
[2] Data are tentative.

TABLE 7.—*Transmountain diversion projects, Upper San Juan Basin to Upper Rio Grande Basin*

Project	State	Local drainage: From—	To—	Reservoirs: Stream or name	Capacity	Conduit system, length in miles: Tunnel	Open	Total	Estimated mean annual yield	Estimated cost: Total	Per acre-foot of diversion
					Acre-feet				*Acre-feet*		
San Juan-Chama	Colorado-New Mexico.	East and west forks San Juan, Turkey, Blanco, Navajo.	Chama	West fork, San Juan East fork, San Juan Blanco Navajo	70,000 35,000 15,000 50,000	12.8	78.3	91.1	350,000	[1]$20,000,000	$57
Animas-Rio Grade	Colorado	Animas, South fork Mineral, Mineral, Cement.	Headwaters Rio Grande.	Howardsville on Animas.	54,000	15.5	11.1	26.6	[2]131,000	10,432,000	80
Weminuche Pass	do	Pine	do				7.5	7.5	[2]20,400	264,000	13
San Juan-South fork Rio Grande.	do	West fork San Juan, Beaver, Wolf.	South fork Rio Grande.			10.9	2.6	13.5	[2]53,000	5,290,000	100

[1] Includes cost of 800,000 acre-feet of terminal storage.
[2] Divertible run-off.

condition: (1) the mean annual run-off of Rio Grande at Lobatos and San Marcial, (2) the minimum and [illegible]ean August run-off at Lobatos, and (3) the maximum [illegible]hortages in San Luis, Middle, and Elephant Butte-Fort Quitman sections, for two periods, 1892–1904 and 1911–35.

Consideration of the data of mean annual run-off of the Rio Grande near Lobatos under the various conditions indicates that the effect of increased storage development in the San Luis Valley is to decrease the annual run-off in high water years by storage and to increase it during low years by release of water held over from the more abundant years. Except for Conditions Nos. 5 and 10, the latter representing greatest possible development in San Luis Valley, the mean annual flow at Lobatos under the various conditions indicated remains practically unchanged from that of the present (Condition No. 2).

Study of the monthly flow at Lobatos under the various conditions indicates an improvement in nearly every case over present conditions, in the regimen of flow from month to month, particularly in the summer and fall months of low-water years. In these months the flow is built up by the improved and redistributed return flow resulting from diversions which storage regulation has permitted to be made more in keeping with the irrigation demand.

Severe shortages are indicated in all three sections of the upper basin in the early critical period 1899–1904 under every condition for which an analysis covering this period was made, with the exception that in the Middle Valley, under Condition No. 11, there was no shortage. Under Conditions Nos. 4 and 5 which include Wagon Wheel Gap Reservoir with return flow to the Rio Grande in San Luis Valley taken at 16 and 8 percent, respectively, of the total Rio Grande diversions in the valley, shortages in the Middle Valley are substantially reduced from those indicated for present conditions, except under Condition No. 5 in the early period for which the shortage remains the same.

In Elephant Butte-Fort Quitman section under Conditions Nos. 4 and 5 the shortages in the early period are increased over those under present conditions. No shortages, however, occur in the 1911–35 period and the minimum content of Elephant Butte Reservoir in this period under Condition No. 5 would have been 364,000 acre-feet.

From a study of the amounts and occurrences of the

TABLE 8.—*Mean annual run-off of Rio Grande at Lobatos and San Marcial, minimum and mean August run-off at Lobatos, and maximum shortages in San Luis, Middle, and Elephant Butte-Fort Quitman sections, 1892–1904 and 1911–35, under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Item	Condition number[1]										
	1	2	3	4	5	6	7	8	9	10	11
Mean annual run-off at Lobatos:											
1892–1904	...	308	...	320	275	...	...	...	...	...	315
[illegible]911–35	[illegible]88	[illegible]73	490	[illegible]85	[illegible]33	...	[illegible]86	...	...	[illegible]47	[illegible]73
[illegible] annual run-off at San Marcial:											
[illegible]892–1904	...	[illegible]89	...	756	732	...	...	...	...	...	693
1911–35	...	1,082	...	1,085	1,038	...	1,084	...	...	946	1,014
Minimum August run-off at Lobatos:											
1902	...	.6	...	1.1	.3	...	...	...	...	...	5.9
1934	1.7	1.2	1.5	15.3	6.5	...	24.5	...	...	2.7	12.1
Mean August run-off at Lobatos:											
1892–1904	...	4.0	...	14.0	8.0	...	...	...	...	...	13.6
1911–35	16.2	15.5	24.1	25.4	16.6	...	34.9	...	...	33.0	22.2
Maximum shortage:											
San Luis section:											
1892–1904	...	...	...	425	...	...	...	...	...	...	...
1911–35	424	...	357	0	...	36	...	141	151	...	...
Middle section:											
1892–1904	...	191	...	162	192	...	...	...	...	...	0
1911–35	...	237	...	161	225	...	80	...	...	119	0
Elephant Butte-Fort Quitman section:											
1892–1904	...	383	...	454	480	...	...	...	...	...	538
1911–35	...	0	...	...	0	...	...	...	...	0	0
Minimum storage in Elephant Butte Reservoir:											
1892–1904	...	0	...	0	0	...	...	...	...	...	0
1911–35	...	700	...	665	364	...	...	...	...	88	205

[1] Conditions:
- No. 1. No increased storage in S.; A. for R.
- No. 2. Present conditions in S.; A. for M. and E.
- No. 3. V. S.; A. for R.; R. R. F.=16 percent.
- No. 4. W.; A. for R. and M.; R. R. F.=16 percent.
- No. 5. W.; A. for R., M., and E.; R. R. F.=8 percent.
- No. 6. Con.; A. for C.; C. R. F.=35 percent.
- No. 7. W. and Con.; A. for R., C., and M.; R. R. F.=16; C. R. F.=35.
- No. 8. W. and V. S.; Max. for R.; total return same as given by no. 4.
- No. 9. Con.; Max. for C.; total return same as given by no. 6.
- No. 10. W., V. S., and Con.; Max. for R. and C.; A. for M. and E.; total return in S. same as given by nos. 4 and 6.
- No. 11. W., S. L., and S. D.; A. for R., M., and E.; R. R. F.=8.

Key to Symbols Used in List of Conditions

- A. =Adopted diversion demand, i. e., 650,000 acre-feet for R, 230,000 for C., 580,000 for M., and 773,000 for E.
- C. =Conejos area.
- Con. =Conejos Reservoirs.
- C. R. F.=Return flow to Conejos in percent of Conejos diversions.
- E. =Elephant Butte-Fort Quitman section.
- [illegible] =Middle section.
- [illegible]x. =Diversion demand for maximum development, i. e., 750,000 acre-feet for R. and 300,000 for C.
- R. =Area served from Rio Grande in San Luis Valley.
- R. R. F.=Return flow to Rio Grande in San Luis Valley in percent of total Rio Grande diversions in the valley.
- S. =San Luis section.
- S. D. =Sump drain.
- S. L. =State Line Reservoir.
- V. S. =Vega-Sylvestre Reservoir.
- W. =Wagon Wheel Gap Reservoir.

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shortages in the three sections of the basin under the various conditions, it is indicated that the transmountain diversions would be beneficial principally in relieving the shortages of critical periods and years, such as 1899–1904 and 1934, although by the same token that there were severe shortages in these years in the Rio Grande Basin, the San Juan supply and hence the diversions would probably have been correspondingly short.

There would be opportunity for use of the imported water for development of new lands during the period of a generation or more when no shortages are indicated under any of the conditions except Nos. 1 and 9, but the new lands would of necessity suffer severe shortages in the years when the transmountain diversions would be needed to alleviate shortages in the present developed areas.

PART I

SECTION 2.—WATER SUPPLY

Description of Basin

The Upper Rio Grande Basin occupies a portion of southern Colorado, a strip through central New Mexico from north to south, and a small portion of western Texas and northern Mexico. The total length of Rio Grande above Fort Quitman, Tex., the lower extremity of the upper basin, is about 650 miles and the tributary drainage area, excluding the closed basin in San Luis Valley, Colo., is 31,000 square miles. For the purposes of this study and more or less in conformity with natural divisions, the basin is segregated into three areas designated as the San Luis section in Colorado, the Middle section in New Mexico, and the Elephant Butte-Fort Quitman section in New Mexico, Texas, and Mexico. These are indicated on the map, plate 1.

The San Luis Section

The San Luis Valley is a plain approximately 90 miles from north to south and 50 miles from east to west. The altitude of the valley floor ranges from 7,440 feet on the south, where Rio Grande passes between the San Luis Hills to about 8,000 feet around its rim. The surrounding mountains attain altitudes generally above 10,000 feet, while Mount Blanca on the east rises to 14,390 feet. The valley is bounded on the west by the Conejos Mountains and La Garita Hills, on the north by the Saguache and Sangre de Cristo Mountains, on the east by the Sangre de Cristo Mountains, and on the south by the San Luis Hills. The Continental Divide is to the west, consisting of the San Juan Mountains and the Cochetopa Hills. The water-producing area comprises the mountainous regions above the 8,000-foot contour defining the rim of the valley. Rio Grande rises in the San Juan Mountains near the Continental Divide and, flowing in a southeasterly direction between the Conejos Mountains and La Garita Hills, enters the valley proper on the west at Del Norte. It continues southeasterly through Monte Vista to Alamosa, at which point it takes a southerly course for nearly 40 miles and, passing through a break in the San Luis Hills, enters New Mexico.

With respect to water supply, San Luis Valley may be conveniently divided into three sections: The closed basin, the southwest area, and the southeast area. A low divide has been formed across the valley by the alluvial fan of Rio Grande on the west and the alluvial material from the Sangre de Cristo Mountains on the east. This divide, almost imperceptible to the eye, extends southeasterly from the vicinity of Del Norte to a point a few miles north of Alamosa and thence easterly to the eastern rim of the Valley. To the north of this divide there is a valley area of 2,940 square miles which is not tributary to Rio Grande. This is termed the Closed Basin. The lowest portion or "sump" of this basin is located close to the foot of the Sangre de Cristo Mountains on the east side of the valley, and is plainly defined by a chain of lakes of which San Luis Lake is the largest, and by a succession of alkali flats extending from Washington Springs near the Denver & Rio Grande Western R.R. on the south to a point on the north some 5 miles northeast of Gibson. The streams entering the valley in the closed basin are La Garita and Carnero from the west, Saguache from the northwest, Kerber and San Luis from the north, and Cotton, Wild Cherry, Rito Alto, North and South Crestone, Willow, Spanish, Cottonwood, Deadman, Sand, Medano, and Zapato from the east. Practically all water produced by these streams that is not consumed in irrigation flows to the sump and is lost by evaporation. In addition, all water diverted from Rio Grande for a large acreage in the closed basin, and not consumed in irrigation there, is lost in the sump area.

The southwest area of San Luis Valley lies south of the closed basin, west of Rio Grande and north of the New Mexico State line. Conejos River, the principal tributary of Rio Grande in Colorado, rises in the mountains to the southwest, enters the valley at its southwest corner and flows northeasterly to join Rio Grande

FIGURE 1.—Canal Heading in San Luis Valley. Headgate in foreground, check structure beyond.

north of La Sauses. Los Pinos and San Antonio Rivers are tributary to the Conejos from the southwest. Los Pinos River joins the San Antonio near Ortiz and the latter joins the Conejos in the valley near Manassa. Tributaries from the west between the Conejos and Rio Grande are La Jara, Alamosa, and Rock Creeks.

The southeast area extends east from Rio Grande to the lower slope of the Culebra Range of the Sangre de Cristo Mountains and, as here considered, from the New Mexico State line north to the south slope of Mount Blanca and to the closed basin. The streams entering this area flow from the east and are, from north to south, Trinchera Creek, Culebra Creek, and Costilla River. Sangre de Cristo and Ute Creeks are tributaries of the Trinchera. Costilla River rises in New Mexico, flows north and west for about 10 miles in Colorado and then turns south and joins the Rio Grande in New Mexico. These streams contribute very little to the Rio Grande as their waters are largely regulated and absorbed by irrigation before they reach the river.

The Middle Section

The Middle section is taken to include the Rio Grande and tributary valleys from the Colorado-New Mexico State line to San Marcial at the head of Elephant Butte Reservoir, a river distance of about 270 mi' The upper half of this stretch of Rio Grande is flank on the east by the southern extension of the Sangre de Cristo Mountains, which maintain their high altitudes as far south as the Glorietta Divide east of Santa Fe. On the west, the Conejos Range extends southward between the river and its principal New Mexico tributary, Rio Chama, succeeded south of the latter by the Jemez Mountains. It is from this portion of the drainage area that Rio Grande receives most of the part of its water supply which originates in New Mexico. South of Santa Fe on the east and Jemez Mountains on the west, the flanking ranges decrease in height. There is also a marked change in the character of the precipitation; heavy winter snows on the higher northern mountains give place to sporadic and sometimes violent downpours, most of them in summer, on the lower southern ranges. Tributary streams south of Rio Chama are therefore largely torrential in character and productive of a relatively small total run-off to Rio Grande.

A few miles north of the Colorado-New Mexico State line, Rio Grande enters a canyon which gradually increases in depth to more than 1,200 feet at Embudo,

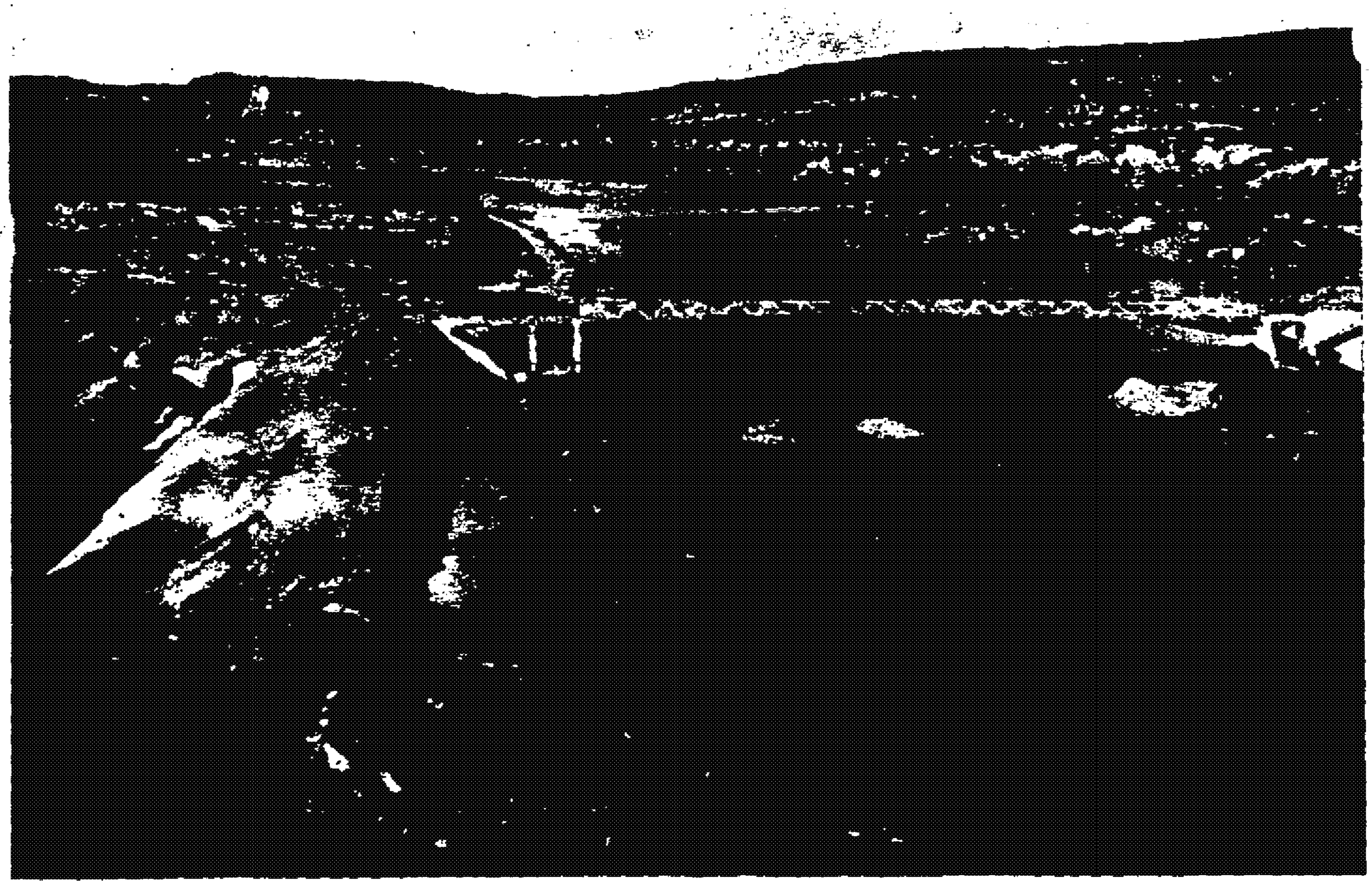


FIGURE 2.—Cochiti Diversion Dam. Middle Rio Grande Conservancy District, New Mexico.

70 miles south of the line. In this stretch, the tributaries are from the east and include Rio Colorado, Rio Hondo, Rio Taos, and Embudo Creek. These streams rise in the Sangre de Cristo Mountains and afford water for irrigation on the mesa lands at the foot of the mountains. There is some residual flow to Rio Grande.

A short distance below Embudo the river enters Espanola Valley, which is some 25 miles long and from 1 to 3 miles wide. Here it is joined by Rio Chama from the west and Rio Santa Cruz from the east. The Chama is an important stream draining some 3,200 square miles and on it, about 60 miles above its mouth, is situate the El Vado Reservoir of the Middle Rio Grande Conservancy District. There is some irrigation development in its mountain valleys. On Rio Santa Cruz there is a small reservoir and the lands in its valley are irrigated.

At the lower end of Espanola Valley, the river enters White Rock Canyon, a narrow tortuous gorge some 20 miles long, and, leaving this at a point almost due west of Santa Fe, it enters a long narrow valley bounded on each side by mesas which rise abruptly to a height of 300 to 500 feet above the valley floor and then slope gently upward to the foot of the mountains. This is the principal valley of the Middle section and it extends 150 miles to San Marcial Narrows, broken only by short canyons or narrows at San Felipe, Isleta, and San Acacia which define the subvalleys of Santo Domingo, Albuquerque, Belen, and Socorro. These valleys vary in width from 1 to 4 or 5 miles. Albuquerque, the largest city of New Mexico, is in Albuquerque Valley, 45 miles below White Rock Canyon. The Middle Rio Grande Conservancy District includes the valley lands from White Rock Canyon to the southern third of Socorro Valley. The principal tributaries are Santa Fe and Galisteo creeks, entering Santo Domingo Valley from the east, Jemez Creek from the west, a few miles below San Felipe Narrows, and Rio Puerco and Rio Salado from the west just above San Acacia Narrows, 65 miles south of Albuquerque. These streams are largely torrential in character and only contribute discharge of consequence to Rio Grande at times of flashy floods. Rio Puerco drains some 5,000 square miles, but this is an area of relatively low altitude and scant precipitation, although subject to irregular and sudden storms of cloudburst proportions. There is some irrigation along Rio Puerco and its tributaries and in Jemez Creek Valleys.

The Elephant Butte-Fort Quitman Section

The Elephant Butte-Fort Quitman section comprises the Rio Grande Valleys from San Marcial to Fort Quitman, Tex., a distance of 250 miles. For 65

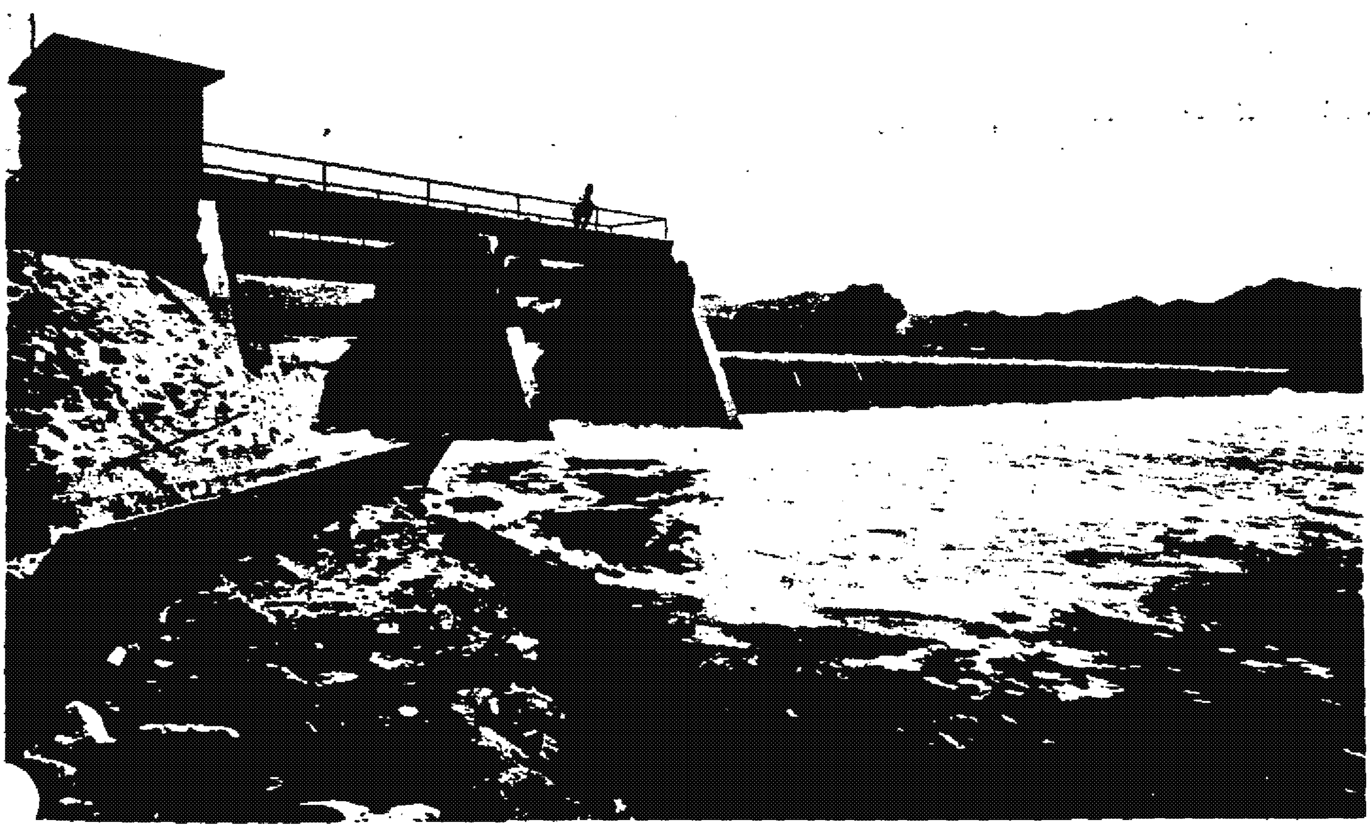
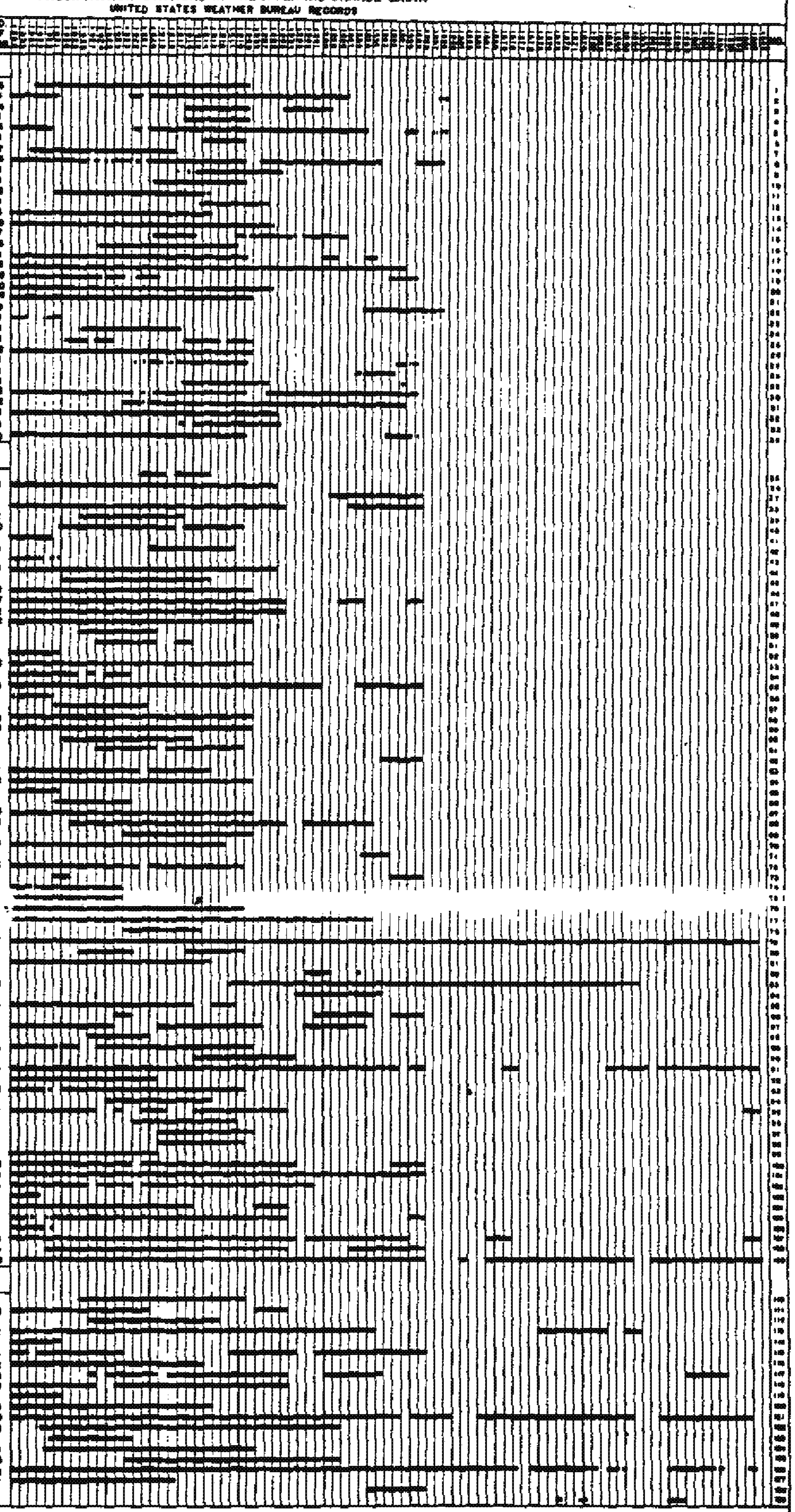


FIGURE 3.—Percha Dam, Rio Grande Project. Head of Rincon Valley, N. Mex.

PRECIPITATION STATIONS IN THE UPPER RIO GRANDE BASIN

UNITED STATES WEATHER BUREAU RECORDS

NO.	STATION	ELEVATION	COUNTY	STATE	NO. OF YRS.
	SAN LUIS SECTION				
1	* GARFIELD	9610	CHAFFEE	COLO.	25
2	* SALIDA	7050	DO	DO	31
3	* MARSHALL PASS	[illegible]	SAGUACHE		14
4	* COCHETOPA	[illegible]	DO		8
5	* WESTCLIFFE	[illegible]	CUSTER		34
6	* HERMIT LAKE	[illegible]	DO		8
7	* CATHEDRAL	[illegible]	HINSDALE		17
8	SAGUACHE	7700	SAGUACHE		42
9	* LAKE CITY	[illegible]	HINSDALE		11
10	* [illegible]	[illegible]	[illegible]		11
11	* [illegible] BASIN	11522	SAN MIGUEL		10
12	* EUREKA	[illegible]	SAN JUAN		6
13	* AMES	[illegible]	SAN MIGUEL		22
14	* SILVERTON	[illegible]	SAN JUAN		29
15	WAGON WHEEL GAP RIVER STA.	8434	MINERAL		17
16	WAGON WHEEL GAP EXP. STA.	9610	DO		16
17	[illegible] (NEAR)	8012	DO		31
18	[illegible]	7570	ALAMOSA		48
19	DEL NORTE	7880	RIO GRANDE		10
20	* [illegible]	[illegible]	SAN JUAN		30
21	LA VETA PASS	[illegible]	COSTILLA		29
22	MONTE VISTA	7664	RIO GRANDE		9
23	* [illegible] SPRINGS (NEAR)	11100	MINERAL		4
24	* PALISADE LAKE	[illegible]	HINSDALE		11
25	BLANCA	7870	COSTILLA		11
26	* CUCHARA CAMPS	[illegible]	HUERFANO		26
27	PLATORA	[illegible]	CONEJOS		11
28	LA JARA	7600	DO		8
29	* PAGOSA SPRINGS	7108	ARCHULETA		11
30	* NORTH LAKE	8700	LAS ANIMAS		48
31	SAN LUIS	7950	COSTILLA		32
32	MANASSA	7700	CONEJOS		31
33	* STONEWALL	[illegible]	LAS ANIMAS		11
34	CUMBRES	[illegible]	CONEJOS	COLO.	30
	MIDDLE SECTION				
35	COSTILLA	7700	TAOS	N.MEX.	7
36	* DULCE	6767	RIO ARRIBA	DO	31
37	* MONERO	7300	DO		11
38	CHAMA	7881	DO		41
39	SAN ANTONIO RANGER STATION	8600	DO		12
40	SUNSHINE VALLEY (NEAR)	7600	TAOS		20
41	CERRO	7600	DO		5
42	[illegible] MINE	[illegible]	DO		10
43	TIERRA AMARILLA	7400	RIO ARRIBA		4
44	RED RIVER CANYON	[illegible]	TAOS		31
45	EAGLE NEST RANGER STATION	[illegible]	DO		17
46	ASPEN GROVE RANCH	[illegible]	RIO ARRIBA		26
47	TRES PIEDRAS	[illegible]	TAOS		37
48	* ELIZABETHTOWN	8400	COLFAX		26
49	[illegible] RANCH	[illegible]	RIO ARRIBA		26
50	[illegible] (NEAR)	7500	TAOS		9
51	VALLECITOS	7200	RIO ARRIBA		9
52	* [illegible] (NEAR)	8219	TAOS		6
53	TAOS CANYON	[illegible]	TAOS		26
54	GAVILAN (NEAR)	7500	RIO ARRIBA		12
55	TAOS	[illegible]	TAOS		44
56	EL RITO		RIO ARRIBA		4
57	* LINDRITH	[illegible]	DO		11
58	* AURORA	[illegible]	COLFAX		26
59	* BLACK LAKE	8340	DO		20
60	CAPULIN RANGER STATION	7800	RIO ARRIBA		15
61	* [illegible]	[illegible]	DO		16
62	[illegible]	[illegible]	DO		6
63	REGINA	7400	SANDOVAL		22
64	* CHACON	8640	MORA		20
65	PENASCO	7500	TAOS		6
66	LA JARA RANGER STATION	7131	SANDOVAL		9
67	TRUCHAS	7800	RIO ARRIBA		26
68	ESPANOLA	[illegible]	DO		33
69	[illegible]	[illegible]	SANTA FE		15
70	[illegible] RANCH	[illegible]	SANDOVAL		29
71	[illegible] SULPHUR SPRINGS		DO		4
72	ALAMO RANCH	7300	DO		26
73	[illegible]	6000	SANTA FE		6
74	FRIJOLES CANYON	[illegible]	SANDOVAL		12
75	LEE RANCH	5000	[illegible]		7
76	JEMEZ SPRINGS	[illegible]	[illegible]		[illegible]
77	* [illegible] RANCH	[illegible]	SAN MIGUEL		4
78	BLAND	7000	SANDOVAL		3
79	SANTA FE	7043	SANTA FE		67
80	SANTA FE CANYON	8100	DO		15
81	* [illegible]	[illegible]	MC KINLEY		23
82	WOODBURY		SANDOVAL		3
83	* FORT WINGATE	[illegible]	MC KINLEY		46
84	GALISTEO	[illegible]	SANTA FE		19
85	* MC GAFFEY RANGER STATION	[illegible]	MC KINLEY		24
86	BERNALILLO	5040	SANDOVAL		15
87	BLUEWATER	[illegible]	VALENCIA		21
88	[illegible]	[illegible]	DO		7
89	* STANLEY (NEAR)	6517	SANTA FE		[illegible]
90	SAN RAFAEL	[illegible]	VALENCIA		12
91	ALBUQUERQUE	5196	BERNALILLO		66
92	SAN FIDEL	[illegible]	VALENCIA		17
93	TIJERAS CANYON R. STATION	[illegible]	BERNALILLO		25
94	* BARTON	[illegible]	DO		12
95	LAGUNA	[illegible]	VALENCIA		27
96	RIO GRANDE INDIAN SCHOOL	[illegible]	BERNALILLO		15
97	* MORIARTY (NEAR)	[illegible]	TORRANCE		11
98	[illegible] RANCH	[illegible]	DO		[illegible]
99	* TAJIQUE (NEAR)	7100	DO		17
100	* ESTANCIA (NEAR)	[illegible]	DO		[illegible]
101	LOS LUNAS (NEAR)	[illegible]	VALENCIA		40
102	* MOUNTAINAIR	6473	TORRANCE		33
103	BERNARDO	4724	SOCORRO		3
104	* [illegible]	7800	CATRON		[illegible]
105	MAGDALENA	[illegible]	SOCORRO		31
106	* MONTE PRIETO	[illegible]	DO		4
107	SOCORRO	4600	DO		[illegible]
108	[illegible] (NEAR)	[illegible]	DO		37
109	SAN MARCIAL	4467	DO	N.MEX.	79
	ELEPHANT BUTTE-FORT QUITMAN SECTION				
110	[illegible] RANCH	[illegible]	SOCORRO	N.MEX.	19
111	[illegible] RANGER STATION	[illegible]	SIERRA	DO	26
112	HERMOSA	7200	DO		15
113	ELEPHANT BUTTE DAM	[illegible]	DO		62
114	* [illegible] RANCH	[illegible]	DO		6
115	HILLSBORO	5234	DO		[illegible]
116	KINGSTON	[illegible]	DO		[illegible]
117	GARFIELD	4100	DONA ANA		23
118	LAKE VALLEY	5012	SIERRA		30
119	HATCH	[illegible]	DONA ANA		6
120	JORNADA EXPER. RANGE	4130	DO		23
121	AGRICULTURAL COLLEGE	[illegible]	DO		79
122	* [illegible]	[illegible]	LUNA		30
123	[illegible]	[illegible]	DONA ANA		8
124	* [illegible]	[illegible]	OTERO		24
125	* [illegible]	4100	DONA ANA	N.MEX.	26
126	EL PASO	3778	EL PASO	TEXAS	76
127	[illegible]	[illegible]	DO	DO	15
128	FORT HANCOCK	3616	HUDSPETH	DO	7
129	FORT QUITMAN	[illegible]	DO	DO	4



* [illegible footnote]

PLATE 2

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miles from San Marcial to Caballo Narrows the flanking hills are close to the river and there is little valley land. The Elephant Butte Reservoir occupies the first 40 miles of this stretch and below it is the small Palomas Valley.

From Caballo Narrows the river enters the Rincon Valley, which is about 30 miles long and has maximum widths of about 2 miles. This terminates in Selden Canyon, at the lower end of which the hills flatten out and recede from the river to form the beginning of Mesilla Valley. This is one of the larger subvalleys. It extends 55 miles south to "The Pass", 4 miles above El Paso, and has a maximum width of about 6 miles opposite Las Cruces, 45 miles north of El Paso.

Below El Paso, Rio Grande is the boundary between Texas and Mexico. On the west side the boundary between New Mexico and Mexico is at "The Pass", but on the east side the New Mexico-Texas line is about 20 miles north of El Paso. The El Paso Valley, which is the lowest in the Upper Rio Grande Basin, is about 90 miles in length from El Paso to the gorge in an extension of the Quitman mountains about 10 miles below Fort Quitman. Widths vary from 4 to 6 miles for much of its length. On the Texas side it includes the lands of the El Paso County Water Improvement District and the Hudspeth County Conservation and Reclamation District. The area on the Mexican side is generally referred to as Juarez Valley. The Rio Grande Project of the Bureau of Reclamation includes the valley lands from Caballo Narrows to El Paso and to a point about 40 miles below the latter, on the Texas side.

Tributaries in the Elephant Butte-Fort Quitman section consist only of arroyos, dry most of the time but subject to flashy floods. The principal ones enter from the west between San Marcial and Rincon Valley and are, in downstream order, Milligan Gulch, San Juan, Nogal, San Jose, Rio Canada Alamosa, Cuchillo, Palomas, Arroyo Seco, Las Animas, Percha, Tierra Blanca, and Jaralosa. The first five are tributary to Elephant Butte Reservoir and the next four are tributary above the dam of Caballo Reservoir now under construction. A channel is being built to divert the flow of the Percha to this reservoir.

Climatological and Related Data

Table 9 gives the altitudes of the valley areas of the Upper Rio Grande Basin.

Temperatures

The mean annual and July and January temperatures and the periods between killing frosts, or the growing seasons, are given in table 10 for representative locations in the three major valley areas of the upper basin. These are taken from the Climatological Summaries to 1930 of the United States Weather Bureau.

TABLE 9.—*Altitudes of valley areas in the Upper Rio Grande Basin*

Area or location	Altitudes
San Luis section—valley floor	From 8,000 to 7,440
Del Norte	7,880
Monte Vista	7,665
Alamosa	7,550
"Sump" in closed basin	7,525
Rio Grande at valley outlet	7,440
Middle section—valley floor	From 5,600 to 4,450
Espanola Valley	5,590
Santo Domingo Valley	5,300
Albuquerque Valley	5,100
Albuquerque	5,000
Belen Valley	4,900
Socorro Valley	4,750
San Marcial	4,450
Elephant Butte-Fort Quitman section	From 4,250 to 3,400
Palomas Valley	4,200
Rincon Valley	4,150
Mesilla Valley	4,000
Las Cruces	3,896
El Paso Valley	3,600
El Paso	3,710
Fort Quitman	3,400

TABLE 10.—*Mean annual, July, and January temperatures and length of growing season in the Upper Rio Grande Basin*

Station	Temperatures in degrees Fahrenheit									Average length of growing season, number of days from last killing frost in spring to first killing frost in fall
	Annual			July			January			
	Average			Average			Average			
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	Maximum	Minimum	Mean	
San Luis section:										
Del Norte	57.7	26.9	42.3	76.4	46.9	61.6	36.6	5.6	21.1	121
Garnett	59.2	23.0	41.1	80.3	44.7	62.5	35.3	−1.1	17.1	97
Manassa	58.3	[illegible]	41.7	73.9	46.7	62.5	[illegible]	[illegible]	[illegible]	79
Middle section:										
Bernalillo	[illegible]	39.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34.3	......
Albuquerque	69.2	41.9	55.6	89.7	62.6	76.2	47.2	22.2	35.0	196
Socorro	74.1	40.7	57.4	92.5	61.8	77.2	52.8	22.6	37.7	195
San Marcial	75.2	41.3	58.2	93.9	62.4	78.2	53.9	22.5	38.2	200
Elephant Butte-Fort Quitman section:										
Elephant Butte	73.8	45.3	59.6	91.6	65.8	78.7	54.3	26.9	40.6	221
Agricultural College	76.2	44.0	60.1	93.4	65.1	79.2	58.1	25.8	42.0	201
El Paso	76.1	50.6	63.6	92.8	69.3	81.6	57.6	32.3	44.9	241
Clint	78.0	42.1	60.1	94.4	61.8	78.1	59.0	22.5	40.7	201
Fort Hancock	80.7	38.4	60.2	98.8	61.3	81.2	60.1	19.1	39.7	......

Precipitation

The longest record of precipitation in the Upper Rio Grande Basin is for Santa Fe. It begins with 1850 and is continuous to date. Other stations with notably long records of complete years are San Marcial, 80 years; New Mexico State Agricultural College, 79 years; El Paso, 68 years; Albuquerque, 66 years; and Elephant Butte, 52 years. In the Middle Valley drainage there are six stations with records of between 40 and 50 years. The longest record in San Luis Valley is that of 46 years for Garnett, a few miles northwest of Alamosa.

Plate 2 gives a list of the precipitation stations in or near the Upper Rio Grande Basin. It also shows in each case the station elevation, its county and State, and the number and period of years of the record as published by the Weather Bureau. The stations are grouped to the three major areas—San Luis, Middle, and Elephant Butte-Fort Quitman sections—and are numbered consecutively from north to south. The locations of these stations are shown on plate 3, "Distribution of precipitation in the Upper Rio Grande Basin," on which is given also the list of stations and numbered designations as indicated at each dot representing a station.

The records of annual precipitation for all stations listed are given in table 117 in Appendix A for all complete years from the initiation of the record to 1935, inclusive. Given also, for each station is the mean annual precipitation for the period of record. The length of the records is so variable that the means for the periods of record do not furnish an appropriate basis for comparison. For the latter the precipitation should be referred to the same period of years for all stations. Based on actual records this would necessitate selection of a period of less than 10 years, since the record for many stations is no longer than that. Obviously this would be undesirable, however, as no account would be taken of the several long-time records to derive means for a much longer and more representative period. The expedient adopted under these circumstances was to select, for the comparison, the 46-year period 1890–1935, inclusive, and in the case of stations having shorter records to estimate the mean by comparison with the precipitation at those nearest stations for which there is an actual record for the 46 years. It is recognized that, due to the marked irregularity in the distribution of precipitation throughout the basin, the figures thus derived are subject to some error. It is believed, however, that they furnish a much better and more truly representative basis for showing the amount and distribution of precipitation than the means based upon the period of record only.

The period 1890–1935 corresponds to that for which estimates of run-off are derived as considered elsewhere in this section of the report. Although precipitation records do not, in general, furnish the appropriate basis for estimates of run-off in the Upper Rio Grande Basin that they do in some other western basins, it is of value to have the precipitation data for a period corresponding to that for which run-off estimates are derived, if only to indicate the general relation which exists.

The estimated 46-year precipitation means are given in table 117, Appendix A, and are indicated at the station locations on plate 3. With these data as a basis, isohyetals or lines of equal precipitation were drawn to differentiate and indicate the variation in mean annual precipitation over the various basin areas. On this map each shade of color bounded by the isohyetals represents an area having mean annual precipitation within the limits indicated in the legend.

It will be noted that there is a range in mean annual precipitation from less than 7 inches to as much as 40 inches. The higher figures are for the high mountain areas of the Sangre de Cristo and the San Juan ranges in Colorado and northern New Mexico, and the lowest for the central areas of the main valleys. The aridity of the latter, as shown by the mean annual precipitation of from 7 to 10 inches only, well explains the requirement for irrigation in the San Luis, Middle, and Elephant Butte-Fort Quitman sections.

To indicate the monthly distribution of precipitation, figure 4 gives the average monthly precipitation in inches and in percent of the annual for three stations—Garnett, Albuquerque, and El Paso—as representative of the main valley areas, and for Cumbres, as representative of the high mountain areas. It will be noted that in the valley areas the months of greatest precipitation are July, August, and September, and that those months account for about half of the annual precipitation. On the other hand, in the high mountain areas, the greatest precipitation, mostly in the form of snow and the chief source of run-off, occurs in December, January, February, and March, and also represents roughly half of the annual precipitation.

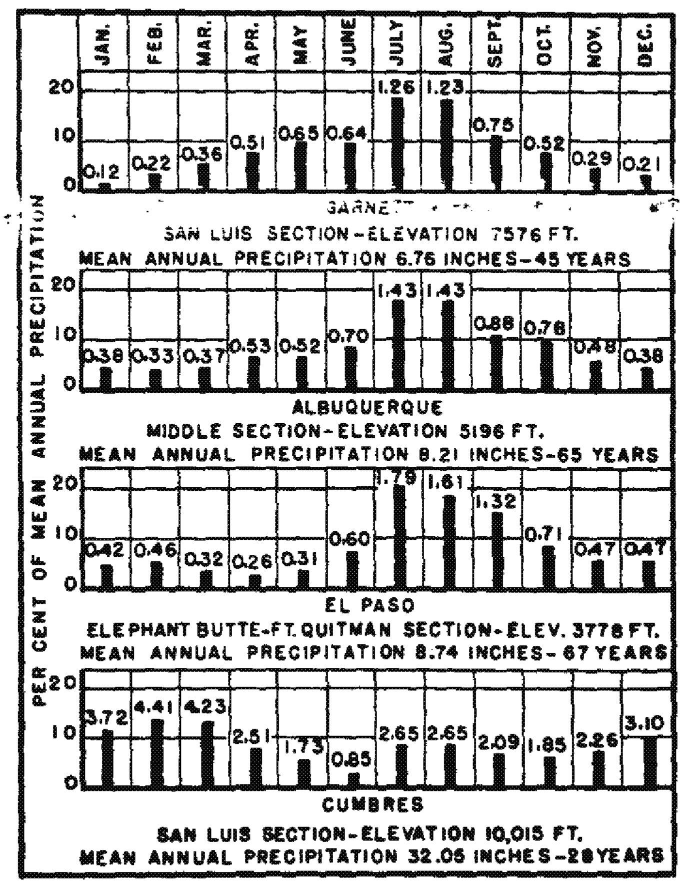

FIGURE 4.—Monthly distribution of precipitation in the Upper Rio Grande Basin. (Figures at top of bars represent average precipitation in inches for period of record.)

Continuation -Table 57- Rio Grande Joint Investigation -Feb. 1938-

Year	Water Districts								Total
	20	21	22	24	25	26	27	35	
1935	389,709	45,810	107,833	30,614	27,372	66,960	8,403	22,323	699,024
1936	390,127	46,256	113,510	33,139	26,540	25,477	5,530	22,435	663,014 443,724
1937	381,856	52,610	94,752	36,269	[illegible]	25,477	5,588	22,892	646,082
1938	377,273	54,954	104,062	35,724	59,920	41,323	3,102	26,035	702,392
1939	373,684	45,519	100,549	36,932	81,700	42,448	5,997	28,503	715,332
1940	368,328	42,053	99,899	19,750	55,429	45,483	5,236	28,092	664,267
1941	382,087	45,178	102,482	37,276	65,542	46,561	7,172	31,358	717,656
1942	372,818	43,633	105,431	24,478	88,152	47,798	19,944	31,742	733,996
1943	354,073	46,229	100,653	36,903	144,541	47,211	11,[illegible]	28,083	769,680
1944	362,393	47,413	97,850	38,598	118,448	47,543	13,889	23,491	749,625
1945	356,167	47,382	99,700	36,569	120,941	48,298	14,177	23,517	746,751
1946	338,701	41,647	98,350	25,755	121,551	48,587	10,459	13,381	698,431
1947	343,609	55,717	102,032	35,589	123,729	49,893	9,136	22,584	742,289
1948	359,288	53,177	100,440	37,696	122,265	46,418	10,434	27,323	757,041
1949	380,035	59,494	100,915	36,813	123,502	48,483	11,540	28,940	789,722
1950	352,945	49,366	97,312	22,173	10,322	21,228	2,492	14,554	570,392
1951	205,119	35,297	73,350	14,976	8,872	4,792	1,079	15,743	359,228
1952	358,527	52,078	109,979	28,749	17,460	17,379	5,330	25,836	615,338
1953	351,835	43,962	98,031	21,433	21,721	18,136	5,605	20,718	581,441
1954	260,482	26,462	80,423	19,970	7,381	6,110	1,395	19,263	421,406

CO - 002977

TX_MSJ_000057

CO - 002978

TX_MSJ_000058

There are very few stations such as Cumbres to give precipitation data for the high mountain areas. But, as shown later, by far the major portion of the Rio Grande flow is derived from the precipitation of these areas. For this reason little opportunity is afforded in the Upper Rio Grande Basin to establish a relationship between precipitation and run-off which can be considered dependable in the estimate of run-off. Most of the precipitation stations are located in the lower areas and although this precipitation is productive of run-off, the derivation of any direct and dependable relation thereto is largely obscured by the irregularities characteristic of the precipitation on the lower areas.

Snow Surveys

Snow surveys for the purpose of forecasting seasonal run-off were initiated in the Upper Rio Grande Basin in 1936. They constitute cooperative projects of Federal and State agencies under the direction of the Bureau of Agricultural Engineering, Department of Agriculture. Of a number of "snow courses" established in the mountains of Colorado in 1935, three are in the upper Rio Grande drainage and were surveyed initially in the spring of 1936. Additional courses in the higher mountains of New Mexico were established in the fall of 1936 and were to be surveyed in 1937. Table 11 lists the snow courses now established in the Rio Grande Basin and their location is indicated on plate 3.

Evaporation

Records of evaporation in the Upper Rio Grande Basin are meager. The longest is that for the station at Elephant Butte Dam, which begins in May 1916 and is continuous to date. This gives the evaporation from free water surface in a class A Weather Bureau evaporation pan. Other stations for which evaporation pan records are available are indicated in table 12. Of these eight stations, only four are maintained at present. The monthly records of evaporation at the stations listed in table 12 are given in tables 118 to 125, inclusive, in Appendix A.

Data on evaporation from water surfaces and soils and on plant transpiration are indispensable to a

TABLE 11.—*Snow courses in the Upper Rio Grande Basin in Colorado and New Mexico*

[Surveyed through Federal and State cooperation under the Bureau of Agricultural Engineering, U. S. Department of Agriculture]

No.	Course	Elevation	County	State	National Forest	Local drainage
1	Upper Rio Grande	9,350	Hinsdale	Colorado	Rio Grande	Rio Grande.
2	La Veta Pass [1]	9,300	do	do	San Isabel	Cuchara Creek.
3	Wolf Creek	10,000	Mineral	do	Rio Grande	South Fork Rio Grande.
4	Silver Lake	9,600	Conejos	do	do	Alamosa Creek.
5	River Springs	9,340	do	do	do	Conejos River.
6	Cumbres Pass	10,000	do	do	do	Cumbres Creek.
7	Red River	9,500	Taos	New Mexico	Carson	Rio Colorado (Red River).
8	Rio Nutrias	7,900	Rio Arriba	do	do	Nutrias Creek.
9	Canjilon	9,500	do	do	do	Canjilon Creek.
10	Taos Canyon	[illegible],000	Taos	do	do	Rio Taos.
11	[illegible]man Hill	[illegible]	do	do	do	Embudo Creek.
12	[illegible] Ranch	[illegible]	Sandoval	do	Santa Fe	Jemez Creek.
13	Aspen Grove	9,100	Santa Fe	do	do	Pojoaque Creek.

[1] Not in Rio Grande drainage but close to the Divide.

TABLE 12.—*Evaporation stations in the Upper Rio Grande Basin*

Station	Location	Altitude	Type of pan	Period of record	Remarks
Wagon Wheel Gap, stations A-1 and A-2.	Near Wagon Wheel Gap dam site on the upper Rio Grande, above San Luis Valley, Colo.	9,600	Weather Bureau class A	August 1919 to October 1924	Maintained in connection with the Wagon Wheel Gap Experiment Station of the U. S. Forest Service. A-1, northern exposure; A-2, southern exposure.
Garnett	18 miles northwest of Alamosa, in San Luis Valley, Colo.	7,576	do	June 1927 to October 1928, April 1930 to November 1931.	Maintained by the Colorado State engineer in connection with the Garnett Evapo-Transpiration Experiment Station.
Near Therma	On west shore of Eagle's Nest Reservoir in Taos County, N. Mex.	8,219	do	February 1930 to December 1932, April 1934 to December 1936.	New Mexico State engineer records; U. S. Weather Bureau records.
Santa Fe	At Santa Fe, N. Mex	7,013	do	May 1913 to November 1914, January 1917 to October 1933.	Do.
Los Griegos	5 miles northwest of Albuquerque, N. Mex.	4,980	do	September 1926 to December 1928, January 1930 to March 1932.	Previous to December 1928 maintained in connection with evapo-transpiration experiment station of Middle Rio Grande Conservancy District; subsequently maintained by New Mexico State engineer.
Elephant Butte Dam	At Elephant Butte Dam, N. Mex.	4,265	do	May 1906 to December 1936	Maintained by U. S. Bureau of Reclamation; reported by U. S. Weather Bureau.
Jornada	18 miles northeast of Las Cruces, N. Mex.	4,150	Floating, 36 inches square, 18 inches deep.	June 1929 to June 1932, January 1935 to December 1936.	Maintained in connection with Jornada experimental range of the U. S. Forest Service.
Agricultural College	At New Mexico College of Agriculture and Mechanic Arts, near Las Cruces.	3,863	Weather Bureau, class A	September 1918 to December 1936.	U. S. Weather Bureau records.

comprehensive determination of the consumptive use of water. The Garnett Experiment Station in San Luis Valley and the Los Griegos Experiment Station near Albuquerque were established and maintained respectively by the Colorado State Engineer and the Middle Rio Grande Conservancy District in cooperation with the Bureau of Reclamation, to determine evaporation not only from free water surfaces but also from soils with varying depths to ground water, as well as the evapo-transpiration losses by native vegetation. The data of these experiments are reviewed and taken into consideration in the determinations presented in part III of this report. To obtain additional data of this character to cover the widely varying conditions from the northern to the southern limits of the upper basin, the Bureau of Agricultural Engineering established and maintained in 1936, as a part of the Rio Grande joint investigation, a number of evaporation and evapo-transpiration stations. They included the Parma, Wright, San Luis Lakes, East Henry, Asay, and West stations in the San Luis section; the El Vado Dam, Simms' Ranch, Isleta, and Socorro stations in the Middle section; and the State College and Mesilla Dam stations in the Elephant Butte-Fort Quitman section. These stations are described and the data obtained at them are presented fully in part III.

The evaporation pan data of tables 118 to 125, Appendix A, together with the data of the 1936 stations, have been used in this report to determine mean monthly rates of evaporation applicable to reservoir and lake surfaces in various parts of the upper basin. Description of the derivation and application of these means will be found in the subsequent analyses for various reservoirs. Mean annual rates for evaporation from a lake surface as derived by comparison of all available records and using a coefficient of 0.69 for reduction of class A pan evaporation to lake surface,

TABLE 13.—*Mean annual evaporation in the Upper Rio Grande Basin*

[Estimated lake surface evaporation at 6 stations]

Station	Mean annual evaporation in feet	Altitude in feet	Mean annual temperature in degrees Fahrenheit [1]	Mean annual precipitation in feet
Wagon Wheel Gap, Colo.	1.9	9,600	35	[2] 1.3
Garnett, San Luis Valley, Colo.	[3] 3.4	7,580	41	0.6
Santa Fe, New Mex.	3.7	7,010	50	1.2
Los Griegos (Albuquerque), N. Mex.	[4] 4.5	4,980	[5] 55	[5] 0.7
Elephant Butte Dam, N. Mex.	[6] 6.0	4,260	61	0.8
Agricultural College, near Las Cruces, N. Mex.	5.2	3,860	60	0.7

[1] From 1935 reports of U. S. Weather Bureau.
[2] Estimated 46-year mean.
[3] Estimate based on mean of available record June to October 1927 to 1931, considered as 60 percent of annual evaporation.
[4] Evaporation station about 4 miles north of Albuquerque.
[5] For Weather Bureau station at Albuquerque.
[6] Refer to table 25 for derivation.

Based on application of coefficient of 0.69 to Weather Bureau class A pan evaporation to derive lake surface evaporation.

are given in table 13 for six stations. For comparative purposes, this gives also the corresponding data on altitudes and annual means of temperature and precipitation at these stations.

Run-Off

Knowledge of the run-off in the Upper Rio Grande Basin is gained from stream-flow measurements. Due probably to the controversies over Rio Grande waters that began as early as the 1890's, stream-flow measurements at key stations on Rio Grande were begun by the Geological Survey at an early date—a fortunate circumstance for present water-supply studies. The station near Del Norte, where Rio Grande enters San Luis Valley, was established in July 1889. That near Lobatos, Colo., which records the Rio Grande flow below the San Luis Valley and near the Colorado-New Mexico State line, was established in June 1899. The station at Embudo, N. Mex., at the head of Espanola Valley, was established in January 1889 and is the oldest station in the basin. The station at Otowi Bridge, formerly referred to as "near Buckman", located at the head of White Rock Canyon and below the confluence of the Rio Chama, was established in February 1895. Measurements at San Marcial, at the lower end of the Middle Valley and upper end of the present Elephant Butte Reservoir, began in January 1895, and the record at El Paso dates back to May 1889. The longest record for any tributary stream is that for the Conejos River near Mogote in Colorado. It begins with May 1903.

The records for these stations are not continuous from the initial date, but the gaps do not seriously impair the utility of the record. The greatest lapse occurred in the Embudo record, a period of 8½ years from 1904 to 1912. The Otowi Bridge and El Paso records have maximum gaps of 3½ years each, Del Norte of 1½ years, and the other stations of a few months only. In general, stations for the measurement of tributary stream flow were established at later dates than those for the main river stations mentioned.

The measurements of stream flow in the Upper Rio Grande Basin have been carried on variously by the Geological Survey, the State Engineering Departments of Colorado and New Mexico, the Bureau of Reclamation, the International Boundary Commission, and other public and private agencies. At present the maintenance of all stations in the upper basin is under the Geological Survey in cooperation with Colorado and New Mexico, with the exception of the Rio Grande stations at San Marcial, El Paso, Tornillo, and Fort Quitman, which are maintained by the International Boundary Commission, and other river stations at Elephant Butte and within the Rio Grande Project, which are maintained by the Bureau of Reclamation.

STREAM MEASUREMENTS IN THE UPPER RIO GRANDE BASIN

No.	Stream	Gaging Stations	Drain. Area Sq. Mi.	Source of Record	No. of Yrs.
	SAN LUIS SECTION				
1	Rio Grande	At Thirty Mile Bridge	160	U-C	20
2	Do	At Wason	780	U-C	30
3	Do	Near Del Norte	1320	U-C	49
4	Do	Near Monte Vista	1660	U-C	11
5	Do	At Alamosa	* 1712	U-C	30
6	Do	Above Mouth Trinchera Cr.		C	1
7	Do	Near Lobatos	* 4800	U-C	38
8	Clear Creek	Below Continental Res.	42	U-C	6
9	Do	Near Creede	161	U-C	6
10	Goose Creek	Near Wagon Wheel Gap	40	U-C	2
11	South Fork Rio Grande	At South Fork	216	U-C	19
12	Pinos Creek	Near Del Norte	52	U-C	7
13	San Francisco Creek	Do	43	C	1
14	Rock Creek	Near Monte Vista	38	U-C	8
15	Do	Near Alamosa		C	1
16	Alamosa Creek	At Jasper	64	U-C	3
17	Do	Near Monte Vista	21	C	1
18	Do	Above Terrace Reservoir	102	U-C	13
19	Do	Below Do	120	U-C	20
20	Do	Near Capulin	128	C	1
21	La Jara Creek	Do	75	U-C	18
22	Do	Below Capulin Canal, nr. Capulin		C	1
23	Do	Near Mouth		C	6
24	Trinchera Creek	Above Turner's Ranch	46	U-C	14
25	Do	Above Mountain Home Res.	61	U-C	16
26	Do	Below Smith Reservoir	300	U-C	6
27	Do	At Mouth near La Sauses		C	1
28	Sangre de Cristo Creek	Near Fort Garland	176	U-C	18
29	Do	Above South Res. near Blanca	221	U-C	8
30	Ute Creek	At Upper Sta. near Ft. Garland	33	C	9
31	Do	Near Fort Garland	32	U-C	18
32	Conejos River	Near Mogote	282	U-C	33
33	Do	Near La Sauses	887	U-C	19
34	San Antonio River	At Ortiz	110	U-C	18
35	Do	At Mouth near Manassa	340	U-C	14
36	Los Pinos River	Near Ortiz	167	U-C	16
37	Culebra Creek	Near Chama, Colorado	70	C	3
38	Do	At San Luis	220	U-C	21
39	Do	At Mouth near San Acacio		C	1
	CLOSED BASIN				
40	San Luis Creek	At Villa Grove		U-C	0
41	Do	Near Villa Grove	286	C	6
42	Do	Do		U-C	6
43	Kerber Creek	Do		U-C	1
44	Do	Do	39	C	6
45	Saguache Creek	Near Saguache	600	U-C	25
46	North Crestone Creek	Near Crestone		U-C	3
47	South Crestone Creek	Do		U-C	3
48	Willow Creek	Do		U-C	3
49	Spanish Creek	Do		U-C	3
50	Carnero Creek	Near La Garita	117	U-C	10
51	La Garita Creek	Do	61	U-C	10
52	Cottonwood Creek	Near Crestone		U-C	2
53	Deadman Creek	Do		U-C	2
54	Sand Creek	Do		C	1
	MIDDLE SECTION				
55	Rio Grande	Below Taos Junction Bridge	* 6950	U-N	12
56	Do	At Embudo	* 7387	U-N	37
57	Do	At Otowi Bridge	* 11303	U-N	30
58	Do	At Cochiti	* 11961	U-N	19
59	Do	At San Felipe	* 13036	U-N	11
60	Do	At Isleta	* 18002	N	1
61	Do	Near Bernardo Bridge		N	1
62	Do	At San Acacia	* 23187	N	1
63	Do	At San Marcial	* 24175	U-N	43
64	Costilla River	At Costilla Reservoir		RECL.	7
65	Do	Near Costilla	228	RECL.-C	8
66	Do	At Meyer's Upper Bridge	230	[illegible]	3
67	Do	Near Mouth	307	N	6
68	Rio Colorado	Near Questa	112	U-N	23
69	Do	Below Questa	167	U-N	17
70	Rio Hondo	Near Valdez		N	2
71	Do	At Valdez	38	U-N	19
72	Do	At Arroyo Hondo	71	U-N	22
73	Rio Pueblo de Taos	Near Taos	67	U-N	5
74	Do	At Taos		N	1
75	Rio Taos	At Los Cordovas	390	U-N	27
76	N.Ch. Rio Pueblo de Taos	At Taos		N	1
77	Rio Lucero	Near Arroyo Seco	17	U-N	8
78	Do	Do Do Do Below Diversion		N	2
79	Rio Fernando de Taos	Near Taos	66	U-N	15
80	Rio Ranchos de Taos	Near Ranchos of Taos	105	N	7
81	Pueblo Creek	Near Penasco		N	1
82	[illegible] Creek	At [illegible]	[illegible]	[illegible]	[illegible]
83	Rio Chama	At Chama	[illegible]	[illegible]	[illegible]
84	Do	At Park View	396	U-N	15
85	Do	Bl. Tierra Amarilla Crk at El [illegible]	372	U-N	6
86	Do	Near Tierra Amarilla		N	1
87	Do	Near Chamita	3202	U-N	24
88	Brazos River	Near Brazos		N	3
89	Do	At Brazos		U-N	1
90	Willow Creek	Near Park View		N	1
91	Rio Canjilon	Near Canjilon	16	N	1
92	El Rito Creek	Near El Rito	52	N	6
93	Rio Ojo Caliente	At La Madera	344	N	6
94	Rio Vallecitos	At Vallecitos	116	U-N	4
95	Santa Clara Creek	Near Santa Clara		N	1
96	Rio Santa Cruz	At Cundiyo	86	U-N	7
97	Nambe Creek	Near Nambe	37	N	4
98	Do	At Pojoaque		N	1
99	Rio Tesuque	Above Diversions nr. Santa Fe		N	1
100	Do	At Tesuque Bridge Do Do Do		N	1
101	Rito Tesuque	Near Santa Fe		N	1
102	Santa Fe Creek	[illegible] nr. Santa Fe	11	U-N	6
103	Do	Near Santa Fe	22	U-N	24
104	Do	At Santa Fe	40	U-N	4
105	Arroyo Hondo	Near Santa Fe	14	U-N	10
106	Jemez Creek	Near Jemez		N	1
107	Do	Near San Ysidro	854	N	8
108	Do	Near Bernalillo		N	1
109	Rio Puerco	At Rio Puerco	4755	U-N	17
110	La Jara Creek	Near La Jara		N	2
111	Bluewater Creek	Near Bluewater	225	U-N	24
112	Do	At Grants		U-N	13
113	San Jose River	Near Grants		N	1
114	Do	Near San Fidel		N	1
115	Do	Near Casa Blanca		N	1
116	Do	Near [illegible]	2765	U-N	6
	ELEPHANT BUTTE-FORT QUITMAN SECTION				
117	Rio Grande	Below Elephant Butte Dam	* 25923	R-U	22
118	Do	Above Percha Dam	* 27218	U-N	16
119	Do	Above Leasburg Dam	* [illegible]	R-N	12
120	Do	At El Paso	* 30413	U-I	44
121	Do	At Tornillo Bridge		U-I	12
122	Do	Near Fort Hancock		I	4
123	Do	At Fort Quitman	* 31964	U-I	13
124	Alamosa River	Near Monticello	390	U-N	7
125	Las Palomas River	Near Las Palomas	185	N	1
	*** **STREAM MEASUREMENTS IN THE SAN JUAN BASIN**				
126	San Juan River	Near Pagosa Springs		C	2
127	Do	At Pagosa Springs	287	C	6
128	West Fork San Juan River	Near Pagosa Springs		C	2
129	Rio Blanco	Do		C	6
130	Rito Blanco	Do		C	2
131	Navajo River	Near Chromo		C	2
132	Do	At Edith	160	U-C-N	17
133	Little Navajo River	At Chromo		C	2
134	Animas River	At Howardsville	56	C	2
135	Cement Creek	Near Silverton	20	C	6
136	Mineral Do	Do	40	C	2

* Exclusive of closed basin area, Colorado.

** Abbreviations: [illegible]

*** Stations maintained to furnish data for investigation of transmountain diversion of San Juan Basin waters to Rio Grande basin.

PLATE 4

Plate 4 lists the upper basin gaging stations for which records are available, indicates the source or agency which has published the records, gives the drainage areas in square miles above the stations, and shows the period for which the records are available. The stations are grouped to the drainages of the three principal areas, San Luis, Middle, and Elephant Butte-Fort Quitman sections. In each section the main river stations are given first, followed by the tributary stations. The stations are numbered consecutively as listed and these numbers are shown for identification on plate 1. At the end of the list of plate 4, a small group of stations in the San Juan River Basin is tabulated. These are stations established and maintained by the Geological Survey in cooperation with Colorado and New Mexico as a part of the Rio Grande joint investigation to furnish run-off data needed in connection with the investigation of projects for the diversion of San Juan Basin waters to the Rio Grande Basin.

The monthly run-off in acre-feet, for the period of record to January 1936, for the stations listed on plate 4 is given in the tables of Appendix A. The sources of the data are indicated in the footnotes for each table. As the daily discharge records for 1936 will appear in the Water Supply Papers of the Geological Survey, no separate publication is made for the present report.

Run-Off at Key Stations, 1890–1935

As previously indicated, there are several stations with long-time records which are key stations with respect to a study of the water supply in the Upper Rio Grande Basin. These are the main-river stations which record the inflow to and outflow from the San Luis, Middle, and Elephant Butte-Fort Quitman sections and those near the sites of major reservoir developments, present and proposed. Since the record for the Del Norte station goes back to 1889 and the records for the other principal stations nearly or quite as far back, it was considered feasible and highly desirable to extend the records and fill in all missing periods with estimates obtained by proper methods in order to derive for key stations a complete monthly record for the 46-year period, 1890–1935. This was done, and the recorded flows plus the estimates to complete the 46-year period are given in tables included in Appendix A, for the following stations: Rio Grande at Wason, Del Norte, Alamosa, Lobatos, Embudo, Otowi Bridge, San Marcial, and El Paso; Conejos River near Mogote; and Rio Chama above El Vado Reservoir. The Rio Grande station at Wason is within the Wagon Wheel Gap Reservoir site. The estimates to extend the records or to fill in missing periods were based on curves of monthly run-off relations to other stations or on mean monthly distribution relations and are explained in detail in the footnotes for each table.

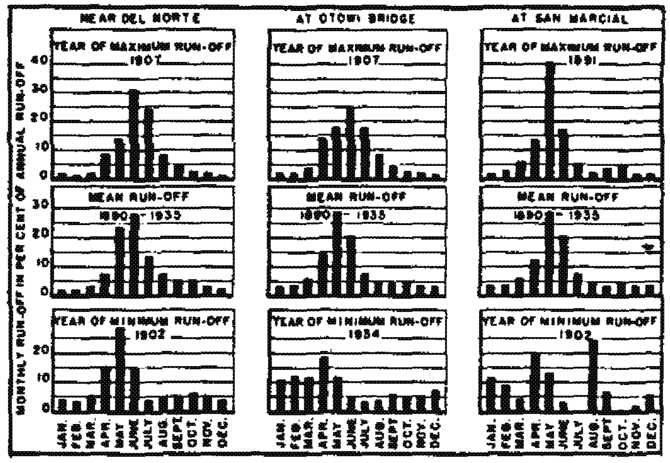

FIGURE 5.—Characteristics of run-off at Rio Grande gaging stations.

The tables for these key stations show the mean annual and mean monthly run-off for the 46-year period 1890–1935, the monthly mean in percent of the mean annual, and the annual run-off in percent of the mean annual. Except for Del Norte, the Rio Grande stations do not wholly represent direct mountain run-off, but record the flow which has passed or is returned from upper irrigated areas plus intermediate tributary inflow. Tables 14 and 15 summarize the characteristic data for Del Norte, Lobatos, Embudo, Otowi Bridge, and San Marcial, selected as representative stations to show the main river run-off over a 46-year period. Figure 5 gives the characteristics of run-off for a maximum, mean, and minimum year for Del Norte, Otowi Bridge, and San Marcial stations, as representative of the run-off at the head, respectively, of the main irrigated areas of the San Luis, Middle, and Elephant Butte-Fort Quitman sections.

TABLE 14.—*Variation in annual run-off at Rio Grande gaging stations, 1890–1935*

Gaging station	Mean annual run-off in acre-feet	Maximum annual run-off in 46-year period			Minimum annual run-off in 46-year period			Flow factor in percent [1]
		In acre-feet	In percent of mean annual run-off	Year	In acre-feet	In percent of mean annual run-off	Year	
Near Del Norte	707,100	1,164,400	165	1907	249,300	35	1902	61
Near Lobatos	550,200	1,436,500	261	1907	[2] 98,700	18	1902	38
At Embudo	860,100	1,977,000	230	1907	260,400	30	1934	43
At Otowi Bridge	1,353,000	2,752,000	203	1907	380,400	28	1934	49
At San Marcial	1,127,700	2,488,000	221	1891	200,600	18	1902	45

[1] Ratio of mean to maximum annual run-off.
[2] 98,800 in 1904.

Total Water Production from Run-off, 1890–1935

To arrive at a comprehensive and adequate knowledge of the available water supply in the Upper Rio Grande Basin it was considered desirable to prepare estimates,

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TABLE 15.—*Average monthly distribution of annual run-off at Rio Grande gaging stations, 1890–1935*

Month	Gaging stations									
	Near Del Norte		Near Lobatos		At Embudo		At Otowi Bridge		At San Marcial	
	Mean run-off—									
	In acre-feet	In percent of annual	In acre-feet	In percent of annual	In acre-feet	In percent of annual	In acre-feet	In percent of annual	In acre-feet	In percent of annual
January	13,500	1.91	17,900	3.25	30,600	3.56	37,900	2.80	37,900	3.36
February	12,200	1.73	18,500	3.36	31,000	3.60	41,000	3.03	41,600	3.69
March	19,500	2.76	31,400	5.70	48,300	5.62	77,000	5.69	63,400	5.62
April	52,400	7.41	48,600	8.83	82,000	9.53	185,800	13.73	138,500	12.28
May	163,200	23.08	128,900	23.43	200,100	23.27	379,300	28.03	318,200	28.22
June	197,500	27.93	146,000	26.54	205,700	23.92	275,100	20.33	230,800	20.47
July	92,300	13.05	47,400	8.62	72,800	8.46	94,700	7.00	81,700	7.24
August	51,900	7.34	19,900	3.62	39,200	4.56	60,400	4.47	48,900	4.34
September	34,300	4.85	20,300	3.69	36,000	4.19	51,400	3.80	41,200	3.65
October	36,200	5.12	28,600	5.20	46,900	5.45	62,900	4.65	52,700	4.67
November	19,600	2.77	22,400	4.07	35,300	4.10	46,700	3.45	34,400	3.05
December	14,500	2.05	20,300	3.69	32,200	3.74	40,800	3.02	38,400	3.41
Total	707,100	100.00	550,200	100.00	860,100	100.00	1,353,000	100.00	1,127,700	100.00

based on all available stream-flow records, of the total water production from run-off for the principal basin drainages. These estimates were made to cover the 46-year period, 1890–1935. The results are summarized in table 16, which indicates that slightly more than 99 percent of the mean annual water production of the upper basin, totaling 3,064,000 acre-feet, originates in Colorado and New Mexico, and that the production of these two States is very nearly equally divided, Colorado producing 51 percent and New Mexico 48 percent of the basin total. The extensive compilations and detail used in the derivation of the water-production estimates for each unit and section of the basin, from which the summary of table 16 is derived, are presented in Appendix B.

TABLE 16.—*Water production from run-off in the Upper Rio Grande Basin*

[Estimated mean annual natural run-off, 1890–1935]

BY SECTIONS

Basin unit	Drainage area in square miles		Mean annual run-off	
	Contributing	Total	In acre-feet	In percent of basin total
San Luis section:				
Southwest area	2,392	....	1,258,600	41.08
Southeast area	566	....	120,400	3.93
Closed basin	1,140	....	187,700	6.12
Total	4,098	[1] 7,890	1,566,700	51.13
Middle section:				
Northern unit	4,641	....	947,600	30.93
Southern unit	8,072	....	385,000	12.56
Total	12,713	19,226	1,332,600	43.49
Elephant Butte-Fort Quitman section:				
San Marcial-Elephant Butte unit	1,747	....	53,000	1.73
Elephant Butte-Leasburg unit	2,163	....	58,500	1.91
Leasburg-El Paso unit	1,327	....	30,800	1.01
El Paso-Fort Quitman unit	1,631	....	22,500	0.73
Total	6,868	6,868	164,800	5.38
Total of sections	....	[1] 33,984	3,064,100	100.00

BY STATES

Colorado	....	[1] 7,890	1,566,700	51.13
New Mexico	....	24,463	1,474,900	48.13
Texas	....	797	11,000	0.36
Chihuahua, Mexico	....	834	11,600	0.38
Total of States	....	[1] 33,984	3,064,100	100.00

[1] Includes closed basin, 2,940 square miles in San Luis Valley, Colo., not tributary.

Rio Grande Run-off Corrected for Present Development

As previously explained, the run-off of Rio Grande near Lobatos represents the residual flow below the San Luis Valley irrigation development. The run-off at Embudo and Otowi Bridge represents this same residual flow plus or minus intermediate tributary inflow or losses, respectively. The run-off at San Marcial represents the residual flow below the Middle Valley irrigation development. In estimates of the water supply for given future conditions it becomes important to determine what the flow, 1890 to 1935, would have been at these gaging stations under present conditions of irrigation development. Put in another way, this means a determination of what the consumption of inflow was in the San Luis and Middle Valleys in this period.

Correction for San Luis Valley development.—While irrigation in San Luis Valley was firmly and widely established prior to 1890, a study of the available data on irrigated acreages indicates a general trend in the direction of expansion until within the past 10 years. The temporary Rio Grande Compact which became effective in 1929 restricts increased use of Rio Grande water in Colorado to an amount offset by drainage return to the river. Accurate annual figures on the total acreage irrigated in San Luis Valley are not available. However, as set forth in table 58 in the section of this report on irrigation development, surveys of the irrigated acreage made by engineers representing the State engineers of Colorado and New Mexico indicated a total for the valley of 494,200 acres in 1926, 507,471 acres in 1927, 534,806 acres in 1932, and what would have been close to 500,000 acres in 1934 but for the reduction due to water shortage. This suggests that the area irrigated during the period 1927–35 remained substantially constant except for variations due to the availability of water. It is considered, therefore, that this period may be taken as representative of present irrigation development and of the use of water in San Luis Valley, and that use in the past may be referred to use in this period to derive corrections to past stream flow for present conditions.

Since, as previously observed, the run-off to the southeast area of San Luis Valley is practically all consumed in irrigation and does not reach the river, the difference between the total inflow to the southwest area and the flow of Rio Grande near Lobatos may be taken to represent the total consumption of southwest area inflow which includes that of Rio Grande near Del Norte. Although this difference does not represent the total depletion of water in San Luis Valley, it does represent a very substantial part of it and, with respect to corrections to the Lobatos flow for past use, may be taken as a complete index of the use factors governing the river flow at that station. In any one year the water consumption and hence the outflow at Lobatos is influenced to a substantial degree by the extent of available inflow. It was necessary, therefore, to establish the present consumption, or that in the period 1927–35, as related to the inflow. This was done for each month of the year by plotting

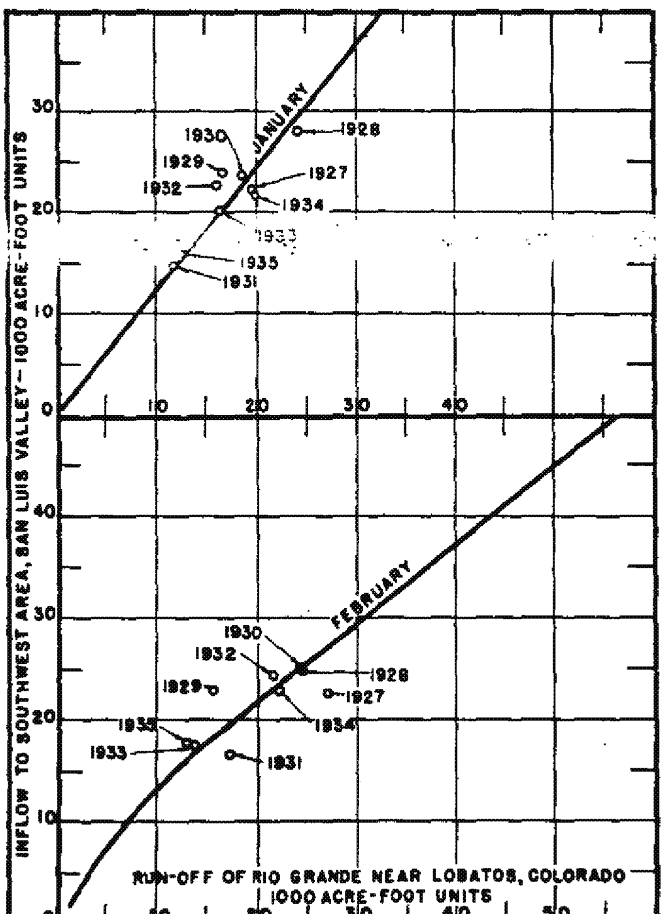

FIGURE 6.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months January and February 1927 to 1935.

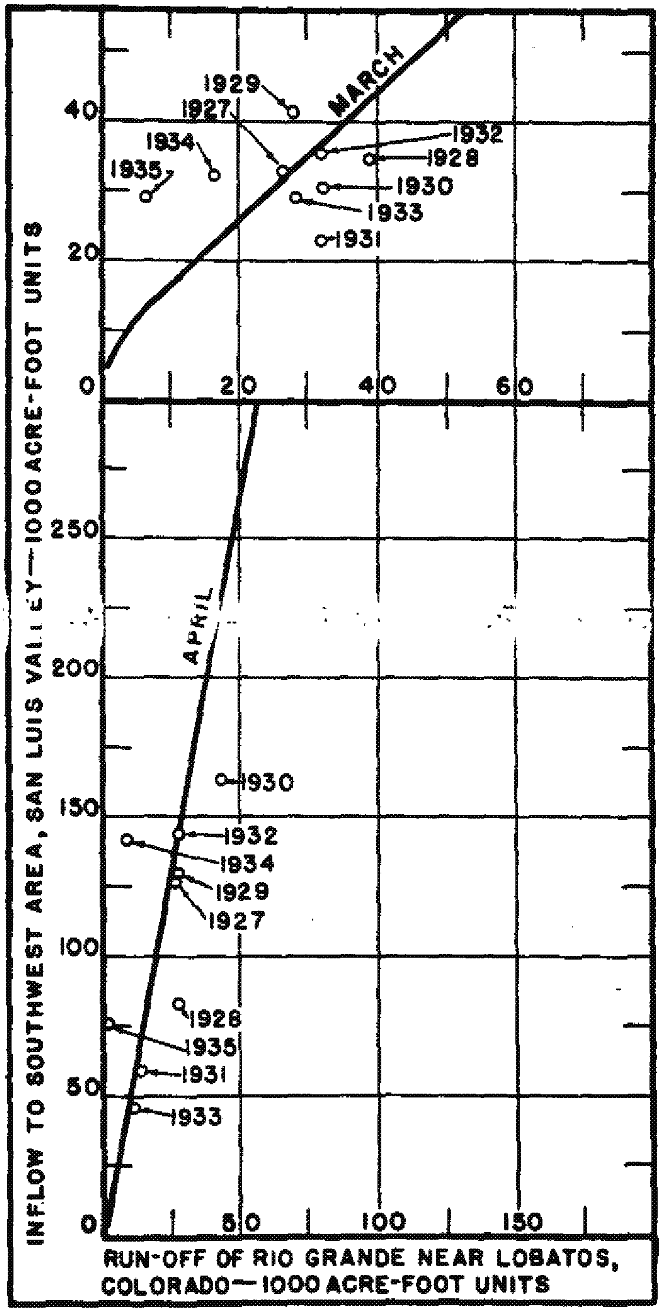

FIGURE 7.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months March and April 1927 to 1935.

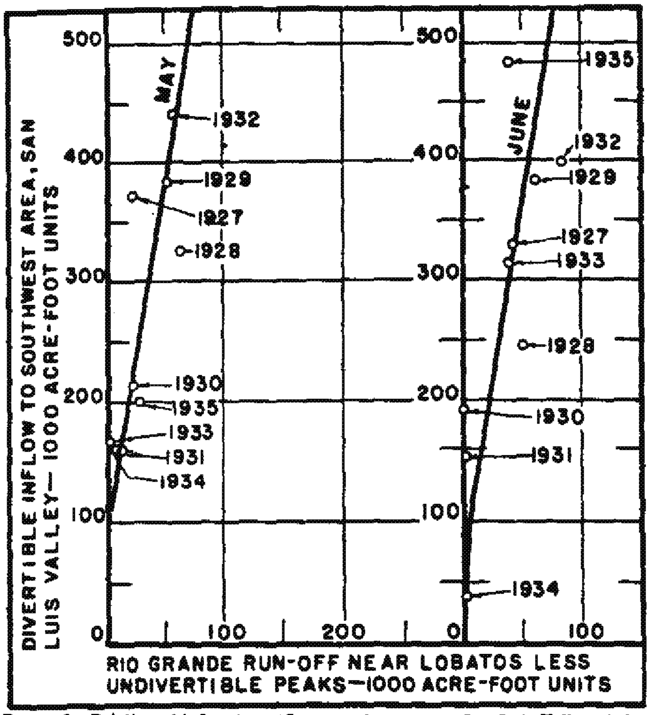

FIGURE 8.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months May and June 1927 to 1935.

the monthly total inflow to the southwest area against the monthly outflow at Lobatos, for the period 1927–35. The total monthly inflow was derived as explained in Appendix B (see table 194) and the outflow was taken

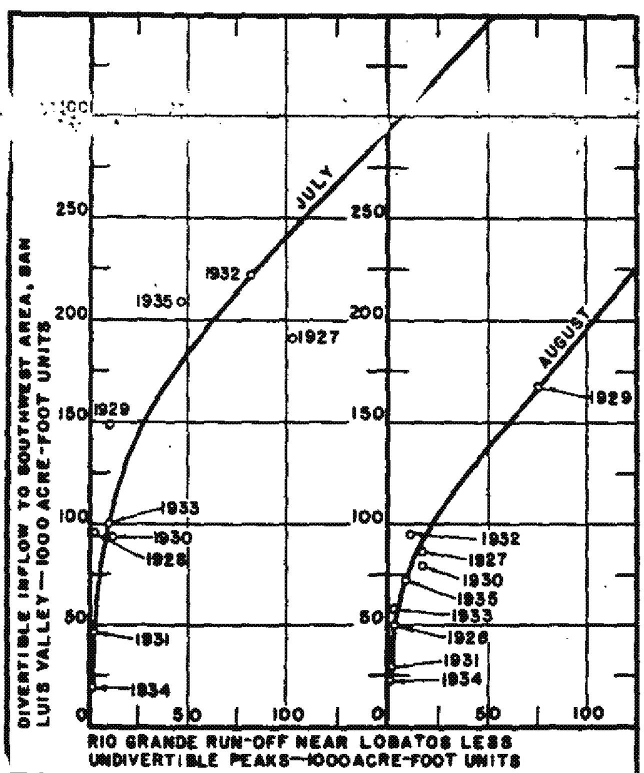

FIGURE 9.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months July and August 1927 to 1935.

from table 131 in Appendix A. The monthly relation curves drawn to fit the plotted points are shown on figures 6 to 11. Although the points for individual years show some deviation from the adopted curves, the latter were so drawn that the algebraic sum of the deviations over the period equals zero. By entering these curves with the monthly inflow to the southwest area in all of the earlier years, 1890 to 1926, as given by table 194 in Appendix B, the corresponding values for the outflow as it would have been in the past under present conditions of irrigation development in the valley were obtained. The difference between these values and the recorded flow at Lobatos as given by table 131, represents the change in depletion or accretion to conform to present

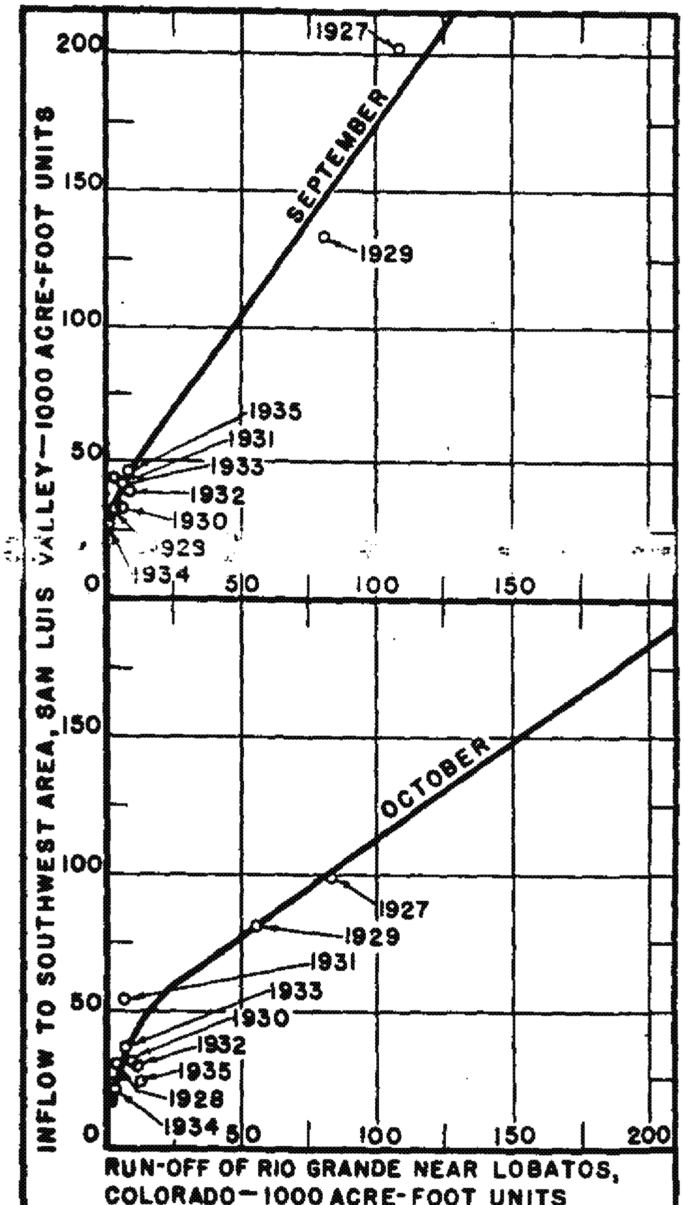

FIGURE 10.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months September and October 1927 to 1935.

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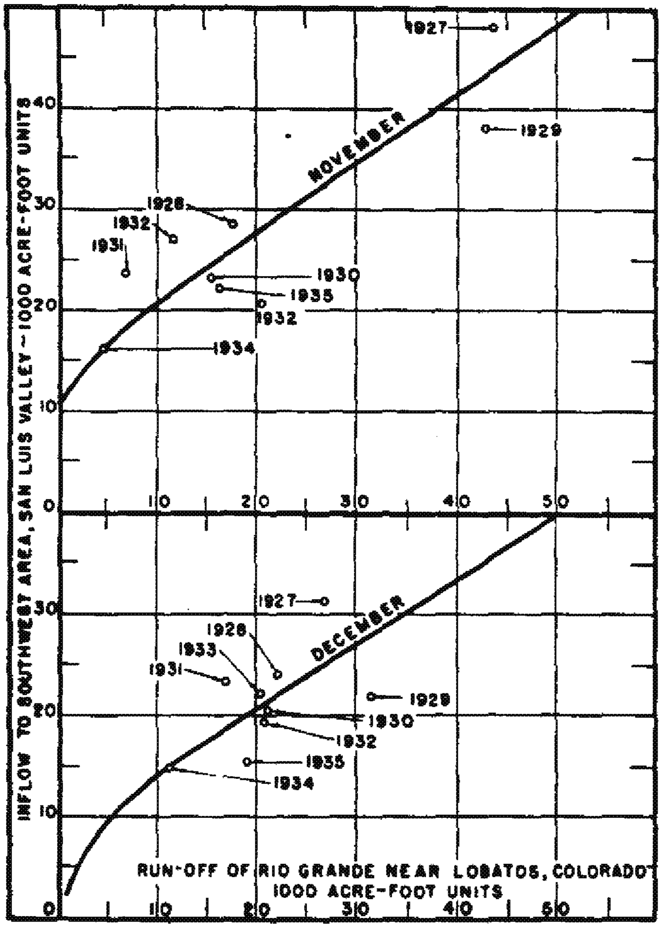

FIGURE 11.—Relation of inflow to outflow, southwest area, San Luis Valley, Colo. For months November and December 1927 to 1935.

conditions. These changes or corrections are given by months in table 17. Those with the minus sign indicate that under present conditions the Lobatos flow would have been less by this amount while those with the plus sign indicate that the flow would have been that much greater. The latter condition is, of course, that which would be anticipated for fall and winter months with the development of drainage and return flow in the later years. It will be noted that the corrections are carried through to December 1935. Present conditions were taken to be represented by the monthly curves plotted for the period 1927–35, and since the points for individual years in this period depart from the curves, these departures gave corrections within this period. The algebraic sum of these last corrections in each of the monthly columns is zero so that as far as the final result is concerned, it is immaterial whether or not they are applied.

During the flood period, May, June, and early July, the discharge of Rio Grande and its tributaries in the San Luis section is frequently, for short intervals, in excess of the diversion capacity of the canals. These flood peaks, therefore, pass from the valley at the Lobatos gaging station and cannot be utilized above that point. A study of the occurrence and volume of these indivertible peaks was made in order to take them into account in the correction of the past Lobatos flow for present development. Inspection of daily discharge records for the peaks of the 1932 and 1935 floods indicated maximum diversions on Rio Grande between Del Norte and Alamosa of approximately 4,000

TABLE 17.—Corrections to recorded flow of Rio Grande near Lobatos, Colo., to give flow under present irrigation development in San Luis Valley

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual total
1890	+3	−5	+14	[2] −30	+2	[2] −80	[1] −33	[1] −15	[1] −8	−9	−2	+1	−162
1891	−5	−3	+2	[1] −35	[2] −104	[2] −86	[1] −64	[1] −20	−5	−30	−9	+8	−341
1892	+2	−2	−18	[1] −44	[2] −77	[2] −58	[2] −7	+1	0	+4	+7	+3	−189
1893	+7	+3	+2	[1] −20	[1] −32	[1] −42	0	0	[1] −1	+4	+9	+3	−67
1894	+9	+9	−2	[2] −17	[1] −18	[1] −5	0	0	+2	[1] −16	+14	+9	−15
1895	−2	−1	+9	[1] −36	[1] −24	[1] −55	[1] −27	[1] −28	[1] −12	−6	−1	+8	−173
1896	−1	+3	+6	−25	[1] −11	−3	[1] −2	−1	+6	+3	+10	+5	−10
1897	+7	+5	+20	[1] −24	[2] −85	[2] −98	[1] −25	[2] −2	+7	+60	−2	+19	−118
1898	+7	+13	+14	[2] −33	−13	−17	[2] −62	[2] −3	[1] −2	+2	+3	+3	−88
1899	−3	−1	−5	[1] −14	[1] −5	+5	+1	+1	[1] −2	+3	+14	0	−6
1900	−1	−1	+3	[1] −7	[2] −10	[1] −45	+1	0	0	+5	+9	−2	−48
1901	−1	−8	−4	+1	[1] −32	[1] −21	[1] −2	−1	+2	+2	+14	+3	−42
1902	0	0	0	−1	[1] −5	[2] −3	0	0	0	+4	+8	+8	+11
1903	+3	+5	+9	0	[2] −27	−161	−30	0	+5	+5	+7	+4	−180
1904	0	+2	+8	+8	+6	0	0	+1	+11	+50	+4	0	+90
1905	−3	−3	−19	[1] −18	[2] −172	−148	−1	[1] −3	0	+1	+4	+1	−361
1906	−4	−3	+6	[1] −17	[2] −53	−56	−33	[1] −17	−4	0	−1	−2	−184
1907	−7	−6	−7	[1] −46	[2] −78	[2] −161	−30	−55	−45	−23	−4	+3	−459
1908	+4	+4	−12	[1] −14	[1] −8	[1] −22	−6	−23	[1] −10	−11	−3	+1	−100
1909	−3	−3	−6	[1] −24	[1] −91	−91	−8	−14	−58	−28	0	+27	−299
1910	−1	+2	−17	[1] −47	[2] −75	[2] −14	+2	−2	0	0	+4	+4	−144
1911	−4	−4	+4	−3	0	−63	−77	−16	−16	+142	−4	+13	−28
1912	−5	+2	−3	[1] −19	−26	[2] −140	+1	−8	[1] −5	−10	−4	−5	−222
1913	+2	0	−7	[1] −22	[1] −11	[1] −25	+3	+1	+1	−8	+1	+27	−38
1914	+5	+5	−3	[1] −14	[1] −52	−81	−8	[1] −28	−27	−5	−7	−2	−217
1915	−3	+2	−4	[1] −16	[1] −36	−44	−2	[1] −13	−11	−8	−1	−2	−138
1916	−2	−3	−3	[1] −16	[1] −51	+22	+26	−33	−10	+16	−13	0	−67
1917	−4	+6	−2	[1] −18	[1] −41	+10	+26	−7	−4	−7	−12	−9	−63
1918	−4	−6	−8	−2	+4	+7	[1] −5	0	−7	−3	+1	−1	−24
1919	+1	+5	−4	[1] −64	[2] −95	−21	+8	−9	−1	−5	−4	+6	−173
1920	−2	−3	−4	[1] −17	−22	−79	−3	−5	[1] −6	[1] −14	−13	−9	−177
1921	−11	−3	−13	−12	−22	−201	0	−26	−22	[1] −19	−8	−2	−339
1922	−8	−1	+1	−8	+15	[2] −60	−21	+7	+1	0	+5	+2	−67

See footnotes at end of table.

TABLE 17.—*Corrections to recorded flow of Rio Grande near Lobatos, Colo., to give flow under present irrigation development in San Luis Valley*—Continued

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual total
1923	−2	−1	+3	−6	+27	−34	+13	−20	−16	−22	−6	+7	−57
1924	0	−14	[1] −18	[1] −63	[2] −85	+1	+1	[1] −1	[2] −1	−2	−7	+1	−158
1925	+2	−5	−6	−4	+5	+15	+6	[1] −6	+5	+15	−1	+10	+36
1926	−3	−9	−17	[1] −16	[1] −18	−20	+2	+1	−1	+1	−3	+2	−81
1927	−2	−6	+1	−2	+25	0	−47	−3	+10	−4	+6	+10	−12
1928	−1	−1	−10	−12	−25	−22	+6	0	0	+3	+4	+3	−55
1929	+3	+6	+9	−2	−2	−8	+16	0	−9	0	−8	−10	−3
1930	0	0	−8	[1] −8	−2	+20	−3	[1] −4	−1	[2] −1	−2	−1	−10
1931	0	−3	−14	−2	0	+11	+1	0	+4	+13	+7	+7	+24
1932	+2	+2	−1	0	+2	−30	0	+8	[1] −2	[1] −2	−11	−3	−35
1933	0	+1	−5	[2] −1	+9	+1	0	+1	0	0	+8	+1	+15
1934	−2	−1	+11	+19	+4	−1	0	0	0	+2	0	0	+32
1935	0	+2	+18	+13	[1] −3	+20	+25	0	0	−3	−4	−7	+70
Total	−27	−15	−80	−728	−1,312	−1,874	−346	−340	−232	+99	+9	+144	−4,702

[1] This is the estimated or recorded (subsequent to 1911) discharge of the Rio Grande at Alamosa. On the assumption that development since 1890 has been largely confined to areas irrigated by river diversions above Alamosa, derived depletion corrections exceeding the Alamosa flow were reduced to the amount of that flow as representing the practical limit of depletion for present conditions.
[2] (See footnote 1.) This is the Alamosa flow reduced by the amount of passing indivertable peaks.

second-feet, and on Conejos River and tributaries below the Mogote and Ortiz stations, of about 1,500 second-feet. Past discharge records of Rio Grande near Del Norte and of Conejos River and its tributaries at the Mogote and Ortiz stations were then examined to determine the occurrence and volume of flood peaks in excess of these diversions. In plotting the points for May, June, and July, figures 8 and 9, showing the relation between inflow and outflow for the southwest area in the period 1927 to 1935, both inflow and outflow figures were reduced by the amount of the indivertible peaks. By entering the curves for these months, then, with the past monthly flow determined to have been divertible, the corresponding Lobatos flow less the indivertible peaks was derived. The depletion changes or corrections for May, June, and July, table 17, were then given by subtracting the curve value, increased by the indivertible peaks, from the recorded Lobatos flow.

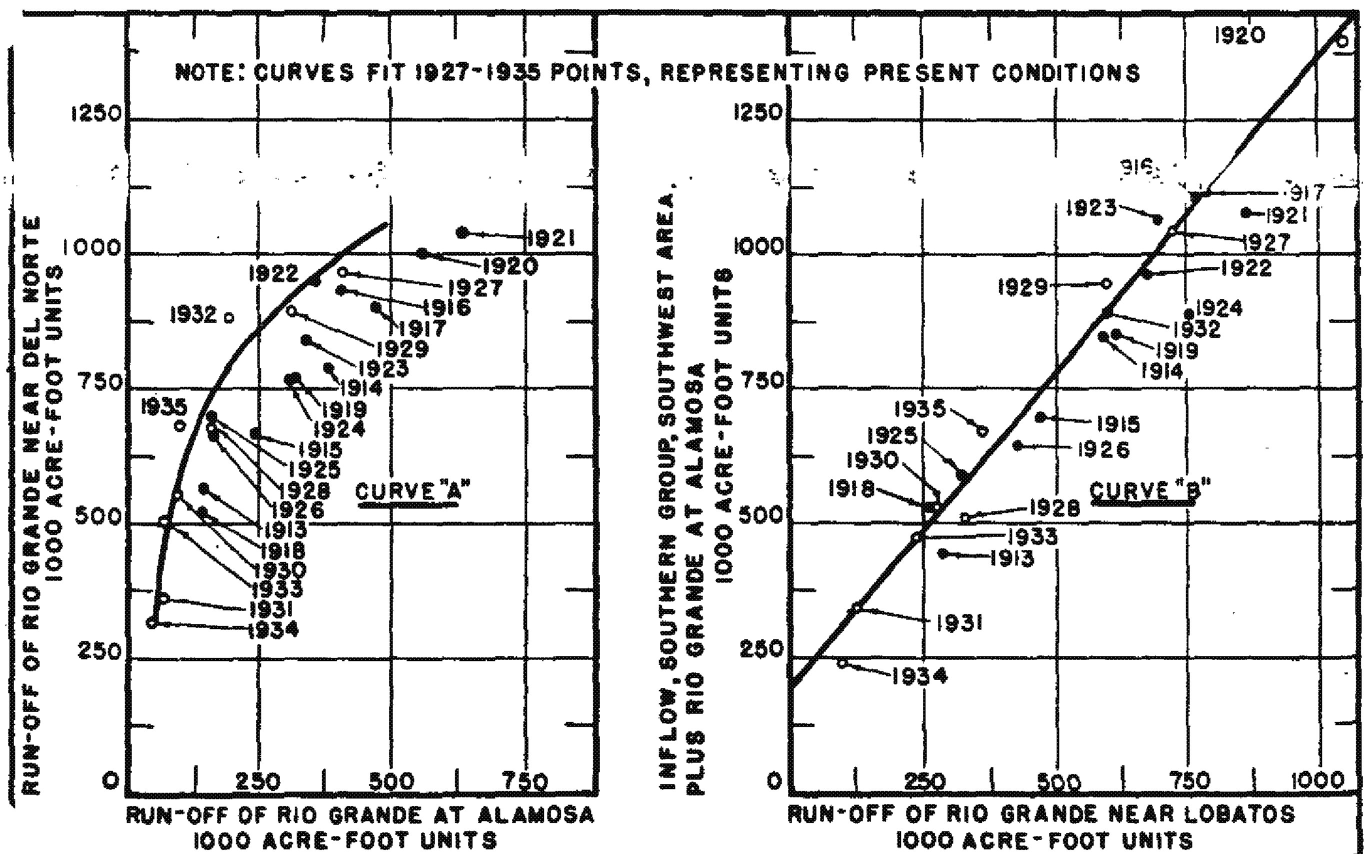

FIGURE 12.—Comparison of inflow and outflow, Rio Grande area above Alamosa and Conejos River-Alamosa Creek area, San Luis Valley, Colo.

A study of all available relevant data seems to indicate that the development which has taken place in San Luis Valley since 1890 has been confined largely to areas which are irrigated by diversions from the Rio Grande above Alamosa. Hence the past flow of the river at Alamosa should represent to a large extent the practical limit by which the flow could have been depleted under present conditions. If, therefore, the corrections derived from the curves as previously described were found to indicate a depletion change greater than the actual flow at Alamosa the corrections were arbitrarily reduced to the amount of the Alamosa flow and they are so shown in table 17. In the case of corrections for May, June, and July, when there were indivertible peaks this modification was made to conform to the flow at Alamosa less the volume of passing indivertible peaks. The record of the river flow at Alamosa does not go back of 1912 and the winter months are generally missing in the earlier years of the record after 1912. As the basis for limitation of the depletion corrections, estimates were made to complete the missing months and to extend this record back to 1890. This was done by reference to Rio Grande flow near Lobatos, using monthly relation curves established for the period of concurrent record. The estimates so derived are given in table 130 in Appendix A.

Some indication of the increase in irrigation development above Alamosa in past years as compared to the correspondingly small change in the Conejos and other portions of the southwest area, is given by the data of figure 12. In curve A the annual run-off of Rio Grande near Del Norte is plotted against that at Alamosa for the period of record of the latter, and in curve B the annual inflow of the southern group in the southwest area (including Conejos, San Antonio, and Los Pinos Rivers and Alamosa and La Jara Creeks, see table 194) plus the flow of Rio Grande at Alamosa is plotted against the Lobatos run-off. In both, the curves are drawn to fit the 1927–35 points as representing present conditions.

Even more strongly indicative of the confinement of increased development largely to the area served by diversions above Alamosa is the comparison of statistics of the acreage irrigated annually in Water District No. 20, comprising chiefly the area served from Rio Grande above Alamosa, and that irrigated in Districts Nos. 21 and 22, comprising the remaining portion of the southwest area. This is shown by the curves of figure 13.

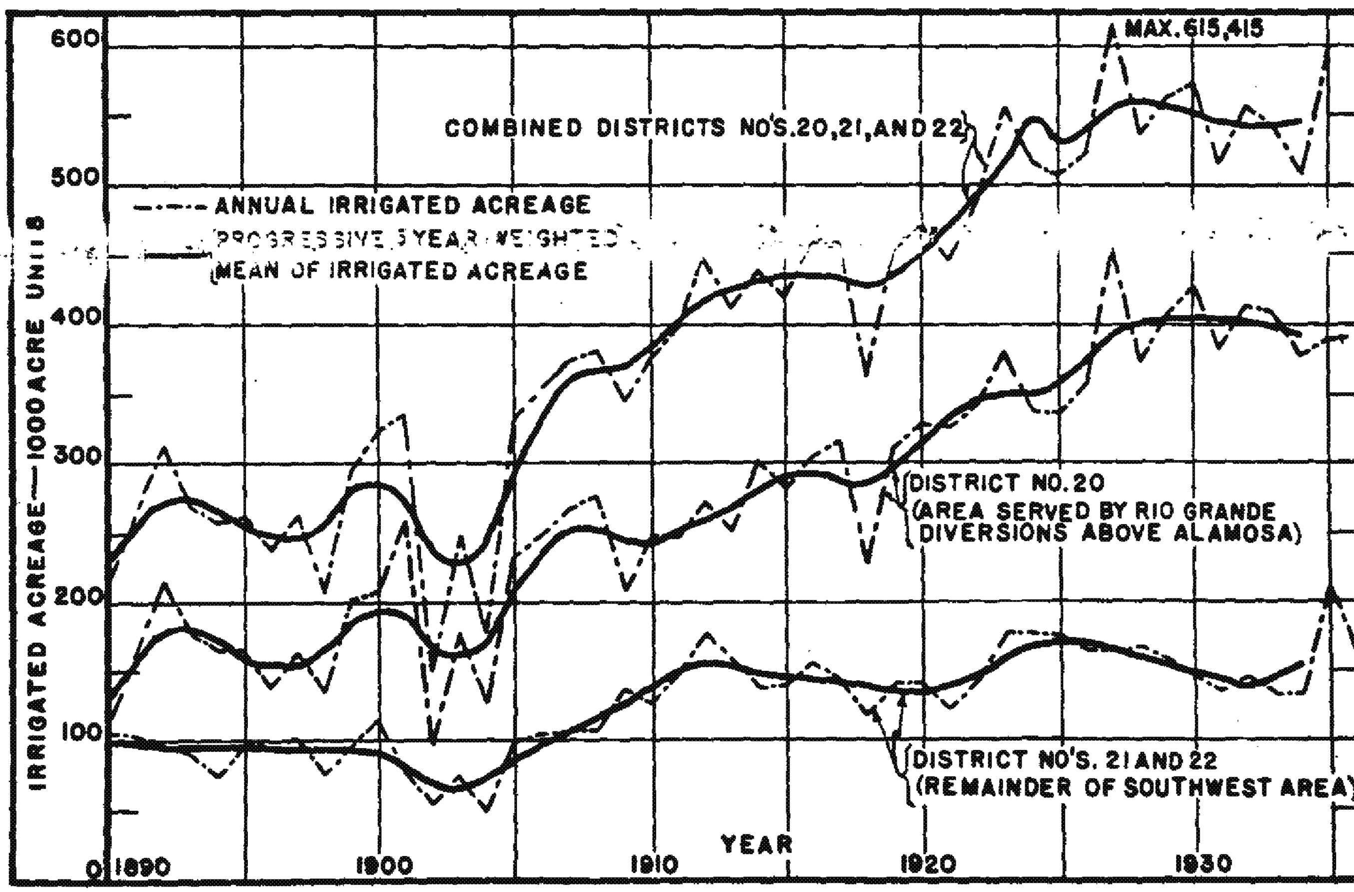

FIGURE 13.—Trend of irrigated acreage in water districts nos. 20, 21, and 22, San Luis Valley, Colo., as plotted from water commissioners' data.

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The acreage figures used are those of the water commissioners. As explained in a later section, these figures not accurate as to the total of the irrigated acreage out in their collection a certain procedure has been consistently followed which has given results which are almost always high. However, for the purpose of showing the trend of irrigation growth as in figure 13 it is believed that the water commissioners' records for Districts 20, 21, and 22 may be used satisfactorily. Smoothed curves representing progressive 5-year weighted means of the irrigated acreage are shown in figure 13 in order to bring out to better advantage the general trends.

The corrections of table 17 applied to the Lobatos record, table 131, gave the estimated run-off of Rio Grande near Lobatos under present conditions of irrigation development in San Luis Valley, as shown by table 18.

The differences between the annual inflow to the southwest area, San Luis Valley, as taken from table 197 in Appendix B and the annual outflow at Lobatos as given by table 131, have been plotted as shown on figure 14. This gives the total consumption or depletion of the inflow to the southwest area including, of course, the heavy diversions from Rio Grande to the Closed Basin. In order to eliminate to some degree the marked annual changes in the depletion due to the varying water supply, and to bring out more clearly the general trend, progressive 5-year weighted means of the depletion were computed and plotted as shown. The curve drawn through these means can probably be taken as a closely representative index of the amount and trend of the water use and irrigation development in San Luis Valley.

Perhaps of greater significance in the planning of future development and adjustments in the use of water in the Upper Rio Grande Basin, is the curve given on figure 15. This shows the depletion of the southwest area inflow expressed as a percentage of that inflow, annually and by progressive 5-year weighted averages. In other words, this curve shows the variation or trend over the years in the extent to which it has been possible to utilize and consume the available inflow. For example, since about 1921 there has been a fairly steady increase in the percentage of available

TABLE 18.—*Estimated run-off of Rio Grande near Lobatos, Colo., under present irrigation development in San Luis Valley*

[Drainage area 4,800 square miles.[1] Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890	16.0	13.0	41.0	48.0	205.0	91.0	32.0	13.0	8.0	10.0	22.0	28.0	527.0	117.6
1891	20.0	19.0	40.0	54.0	142.0	127.0	47.0	14.0	8.0	50.0	26.0	30.0	577.0	128.8
1892	20.0	20.0	27.0	69.0	123.0	72.0	9.0	2.0	1.0	5.0	11.0	12.0	371.0	82.8
1893	11.0	11.0	21.0	31.0	92.0	61.0	1.0	1.0	3.0	5.0	11.0	12.0	260.0	58.0
1894	12.0	11.0	25.0	28.0	65.0	10.0	1.0	1.0	3.0	9.0	16.0	19.0	200.0	44.6
1895	14.0	18.0	40.0	56.0	82.0	71.0	36.0	16.0	10.0	9.0	23.0	29.0	289.0	86.8
1896	[illegible]	22.0	47.0	40.0	47.0	[illegible]	[illegible]	[illegible]	[illegible]	10.0	[illegible]	[illegible]	[illegible]	[illegible]
1897	[illegible]	[illegible]	41.0	38.0	139.0	77.0	35.0	[illegible]	[illegible]	34.0	56.0	41.0	[illegible]	[illegible]
1898	24.0	25.0	42.0	51.0	39.0	130.0	30.0	3.0	4.0	5.0	9.0	13.0	430.0	96.0
1899	13.0	12.0	26.0	23.0	27.0	6.0	3.6	4.8	4.1	10.2	20.4	15.7	174.3	38.9
1900	11.3	12.9	21.4	13.2	98.0	63.0	2.2	.7	1.2	6.7	12.3	14.9	255.8	57.1
1901	14.4	10.9	18.3	17.8	92.0	45.0	3.0	2.4	4.6	5.0	16.1	12.2	241.7	54.0
1902	11.1	8.9	18.8	17.3	23.5	3.7	.7	.8	1.0	5.3	9.1	9.7	109.7	24.5
1903	4.5	6.4	11.1	18.7	97.0	218.0	42.4	2.9	10.4	8.9	15.3	11.4	447.0	99.8
1904	7.4	8.3	14.8	17.1	7.3	1.2	1.1	9.6	22.7	147.8	21.9	18.4	277.6	62.0
1905	18.5	15.0	36.2	28.0	178.0	282.0	15.7	7.0	3.8	7.3	17.6	16.4	625.5	139.6
1906	12.6	12.0	26.9	28.3	152.0	204.0	57.4	13.9	21.2	56.8	44.4	28.7	658.2	146.9
1907	23.7	23.2	40.9	71.0	128.0	250.0	304.0	52.0	28.2	12.4	24.1	26.0	977.5	218.2
1908	13.0	13.0	29.7	23.4	89.0	46.4	13.4	15.4	8.2	6.8	11.9	15.8	235.0	52.4
1909	15.4	16.4	24.1	39.1	122.0	178.0	29.3	14.7	82.0	25.4	33.9	54.1	634.4	141.6
1910	23.0	21.7	59.2	74.0	132.0	46.1	4.0	3.6	2.6	7.4	17.6	21.8	412.0	92.0
1911	18.8	17.1	27.1	34.4	130.0	180.0	145.0	19.6	25.6	335.0	43.6	43.7	1,008.9	225.2
1912	26.6	30.0	33.7	31.0	236.0	166.0	50.5	9.3	6.7	7.4	17.6	13.4	627.2	140.0
1913	13.0	12.0	18.0	35.1	39.5	27.7	7.9	3.3	5.1	15.6	25.0	41.0	243.2	54.3
1914	21.0	23.0	28.6	24.5	80.0	74.0	40.4	15.7	21.6	40.1	18.5	17.0	374.4	83.6
1915	16.0	18.0	20.5	33.0	68.0	81.0	37.7	13.1	5.7	7.6	18.5	16.9	333.0	74.3
1916	20.6	23.2	44.6	35.5	112.0	138.0	63.7	50.6	15.5	110.1	52.5	32.0	697.5	155.7
1917	23.0	27.0	30.0	37.8	75.0	306.0	183.0	10.6	5.5	5.1	10.4	13.0	725.4	161.9
1918	13.3	14.5	26.0	13.4	83.1	50.2	16.1	3.2	15.5	7.5	20.7	18.7	230.2	53.4
1919	17.8	30.4	30.6	66.0	142.0	42.7	48.7	11.8	6.1	7.2	21.8	29.5	430.2	96.0
1920	21.1	34.4	37.1	16.0	344.0	229.0	116.0	17.1	11.0	9.2	24.4	24.3	863.6	192.8
1921	19.7	39.7	38.6	12.3	70.8	188.0	57.4	37.3	19.3	8.6	23.4	24.8	523.9	116.9
1922	21.6	27.7	34.0	17.5	212.0	198.0	20.0	12.9	5.9	6.0	25.2	26.1	606.9	135.5
1923	21.1	22.6	30.7	17.8	182.0	126.0	41.6	28.0	45.3	88.6	53.5	47.3	639.5	142.7
1924	24.0	24.5	28.5	109.0	344.0	82.5	11.0	3.6	3.2	5.6	10.2	21.9	565.0	126.1
1925	18.0	21.0	33.6	28.1	43.0	32.7	14.5	12.4	28.4	48.0	34.1	45.2	359.0	80.1
1926	23.6	31.0	21.8	27.4	95.0	87.0	16.7	4.7	2.7	6.0	13.6	25.2	344.7	76.9
1927	17.7	31.0	27.7	24.5	121.5	118.0	81.0	18.8	119.0	80.8	49.8	37.0	711.8	158.9
1928	23.2	23.5	29.3	15.7	69.1	30.0	8.6	3.4	4.1	7.6	21.9	25.1	270.4	60.4
1929	18.8	21.7	37.0	26.3	118.0	84.2	38.3	76.2	71.9	55.8	34.9	21.7	594.8	132.8
1930	18.6	34.3	24.6	36.4	38.0	53.0	8.9	12.3	4.5	8.0	13.6	30.2	260.4	58.1
1931	12.0	14.1	18.2	12.0	10.9	14.0	2.3	2.0	7.2	18.9	13.9	24.0	149.5	33.4
1932	18.2	23.7	31.3	38.4	170.0	140.0	86.7	19.0	7.3	9.0	9.8	18.0	561.4	125.3
1933	18.5	14.9	23.7	10.1	42.0	78.6	9.9	3.8	5.5	7.5	19.7	21.5	252.0	56.2
1934	18.0	21.2	27.5	27.7	10.7	.8	.7	1.2	1.9	5.0	4.7	11.4	130.8	29.2
1935	12.6	15.0	24.2	14.9	42.5	195.0	73.7	9.3	9.2	9.3	12.3	12.1	430.1	96.0
[illegible]n	17.3	18.2	29.6	33.8	100.4	106.3	39.9	12.5	15.2	30.6	22.6	23.4	448.0	100.0
[illegible]nt of annual	3.86	4.06	6.61	7.32	22.41	23.80	8.91	2.79	3.39	6.86	5.05	5.22	100.0	

[1] Exclusive of closed basin area.

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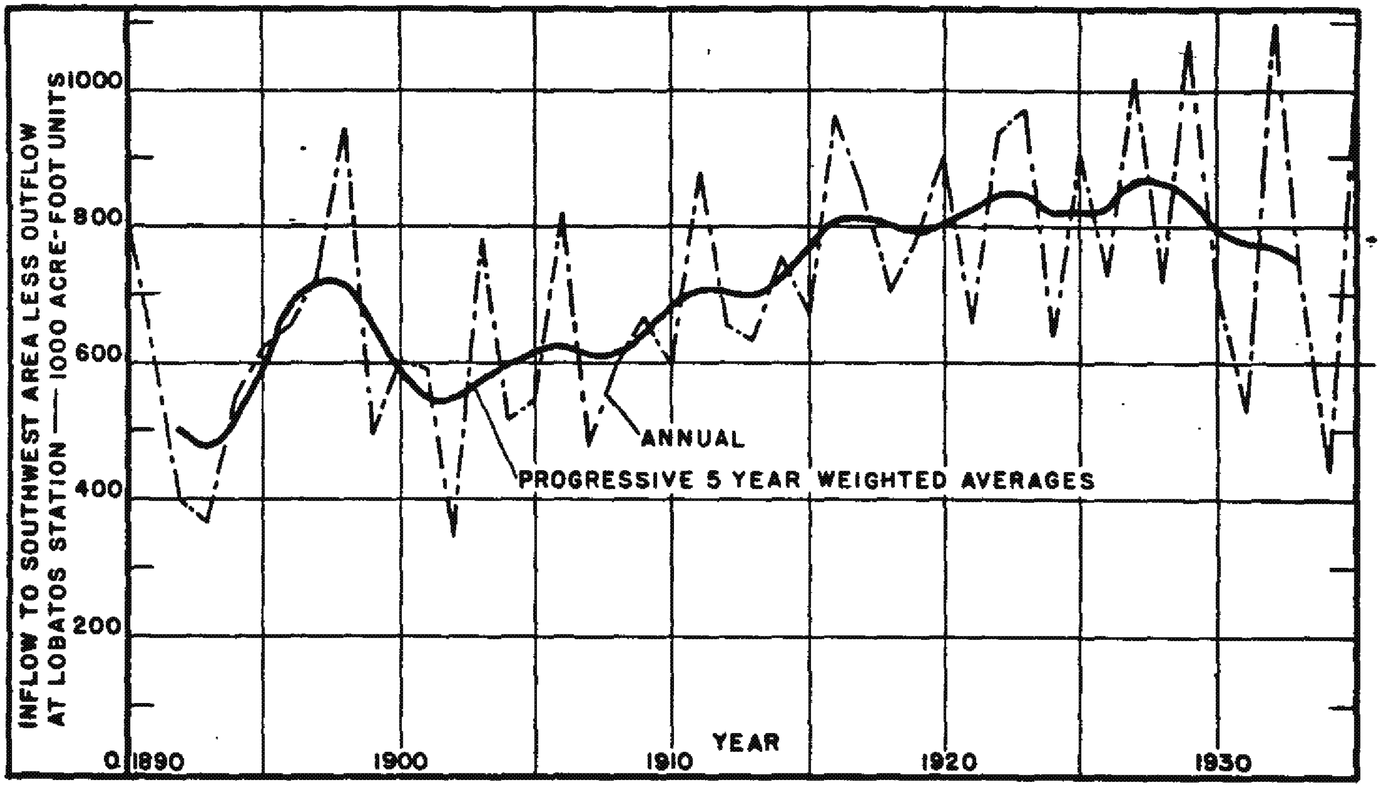

FIGURE 14.—Depletion of inflow to southwest area, San Luis Valley, Colo., 1890–1935.

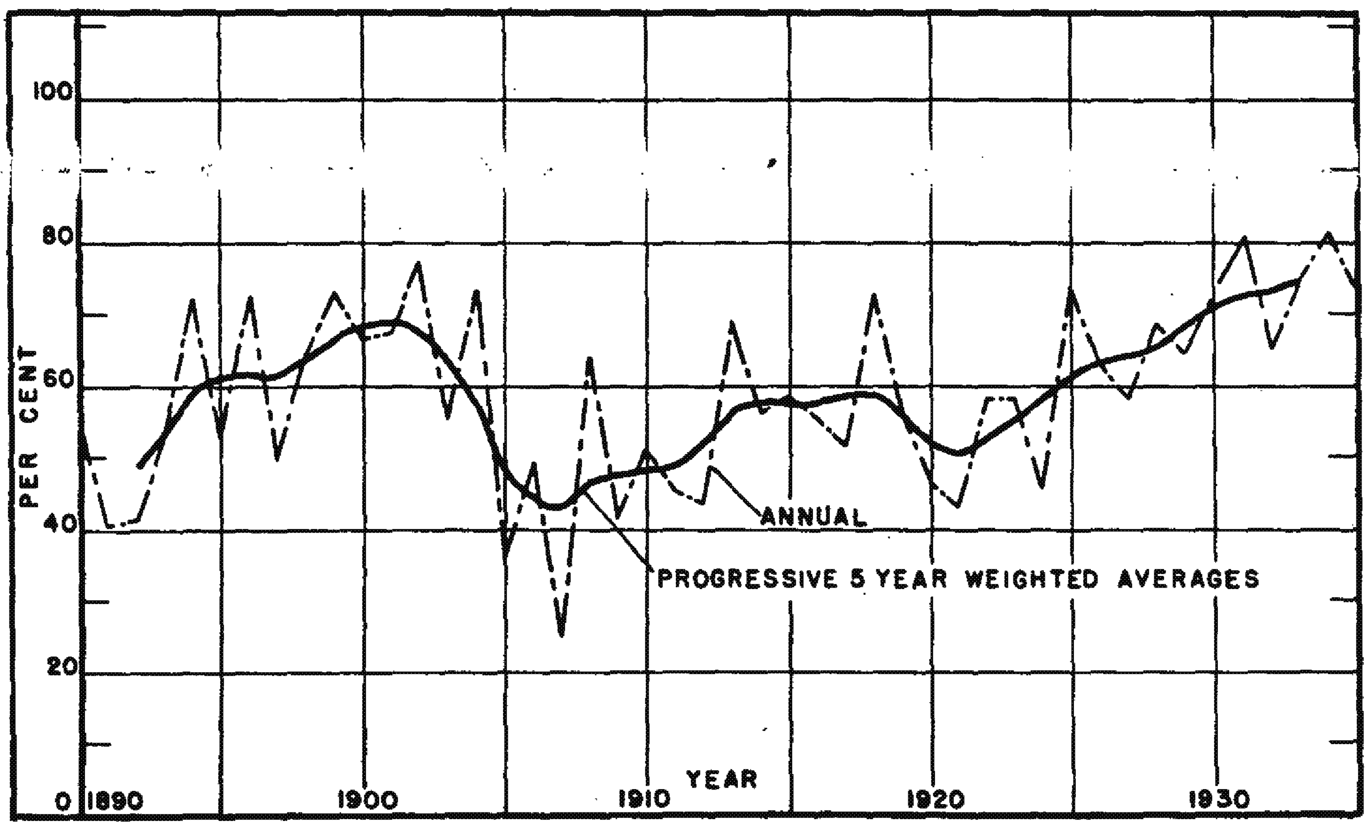

FIGURE 15.—Depletion of inflow to southwest area in percent of inflow, San Luis Valley, Colo., 1890–1935.

supplies utilized, as shown by figure 15, although in his period there has been little if any general increase in the consumption of inflow, as shown by figure 14. The severe droughts of 1931 and 1934 occurred in this period and although water supplies were greatly diminished, an effort was made to maintain use as shown by the continued rise of the percentage curve (fig. 15). The greater efficiency in use in this period was produced by decreasing waste, by diverting drain waters, and by pumping ground water. The data upon which figures 14 and 15 are based are given in table 19.

TABLE 19.—*Depletion of inflow to southwest area, San Luis Valley, Colo.*

[Unit 1,000 acre-feet]

Year	Inflow to southwest area	Outflow at Lobatos station	Depletion			
			Annual (1)−(2)	Progressive 5-year weighted averages from column (3) [1]	Annual in percent of inflow (3)÷(1)	Progressive 5-year weighted averages from column (5) [1]
	(1)	(2)	(3)	(4)	(5)	(6)
1890	1,490	689	801	------------	53.8	------------
1891	1,543	918	625	------------	40.5	------------
1892	958	560	398	503	41.5	48.5
1893	691	327	364	470	52.7	53.1
1894	766	215	551	519	71.9	60.0
1895	1,184	562	622	594	52.5	60.9
1896	899	247	652	682	72.5	62.0
1897	1,458	735	723	719	49.6	60.9
1898	1,459	518	941	723	64.5	64.2
1899	673	180	493	662	73.2	66.4
1900	905	304	601	583	66.4	69.1
1901	874	284	590	548	67.5	68.8
1902	441	99	342	542	77.6	68.7
1903	1,408	627	781	578	55.5	63.5
1904	704	188	516	596	73.3	58.8
1905	1,532	986	546	619	35.6	48.0
1906	1,661	842	819	624	49.3	45.1
1907	1,914	1,436	478	610	25.0	42.1
1908	933	335	598	611	64.1	47.4
1909	1,602	[illegible]	569	538	[illegible]	47.5
1910	1,149	[illegible]	[illegible]	[illegible]	[illegible]	48.3
1911	1,913	[illegible]	376	713	[illegible]	48.7
1912	1,504	849	655	704	43.6	52.0
1913	913	281	632	696	69.2	56.8
1914	1,348	591	757	722	56.2	58.1
1915	1,142	471	671	769	58.8	57.8
1916	1,724	764	960	819	55.7	57.4
1917	1,631	788	843	812	51.7	58.5
1918	964	263	701	802	72.7	59.5
1919	1,392	612	780	784	56.0	55.6
1920	1,943	1,041	902	802	46.4	52.0
1921	1,519	863	656	824	43.2	50.3
1922	1,613	674	939	846	58.2	52.1
1923	1,667	696	971	849	58.2	56.5
1924	1,391	753	638	815	45.9	58.0
1925	1,228	323	905	825	73.7	61.7
1926	1,153	426	727	817	63.1	63.0
1927	1,736	724	1,012	878	58.3	64.0
1928	1,040	325	715	861	68.7	65.1
1929	1,675	598	1,077	847	64.3	68.2
1930	980	270	710	794	72.4	71.2
1931	653	126	527	776	80.7	72.8
1932	1,692	596	1,096	767	64.8	73.3
1933	945	237	708	747	74.9	74.6
1934	539	99	440	------------	81.6	------------
1935	1,356	360	996	------------	73.4	------------
46-year mean	1,259	550	709	------------	59.1	------------

[1] Computed as ⅛ of the sum of 3 times the year under consideration, plus 2 times each of the adjacent years, plus the second year removed in each direction.

Correction for Middle Valley development.—Determination of the depletion or total consumption of inflow in past years in the Middle section, in order to correct past Rio Grande flows to present conditions, is extremely difficult because of the meagerness and uncertainty of records of tributary inflow between Otowi Bridge and San Marcial, the controlling upper and lower river stations, respectively, for the principal unit of water consumption in the Middle section. This tributary inflow, though largely unmeasured, is obviously of such magnitude that total consumption of inflow between Otowi Bridge and San Marcial cannot be derived as the difference in river flow between those stations. The following paragraphs outline the study which was made to derive some estimate of this total consumption of inflow, based upon the very inadequate data available.

As a measure of tributary inflow, investigation was first made of gains in the river flow between intermediate stations. For this purpose there was available the record of the river flow at San Felipe for 1926 to 1936, inclusive. This record was extended to cover 1890–1935 by relating monthly gains between Lobatos and Otowi Bridge and between Lobatos and San Felipe for the period of concurrent record, and estimating the gains to San Felipe for the earlier years from the resulting relation curves. Using this extended record the monthly river gains between Otowi Bridge and San Felipe and between San Felipe and San Marcial were derived as shown in tables 20 and 21. As indicated, the mean annual gains are 81,600 acre-feet from Otowi Bridge to San Felipe and 61,400 acre-feet from San Felipe to San Marcial. This study showed many gains between Otowi Bridge and San Felipe where, for the same months, comparison of Otowi Bridge and San Marcial flows showed losses. The gains in tables 20 and 21 represent the excess of tributary inflow, surface and seepage, over consumption in and [illegible] the respective river sections, as derived for monthly periods. Inasmuch as the flow of the tributary streams in the Middle Valley is flashy, with flood flows extending over a few days only, a study of gains based on daily river flows would in all probability show higher gains than those of tables 20 and 21. Lack of long time daily records, however, precluded such a study.

The total consumption of inflow in the past, Otowi Bridge to San Marcial, like that in the southwest area of San Luis Valley, has, within limits, varied more or less directly with the available water supply; in the case of the Middle Valley, with both side inflow and river flow at Otowi Bridge, but chiefly the latter. Estimate of past consumption of inflow in the Middle Valley, therefore, involves determination of the relation between Otowi Bridge-San Marcial losses and the Otowi Bridge flow. Assuming that the consumption of inflow, Otowi Bridge to San Marcial, could be taken as closely approaching the indicated Otowi Bridge-San Marcial loss during the frequent periods when tributary inflow has apparently approached zero, study was next directed to the determination of a large number of such losses for

TABLE 20.—*Rio Grande gains between Otowi Bridge and San Felipe, N. Mex.*

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890	0	3.0	0	10.0	25.0	16.0	20.0	2.0	0	0	3.0	5.0	84.0
1891	0	3.0	18.0	15.0	16.0	23.0	27.0	2.0	0	0	5.0	4.0	113.0
1892	0	3.0	20.0	25.0	38.0	10.0	6.0	0	0	0	2.0	2.0	106.0
1893	0	2.0	0	0	0	6.0	3.0	0	0	0	2.0	3.0	16.0
1894	0	2.0	0	0	0	0	0	0	0	0	5.0	6.0	13.0
1895	0	2.2	15.7	14.0	0	15.0	20.0	.9	0	0	4.4	4.2	76.4
1896	0	2.5	4.8	0	0	0	1.7	0	0	0	2.4	3.0	14.4
1897	0	2.9	5.2	14.0	68.0	20.0	14.7	1.6	0	0	.1	1.8	128.3
1898	0	2.1	0	4.0	0	2.0	16.0	.8	0	0	6.4	5.8	37.1
1899	0	3.4	3.8	0	0	0	3.4	0	.9	0	6.0	4.8	22.3
1900	1.2	2.7	.2	0	0	0	0	0	0	0	2.7	2.0	8.8
1901	0	3.5	0	0	0	0	11.2	1.2	0	0	4.5	3.5	23.9
1902	0	2.8	0	0	0	0	.3	.8	0	0	.6	3.8	8.3
1903	0	3.3	28.8	1.0	2.0	55.0	25.0	.4	0	0	.8	2.4	118.7
1904	0	2.8	0	0	0	0	0	7.0	42.0	1.0	7.6	2.6	63.0
1905	0	4.4	50.0	2.0	53.0	14.0	10.3	.3	0	0	4.0	4.1	142.1
1906	0	3.0	0	0	25.0	23.0	24.0	2.0	0	0	8.0	5.0	90.0
1907	3.0	3.0	16.0	17.0	1.0	39.0	45.0	12.0	0	0	4.0	4.0	144.0
1908	9.0	5.0	14.0	0	0	1.0	11.0	3.0	0	0	2.0	3.0	48.0
1909	0	3.0	0	2.0	12.0	23.0	25.0	4.2	17.0	0	0	1.5	87.7
1910	0	1.7	10.0	5.0	0	0	0	0	0	0	2.2	2.7	21.0
1911	1.3	2.5	25.4	0	0	4.0	61.0	.5	0	1.0	43.0	10.5	149.2
1912	0	2.3	17.3	0	25.0	39.0	27.0	1.0	0	0	.7	2.5	114.8
1913	.2	3.1	0	0	0	0	7.2	0	0	0	3.7	3.8	18.0
1914	2.1	3.2	18.6	0	0	6.0	40.0	5.0	0	0	7.0	3.6	85.5
1915	0	3.0	11.0	5.0	22.0	30.0	17.5	1.8	0	0	.5	3.3	94.1
1916	0	3.4	24.0	8	33.0	20.0	22.5	2.0	0	0	7.2	4.4	124.5
1917	0	2.5	1.2	0	0	18.0	11.0	0	0	0	.6	2.8	36.1
1918	0	1.4	1.2	0	0	4.0	12.5	0	0	0	3.0	5.5	27.6
1919	0	2.4	13.8	5.0	15.0	13.0	46.0	4.1	0	0	6.4	6.9	112.6
1920	1.5	6.3	15.2	0	65.0	46.0	25.0	.3	0	0	4.5	2.6	166.4
1921	0	2.9	12.0	0	0	45.0	16.0	11.0	4.3	0	2.2	5.5	98.9
1922	1.5	2.8	6.9	0	0	9.0	11.0	.3	0	0	.1	4.8	36.4
1923	0	3.1	0	0	0	5.0	4.8	1.0	8.0	0	12.5	6.0	40.4
1924	0	3.5	0	5.0	23.0	11.0	18.6	.8	0	0	3.5	5.6	66.0
1925	0	2.9	5.4	0	0	0	10.3	3.2	0	0	5.3	4.4	31.5
1926	14.8	31.1	49.4	72.0	103.0	0	17.2	2.2	0	0	19.4	10.2	319.3
1927	8.2	7.8	7.9	0	24.0	27.0	131.0	36.6	47.0	6.0	10.6	9.1	315.2
1928	2.8	4.5	20.3	2.4	0	14.0	5.4	52.4	.7	3.3	2.7	3.8	112.3
1929	0	0	0	0	0	0	25.6	7.0	32.0	7.0	18.8	18.1	106.5
1930	5.3	0	4.7	0	0	9.4	17.2	0	0	0	0	0	36.6
1931	0	.7	3.6	0	15.0	0	2.8	.8	3.2	0	0	2.8	28.9
1932	.9	1.6	0	0	27.0	0	17.0	1.2	0	0	2.2	3.7	53.6
1933	2.1	4.2	19.3	0	0	21.0	5.2	4.7	0	0	8.7	19.6	84.8
1934	10.2	6.9	0	0	5.3	0	0	0	0	0	0	4.1	26.5
1935	0	0	.2	2.3	8.0	22.0	4.8	35.9	11.4	0	11.5	3.5	99.6
46-year mean	1.4	3.6	9.6	4.5	13.2	12.8	17.7	4.6	3.6	.4	5.4	4.8	81.6

TABLE 21.—*Rio Grande gains between San Felipe and San Marcial, N. Mex.*

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890	2.0	0	0	0	0	0	0	0	0	0	0	0	2.0
1891	0	16.0	37.0	0	264.0	7.0	0	0	57.0	0	0	0	381.0
1892	0	0	0	0	0	0	0	0	0	0	0	0	0
1893	11.0	0	0	0	0	0	0	0	0	0	0	0	11.0
1894	2.0	0	0	0	0	0	0	0	0	29.0	0	0	31.0
1895	3.0	18.8	29.0	0	0	0	20.0	87.0	0	0	0	0	157.8
1896	9.0	2.1	0	0	0	0	1.7	0	0	21.6	0	5.1	39.5
1897	0	0	0	0	0	0	0	0	77.0	151.0	104.0	119.0	451.0
1898	50.9	22.4	32.2	1.0	0	0	0	0	0	0	0	0	106.5
1899	8.9	0	0	0	0	0	0	0	0	0	0	0	8.9
1900	2.6	.1	0	0	0	0	0	0	16.1	0	0	0	18.8
1901	4.0	0	0	0	0	0	3.3	13.5	9.6	0	0	0	30.4
1902	0	0	0	0	0	0	0	14.2	0	0	0	0	14.2
1903	0	0	0	0	0	0	0	0	0	0	0	0	0
1904	2.8	0	0	0	0	0	0	0	0	209.0	0	3.8	215.6
1905	0	7.9	10.0	58.0	124.0	127.0	0	0	0	0	.4	0	327.3
1906	3.5	1.7	13.9	0	0	0	0	0	0	0	0	27.1	46.2
1907	.6	12.7	0	0	0	0	0	0	42.0	0	0	0	55.3
1908	0	0	0	0	0	0	0	0	0	0	0	4.4	4.4
1909	4.6	0	0	0	0	0	0	0	0	0	10.6	4.8	20.0
1910	30.3	9.0	0	0	0	0	0	0	0	0	0	0	39.3
1911	0	0	0	0	0	0	0	0	0	0	0	0	0
1912	5.3	0	0	0	0	0	0	0	0	0	0	0	5.3
1913	0	0	0	0	0	0	0	0	0	0	0	0	0
1914	0	0	0	0	0	0	0	0	0	0	0	0	0
1915	0	0	0	32.0	0	0	11.0	0	0	0	0	0	43.0
1916	4.8	0	0	0	0	0	0	0	0	6.0	0	0	10.8
1917	9.6	0	0	0	0	0	0	0	0	0	0	0	9.6
1918	1.0	0	0	0	0	0	0	0	0	0	0	0	1.0
1919	2.4	0	0	0	0	0	64.0	0	0	0	0	0	66.4
1920	1.3	3.4	0	1.0	0	112.0	0	0	0	0	0	0	117.7
1921	6.0	0	0	0	0	0	82.0	0	0	0	0	0	88.0
1922	3.5	0	0	0	0	0	0	0	0	0	0	0	3.5
1923	0	0	0	0	0	0	0	0	0	0	0	0	0
1924	12.0	13.1	18.9	34.0	0	0	0	0	0	0	0	0	79.[illegible]
1925	0	0	0	0	0	0	0	0	0	0	0	0	0

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TABLE 21.—*Rio Grande gains between San Felipe and San Marcial, N. Mex.*—Continued

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1926	0	0	0	0	0	36.0	0	0	0	0	0	0	36.0
1927	0	0	0	0	0	0	0	0	0	0	0	0	0
1928	0	0	0	0	0	0	0	0	0	0	0	0	0
1929	0	0	0	0	0	0	0	106.0	128.0	12.0	0	0	246.0
1930	0	0	0	0	0	0	0	0	0	0	0	0	0
1931	3.8	0	0	0	0	0	0	0	0	13.4	0	0	17.2
1932	3.6	0	0	0	0	0	0	18.0	0	0	0	0	21.6
1933	.8	0	0	0	0	37.0	3.5	3.0	13.8	0	0	0	58.1
1934	0	0	0	0	0	0	0	23.7	6.9	0	0	0	30.6
1935	12.1	8.4	0	0	0	0	0	0	0	0	0	9.5	30.0
46-year mean	4.2	2.7	3.1	2.8	3.4	6.9	4.0	6.8	7.6	9.6	2.5	3.8	61.4

a wide range of Otowi Bridge flows during each month of the year, using daily river discharge data. These losses, in second-feet, were computed for single days at intervals of from 5 to 10 days throughout 35 years of available record for Otowi Bridge and San Marcial, utilizing days when the flow appeared to be uniform and not affected by appreciable volumes of tributary inflow. For the movement of water between Otowi Bridge and San Marcial, a lag of 2 days was allowed for flows exceeding 1,000 second-feet and 3 days for lesser flows. The losses so derived were plotted against the corresponding Otowi Bridge flows using a separate graph for each month of the year as shown by figure 16.

In plotting the points originally a legend was used to segregate the losses to four periods, 1890–1905, 1906–19, 1920–29, and 1930–35. (Differentiation for the period 1930–35 only was finally shown on figure 16.) This was done to furnish a basis for observation of whether any distinct changes or trends in the loss relationship might have occurred over the years. The period 1930–35 covers that of the construction of the irrigation and drainage works of the Middle Rio Grande Conservancy District. Another segregation was for the loss as determined by "seepage runs". In October 1913, January 1924, and October 1926, the New Mexico State engineer's office made a series of measurements of the river flow including, in the section from Otowi Bridge to San Marcial, measurements of all intermediate diversions and inflow. This was done at times when there was uniform river flow so that the results of the seepage run would give as closely as possible the actual river loss and side inflow between Otowi Bridge and San Marcial. The data of these measurements, as taken from published reports, furnished three definite determinations of river loss and side inflow which were plotted as shown on figure 16 for January and October. Inspection of the plotted points shows a wide variation in loss depending upon the supply. The original segregation of points to four periods appeared to give little justification, however, for any deduction of a fixed trend definite change in the loss relationship over the periods, with possibly one exception. For the winter months November to March there appeared to be some indication of lower losses for given Otowi Bridge flows in the period 1930–35. This is an effect which might be expected with the development of the Middle Rio Grande Conservancy District drainage system in this period.

On each of the graphs, curves were drawn to define for each month the Otowi Bridge flow-inflow loss relationship for the greatest losses, eliminating eratics. These were drawn by enveloping the area of greatest congestion of points, disregarding isolated points representing exceptionally high losses due presumably to unusual circumstances of use or to faulty deduction because of the lack of uniform flow or possible errors in one or the other of the river flow records. In order to estimate the monthly loss or consumption of inflow the curves of figure 16 were converted to give the monthly loss relationship in acre-feet as shown by figure 17. Entering these curves with the monthly flow at Otowi Bridge, 1890 to 1935, corresponding values for the monthly consumption of inflow in this period were obtained. These values were then adjusted to conform to and be consistent with the losses indicated by the Otowi Bridge-San Marcial differences for the months under consideration, and with the results of the previous study of river gains, Otowi Bridge to San Felipe and San Felipe to San Marcial. In the adjustment, side inflow was made to exceed river gains by an amount conservatively estimated to cover consumption in the river section showing a gain. In the case of material gains, slight adjustment was made also to cover greater consumption due to such factors as expanded water surfaces and overflows. The final determinations for the monthly consumption of inflow are shown in table 22. These figures give a mean annual consumption of inflow, 1890 to 1935, of 585,600 acre-feet.

The difference between the consumption figures of table 22 and the corresponding Otowi Bridge-San Marcial differences was credited to tributary inflow which reached the stream either by surface flow or from ground water. The values for the monthly tributary inflow so derived are shown in table 23 and give a mean

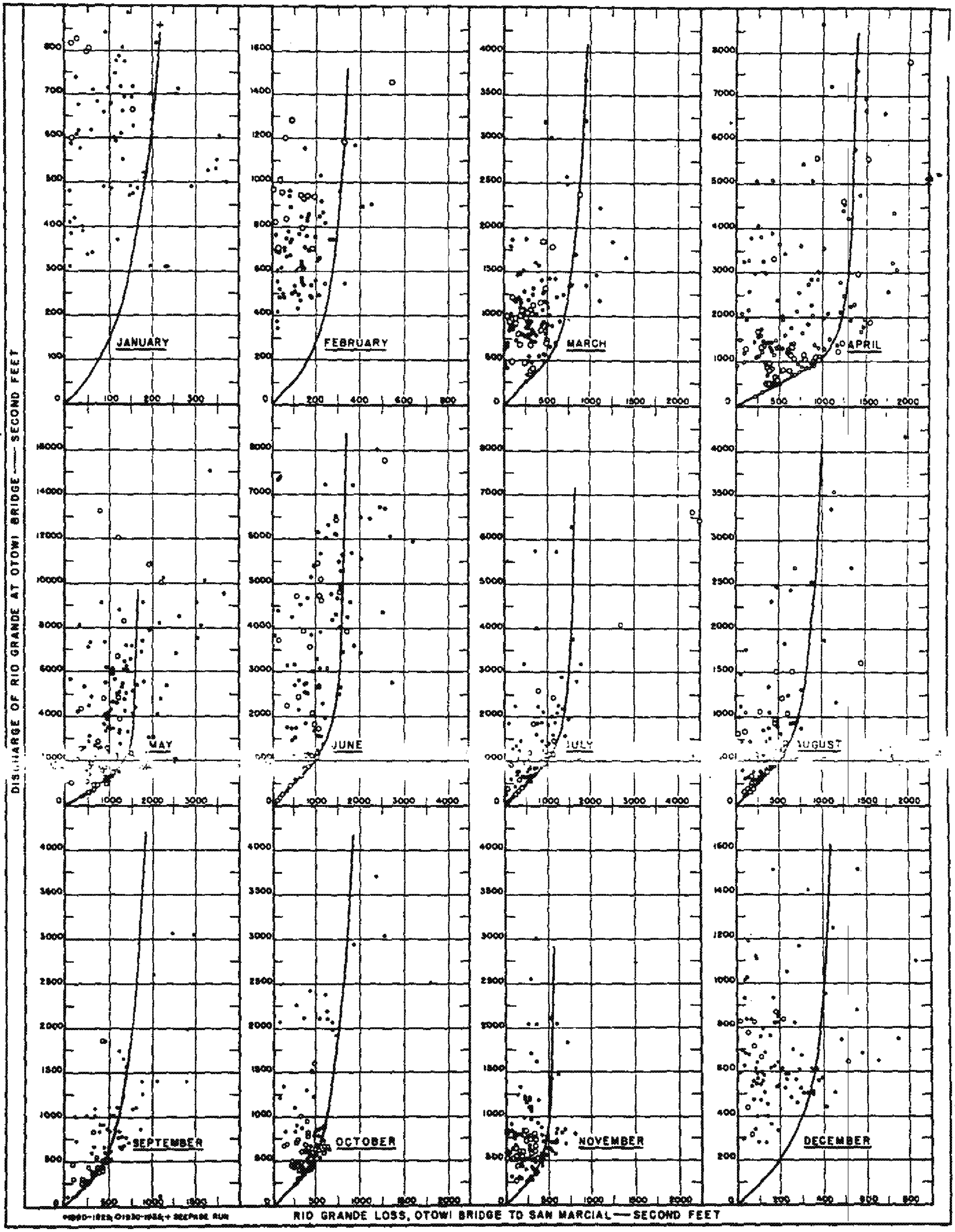

FIGURE 16.—Relation of Otowi Bridge discharge to Rio Grande loss, Otowi Bridge to San Marcial. For months of January to December 1890-1935.

TABLE 22.—*Estimated consumption of inflow to the Middle Valley, Otowi Bridge to San Marcial*

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890	11.0	16.0	41.0	120.0	130.0	97.0	88.0	47.0	32.0	42.0	28.0	24.0	676.0
1891	13.0	17.0	49.0	80.0	120.0	100.0	89.0	49.0	31.0	47.0	34.0	27.0	656.0
1892	12.0	17.0	72.0	200.0	104.0	95.0	50.0	14.0	8.0	15.0	25.0	17.0	629.0
1893	9.0	14.0	28.0	110.0	97.0	190.0	30.0	18.0	21.0	25.0	22.0	18.0	582.0
1894	9.0	12.0	38.0	74.0	94.0	40.0	19.0	22.0	20.0	25.0	29.0	28.0	410.0
1895	11.0	18.0	47.0	80.0	95.0	95.0	85.0	51.0	31.0	31.0	29.0	23.0	596.0
1896	12.0	16.0	46.0	78.0	89.0	30.0	29.0	16.0	18.0	25.0	24.0	21.0	404.0
1897	11.0	15.0	42.0	105.0	105.0	100.0	76.0	28.0	32.0	49.0	32.0	23.0	618.0
1898	10.0	14.0	31.0	80.0	92.0	105.0	90.0	34.0	19.0	22.0	32.0	23.0	554.0
1899	10.0	16.0	60.0	130.0	90.0	24.0	39.0	23.0	52.0	26.0	42.0	23.0	535.0
1900	12.0	15.0	40.0	51.0	95.0	90.0	19.0	10.0	31.0	24.0	26.0	21.0	434.0
1901	10.0	16.0	37.0	67.0	96.0	85.0	47.0	42.0	28.0	26.0	23.0	20.0	497.0
1902	11.0	14.0	31.0	70.0	67.0	28.0	17.0	33.0	25.0	17.0	18.0	16.0	347.0
1903	10.0	13.0	45.0	77.0	100.0	110.0	86.0	27.0	22.0	22.0	22.0	18.0	552.0
1904	10.0	13.0	24.0	28.0	25.0	17.0	16.0	50.0	145.0	60.0	30.0	22.0	440.0
1905	12.0	17.0	55.0	80.0	110.0	110.0	54.0	36.0	22.0	24.0	28.0	22.0	570.0
1906	12.0	15.0	37.0	77.0	184.0	125.0	88.0	49.0	34.0	43.0	32.0	26.0	722.0
1907	14.0	17.0	49.0	180.0	130.0	190.0	205.0	75.0	48.0	38.0	30.0	23.0	999.0
1908	13.0	17.0	51.0	76.0	90.0	88.0	59.0	50.0	36.0	40.0	26.0	21.0	567.0
1909	12.0	16.0	42.0	135.0	250.0	190.0	75.0	50.0	53.0	40.0	26.0	22.0	911.0
1910	12.0	15.0	70.0	125.0	130.0	84.0	10.0	23.0	20.0	21.0	28.0	21.0	559.0
1911	20.0	17.0	48.0	76.0	110.0	97.0	100.0	46.0	37.0	60.0	62.0	32.0	705.0
1912	13.0	17.0	48.0	75.0	230.0	110.0	82.0	42.0	31.0	30.0	27.0	21.0	726.0
1913	12.0	16.0	39.0	75.0	90.0	80.0	40.0	17.0	23.0	38.0	29.0	22.0	481.0
1914	12.0	17.0	48.0	77.0	112.0	96.0	90.0	53.0	51.0	42.0	30.0	22.0	649.0
1915	12.0	16.0	45.0	83.0	98.0	210.0	75.0	47.0	32.0	30.0	26.0	23.0	697.0
1916	13.0	17.0	58.0	79.0	99.0	140.0	76.0	55.0	34.0	50.0	33.0	25.0	679.0
1917	13.0	17.0	43.0	77.0	96.0	108.0	92.0	35.0	25.0	24.0	27.0	22.0	579.0
1918	11.0	16.0	44.0	60.0	91.0	85.0	63.0	27.0	41.0	27.0	27.0	24.0	516.0
1919	12.0	16.0	47.0	80.0	100.0	92.0	90.0	49.0	30.0	34.0	29.0	25.0	604.0
1920	13.0	20.0	47.0	75.0	260.0	110.0	91.0	44.0	32.0	33.0	30.0	24.0	779.0
1921	13.0	17.0	49.0	63.0	95.0	105.0	82.0	59.0	42.0	32.0	29.0	25.0	611.0
1922	14.0	17.0	46.0	72.0	97.0	97.0	70.0	21.0	13.0	16.0	35.0	35.0	533.0
1923	13.0	17.0	41.0	70.0	100.0	95.0	58.0	48.0	47.0	47.0	34.0	26.0	596.0
1924	13.0	19.0	42.0	86.0	110.0	92.0	55.0	31.0	23.0	29.0	42.0	41.0	583.0
1925	30.0	17.0	46.0	76.0	80.0	48.0	58.0	57.0	32.0	38.0	30.0	26.0	538.0
1926	20.0	40.0	68.0	77.0	110.0	105.0	50.0	21.0	22.0	23.0	46.0	24.0	606.0
1927	12.0	17.0	44.0	77.0	180.0	93.0	165.0	43.0	50.0	47.0	32.0	26.0	756.0
1928	14.0	17.0	46.0	70.0	100.0	85.0	25.0	70.0	15.0	18.0	32.0	21.0	513.0
1929	13.0	16.0	43.0	73.0	97.0	91.0	52.0	60.0	50.0	45.0	32.0	26.0	598.0
1930	14.0	18.0	42.0	78.0	88.0	75.0	64.0	45.0	25.0	37.0	27.0	23.0	536.0
1931	12.0	17.0	43.0	63.0	83.0	38.0	24.0	23.0	36.0	37.0	26.0	23.0	425.0
1932	12.0	18.0	52.0	95.0	136.0	90.0	90.0	38.0	27.0	28.0	28.0	23.0	637.0
[illegible]	12.0	16.0	42.0	57.0	90.0	92.0	47.0	30.0	27.0	26.0	25.0	23.0	437.0
	12.0	17.0	36.0	62.0	45.0	17.0	14.0	17.0	22.0	20.0	19.0	20.0	301.0
	12.0	16.0	29.0	55.0	92.0	98.0	72.0	50.0	37.0	34.0	29.0	23.0	547.0
mean	12.7	16.7	45.0	83.8	109.8	94.4	65.1	38.6	33.3	32.8	29.8	23.6	585.6

TABLE 23.—*Estimated tributary inflow to the Middle Valley, Otowi Bridge to San Marcial*

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890	8.0	9.0	34.0	12.0	30.0	62.0	22.0	31.0	23.0	1.0	8.0	14.0	254.0
1891	7.0	36.0	104.0	68.0	400.0	130.0	45.0	16.0	84.0	37.0	6.0	5.0	938.0
1892	9.0	16.0	24.0	33.0	117.0	41.0	46.0	1.0	2.0	0	3.0	6.0	298.0
1893	14.0	12.0	17.0	10.0	47.0	7.0	3.0	0	0	0	0	13.0	123.0
1894	5.0	13.0	26.0	64.0	44.0	30.0	18.0	0	3.2	54.0	0	7.0	264.2
1895	10.0	37.0	91.7	21.0	34.0	52.0	125.0	138.9	13.0	11.9	5.7	17.2	557.4
1896	15.1	20.6	6.6	58.0	47.0	8.0	32.4	8.4	7.9	42.3	6.8	29.1	282.2
1897	1.8	9.2	22.0	15.0	158.0	100.0	44.7	6.7	105.5	195.0	136.1	143.8	937.8
1898	46.0	48.5	59.8	85.0	58.0	7.0	95.0	10.6	3.4	.1	6.6	7.2	427.2
1899	11.9	5.0	6.3	8.1	7.0	1.3	30.8	7.2	1.8	.1	6.5	6.6	92.6
1900	15.8	17.8	20.4	4.8	7.0	77.0	.8	0	17.5	.3	3.1	2.1	166.6
1901	6.6	5.0	6.5	7.3	33.0	50.2	61.5	56.7	31.1	12.8	15.6	10.7	297.0
1902	4.1	4.2	5.3	12.5	20.2	6.2	.3	48.0	9.5	.6	4.2	8.1	123.2
1903	4.1	10.2	16.6	6.0	11.0	61.0	26.8	3.5	1.1	.7	2.3	13.3	156.6
1904	5.9	7.7	8.8	.7	.8	0	11.4	14.0	41.7	270.0	32.4	28.4	421.8
1905	7.6	29.3	115.0	160.0	287.0	251.0	36.1	17.4	4.1	5.3	32.4	18.4	943.6
1906	12.5	19.7	47.9	65.0	30.0	25.0	51.0	9.2	5.5	12.8	31.8	58.1	368.5
1907	17.6	32.7	37.5	18.0	11.0	44.0	49.0	13.0	90.0	33.5	32.5	26.7	405.5
1908	12.6	17.0	20.4	50.0	45.0	28.6	48.0	48.7	.7	.8	20.9	28.4	320.0
1909	14.6	10.3	33.6	4.0	16.0	24.0	28.4	12.9	30.0	18.5	36.5	28.3	256.1
1910	35.9	25.7	14.0	10.0	13.0	17.1	.1	8.2	3.0	.6	3.1	11.9	142.6
1911	2.5	11.2	43.5	18.5	6.0	27.0	142.0	39.7	11.9	37.0	46.0	11.5	396.8
1912	14.7	18.6	30.7	84.0	81.0	46.0	79.0	11.8	.3	.8	16.3	18.5	316.7
1913	1.6	18.2	26.4	28.1	39.0	63.1	9.1	.4	2.1	21.2	14.9	11.7	234.8
1914	9.2	14.3	23.5	23.0	6.0	48.0	110.0	22.2	.8	32.2	17.2	25.6	332.0
1915	8.2	14.0	23.2	130.0	82.0	36.0	103.5	22.0	6.5	3.1	13.2	19.7	403.4
1916	16.7	14.5	28.0	47.0	36.0	31.0	22.2	30.8	2.7	47.0	26.3	18.3	301.5
1917	16.5	12.4	17.0	8.6	22.0	20.0	70.0	3.5	4.9	.2	4.1	15.2	196.4
1918	6.2	6.2	21.8	19.1	23.0	16.2	19.9	2.3	0	7.0	11.3	20.2	153.3
1919	10.7	17.8	36.4	80.0	17.0	58.0	200.0	41.9	.9	14.0	15.4	26.0	518.1
1920	15.8	30.7	45.4	72.0	76.0	365.0	83.0	28.2	.6	1.0	13.6	15.5	643.8
1921	12.9	14.4	28.8	88.1	52.0	82.0	180.0	25.0	9.2	10.5	16.9	26.7	493.5
1922	19.0	15.6	26.8	46.5	40.0	30.0	37.6	.3	0	.1	.1	5.5	230.5
1923	9.6	10.2	36.2	30.5	8.0	85.0	28.6	44.1	80.0	8.6	40.5	24.2	354.5
[illegible]	24.4	35.7	58.4	125.0	84.0	22.0	40.6	7.0	2.3	.5	4.3	6.7	369.9
	1.3	4.7	7.8	22.2	14.9	2.6	10.6	3.5	18.4	2.9	8.6	13.0	111.5
	15.4	31.5	51.4	20.0	106.0	42.0	28.2	2.5	3.3	1.3	20.4	17.1	338.1

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TABLE 23.—*Estimated tributary inflow to the Middle Valley, Otowi Bridge to San Marcial*—Continued

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Ann.
1927	15.6	9.8	12.7	34.0	31.0	37.0	133.0	55.5	82.0	21.0	21.2	20.8	473.6
1928	12.9	14.9	20.6	13.8	4.0	56.0	6.9	54.8	4.7	0	3.7	18.1	210.4
1929	3.8	7.3	22.5	31.8	25.0	39.0	38.5	173.0	210.0	64.0	42.2	28.0	685.1
1930	10.6	11.8	45.6	41.0	57.0	40.9	77.7	30.8	2.9	.6	3.9	19.0	341.8
1931	14.6	16.4	28.5	44.8	51.8	4.6	10.4	7.3	37.0	20.6	16.1	24.4	285.5
1932	16.5	19.4	20.2	3.0	30.0	6.0	104.0	57.2	7.9	9.7	14.4	19.7	308.0
1933	14.9	16.1	30.0	14.8	7.5	150.0	38.3	37.7	16.0	11.7	17.3	28.5	382.8
1934	19.7	16.8	18.8	21.4	6.0	.9	.5	34.2	24.6	1.5	1.2	19.5	165.1
1935	22.7	23.8	23.3	20.7	73.0	103.0	19.7	73.9	37.8	16.6	25.1	36.0	475.6
46-year mean	12.7	17.2	31.4	36.5	48.8	50.1	51.7	27.1	22.0	22.6	17.6	21.0	358.7

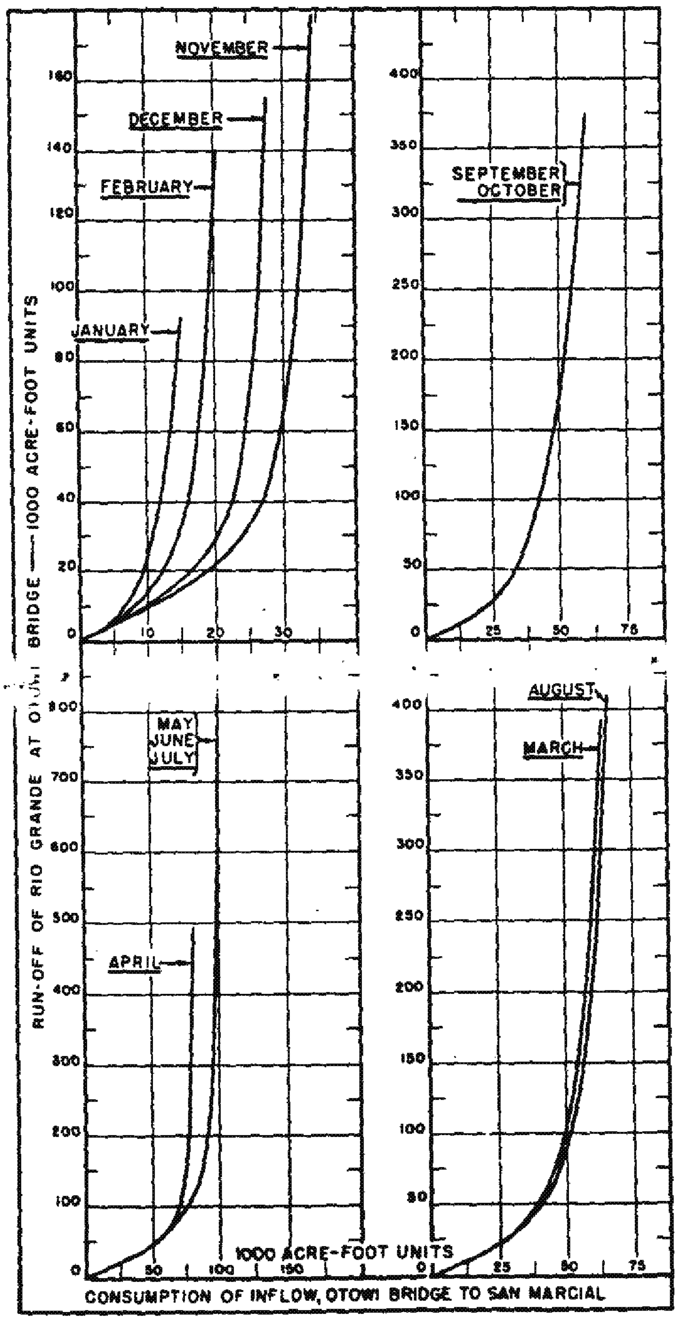

FIGURE 17.—Relation of Otowi Bridge flow to consumption of Middle Valley inflow, Otowi Bridge to San Marcial. For months of January to December 1890-1935.

annual side inflow, 1890 to 1935, of 358,700 acre-feet. These data give a very poor correlation with available records of flow at gaging stations on tributary streams, but the latter are very incomplete and meager. A fair correlation is indicated with the mean annual water production as previously developed for the southern unit of the Middle section (see table 199 in Appendix B), after the latter is corrected for the irrigation consumption on the tributary streams. Many inconsistencies appear in a comparison by individual years.

In order to smooth the effect of annual irregularities and to bring out more clearly the relation between and general trend over the years of the total inflow, Otowi Bridge to San Marcial, its consumption and the residual flow at San Marcial, progressive 5-year weighted means of these quantities were computed and plotted in figure 18. The curve designated "available inflow" was made up from the sum of the Rio Grande flow at Otowi Bridge and the estimated side inflow as given by table 23. The "consumption of inflow" curve was derived from the figures of table 22, and the curve of "residual flow at San Marcial" from those of table 161 in Appendix A. No marked long-time trend in consumption of inflow is exhibited. Rather, it is indicated that little change in this consumption, except that due to variation in the water supply, has occurred since 1890.

Because of the uncertainty with respect to tributary inflow, past stream-flow depletion in the Middle Valley is, as previously indicated, highly indeterminate. The method employed herein to estimate it involves selections which are more or less a matter of individual judgment. Because of the unfortunate lack of basic data there is, however, no method of approaching this determination which does not rely to some extent on the judgment of the investigator. If the effect upon the Elephant Butte-Fort Quitman section of present and given future conditions of irrigation development in the San Luis and Middle sections is to be determined upon the basis of stream flow in the past, it is indispensable that some knowledge or estimate of past depletion be available so that the past San Marcial flows can be modified by the differentials between the past and present or future depletion. The estimate

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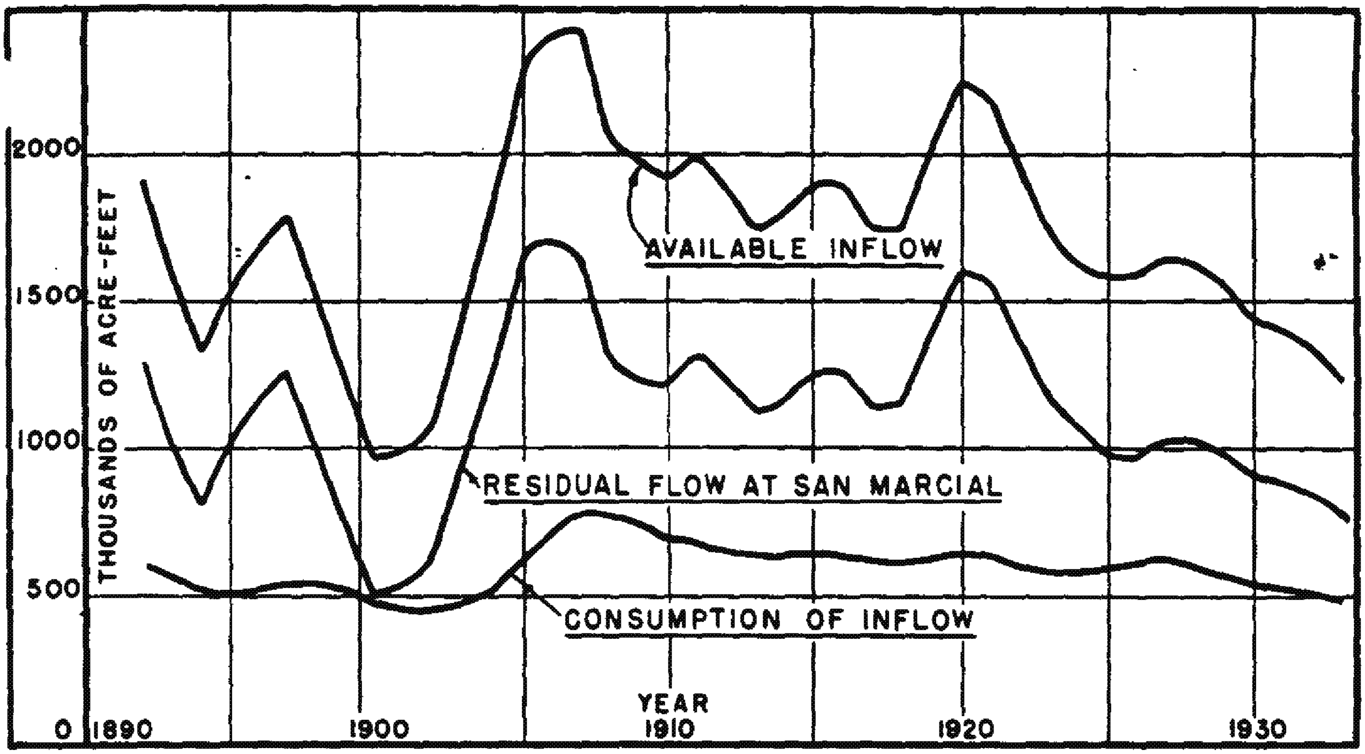

FIGURE 18.—Available inflow, consumption of inflow, and residual flow at San Marcial, Middle Rio Grande Valley, Otowi Bridge to San Marcial, 1890-1935. (Available inflow is Rio Grande flow at Otowi Bridge plus estimated side inflow, Otowi Bridge to San Marcial. Curves are plotted from progressive 5-year weighted means of annual data.)

herein of past depletion in the Middle Valley was derived to meet this particular requirement of analysis. Although subject to relatively wide variation in derivation because of the indeterminate character of available data, this estimate is believed to approach within reasonable limits the actual consumption of inflow which occurred, and to be adequate for purposes of analysis if, based thereon, a reasonably wide latitude is maintained in determining the sufficiency of water supplies or additional requirements for water. The estimate is not, however, considered to be sufficiently close, nor is it thought possible with available data to derive an estimate which would be sufficiently close, to permit of exact or even close deductions with respect, for example, to the effect on the regimen of the river of the works and operations of the Middle Rio Grande Conservancy District, or to the effect of certain conditions obtaining in particular years.

Deduced San Marcial Flow.—In the preceding derivations the San Marcial flow used was that published by the Geological Survey and given in table 161 in Appendix A. In a number of reports a question has been raised concerning the accuracy of portions of the San Marcial record. In order to check the record, at least for large discrepancies, a study was made to estimate the inflow to Elephant Butte Reservoir at San Marcial, using the records of reservoir storage, releases, evaporation, and rainfall available since January 1915. The records of releases and evaporation used are given in tables 187 and 123, respectively, in Appendix A. Monthly change in storage was computed from a compilation furnished by the Bureau of Reclamation showing storage on hand on the first day of each month. These storage figures, shown to the nearest thousand acre-feet in table 24, have been corrected for reductions in reservoir capacity due to accumulations of silt from September 1925 to December 1934, inclusive, in accordance with the silt survey of September 1925, and from January to December 1935, in accordance with the April 1935 survey.

Evaporation was computed by applying a correction factor of 0.687 to the Standard Weather Bureau class A pan record at Elephant Butte Dam covering the periods 1915 to 1925 and July 1933 to June 1936. This factor for reduction of pan to reservoir evaporation is derived from the Rohwer experiments as reported in Technical Bulletin No. 271, December 1931, of the Department of Agriculture. In averaging the pan records, those for the period January 1926 to June 1933 were not used since it was indicated that evaporation was then affected by shade from trees near the pan. The correction factor applied to the averaged pan records gave the monthly values for reservoir evaporation listed in table 25. Using a tabulation of mean monthly storage content furnished by the Bureau of Reclamation, the computed rates of evaporation were applied to the mean reservoir surface area for each month as determined from area capacity relations

TABLE 24.—*Storage in Elephant Butte Reservoir*

Content on the first of the month. Unit 1,000 acre-feet

Year	January	February	March	April	May	June	July	August	September	October	November	
1915	....	9	17	61	202	452	496	515	442	375	359	358
1916	359	404	406	491	608	896	880	795	806	752	887	942
1917	864	818	752	676	661	769	995	964	848	731	607	561
1918	535	562	528	500	447	458	424	351	277	203	190	187
1919	223	257	262	296	533	934	975	1,112	1,079	989	990	1,000
1920	1,041	1,069	1,120	1,119	1,145	1,640	2,093	2,058	1,953	1,819	1,751	1,744
1921	1,729	1,753	1,732	1,707	1,628	1,894	2,077	2,091	2,081	1,972	1,877	1,830
1922	1,826	1,840	1,811	1,771	1,707	1,880	1,990	1,852	1,697	1,619	1,487	1,461
1923	1,441	1,461	1,450	1,427	1,358	1,504	1,522	1,382	1,365	1,380	1,418	1,507
1924	1,565	1,596	1,593	1,573	1,826	2,205	2,141	2,031	1,842	1,760	1,719	1,682
1925	1,671	1,662	1,645	1,582	1,524	1,435	1,302	1,170	1,088	1,052	1,073	956
1926	985	1,020	1,033	1,031	1,045	1,331	1,413	1,326	1,196	1,115	1,098	1,079
1927	1,098	1,125	1,123	1,081	1,089	1,259	1,273	1,267	1,194	1,286	1,347	1,368
1928	1,387	1,410	1,418	1,376	1,273	1,424	1,379	1,221	1,104	1,007	979	971
1929	983	996	990	962	901	1,079	1,070	996	1,155	1,360	1,461	1,505
1930	1,541	1,568	1,575	1,553	1,605	1,599	1,520	1,471	1,384	1,286	1,257	1,254
1931	1,273	1,307	1,336	1,291	1,241	1,217	1,091	966	873	860	892	888
1932	924	964	1,002	1,036	1,172	1,517	1,596	1,578	1,487	1,389	1,381	1,381
1933	1,395	1,432	1,434	1,395	1,273	1,213	1,392	1,294	1,181	1,119	1,108	1,125
1934	1,130	1,166	1,151	1,096	998	894	767	635	518	492	494	493
1935	470	506	528	506	436	496	673	580	568	582	601	633

From records of Rio Grande Project, U. S. Bureau of Reclamation.

NOTE.—In the figures up to September 1925 no correction has been made for reduction in reservoir capacity due to silt accumulations. In the figures from September 1925 to December 1934, inclusive, corrections have been made in accordance with the silt survey of September 1925 and from January to December 1935 in accordance with the survey of April 1935.

shown by the original survey for the period January 1915 to August 1925, by the 1925 silt survey for the period September 1925 to December 1934, and by the 1935 silt survey for the period January to December 1935, to derive the total monthly evaporation in acre-feet.

TABLE 25.—*Evaporation from Elephant Butte Reservoir*

[Average monthly evaporation in feet]

Month	Evaporation	Month	Evaporation
January	0.16	August	0.64
February	.26	September	.54
March	.46	October	.46
April	.54	November	[illegible]
May	.40	December	[illegible]
June	.37		
July	.75	Total	6.00

Derived by application of coefficient of 0.687 to average of Weather Bureau class A evaporation pan records at Elephant Butte Dam, 1915 to 1925 and July 1933 to June 1936.

Rainfall accretion to the reservoir was determined similarly by applying to its mean water-surface area for each month the corresponding monthly precipitation at the Elephant Butte Dam station.

In Appendix B the tributary run-off of the San Marcial-Elephant Butte unit is developed from precipitation data by comparison to the precipitation-run-off relations found for the Elephant Butte-Leasburg and Leasburg-El Paso units. The run-off so derived, shown in column 4 of table 202, less the flow of Alamosa River which is used in irrigation, was taken in the present study as representing the arroyo inflow to Elephant Butte Reservoir. Monthly distribution of the annual inflows was based upon the corresponding distribution of precipitation at the stations used for this unit.

An estimate of reservoir seepage was made by comparing the total visible surface inflow as given by the data of storage changes, releases, evaporation, rainfall, and arroyo inflow to the measured inflow at San Marcial for the period January 1926 to May 1934. With the exception of 1 month in 1929 and 3 months in 1932, the recorded San Marcial flow appeared to be more uniformly consistent with the estimated inf[illegible] as derived by this study and hence to be a com[illegible] tively good record. The reservoir content at [illegible] beginning and end of this period was practically the same, so that the effect of bank storage and release was eliminated. For the 101 months of the period, the total difference, attributable to seepage, amounted to 559,000 acre-feet, or an average of 5,540 acre-feet per month. A seepage correction of 6,000 acre-feet per month, April to September, and 5,000 acre-feet per month, October to March, or a total of 66,000 acre-feet per year, was applied throughout the period of record. For the years when the reservoir first filled this correction is probably too small but no attempt was made to allow for this priming.

The monthly inflow at San Marcial, 1915 to 1935, as estimated by this study, is shown in table 26, and is to be compared with the recorded inflow as given in table 161 in Appendix A. A comparison of the annual inflow as estimated and as recorded is shown in table 27. These comparisons reveal wide discrepancies in certain months, particularly during the flood season. Small differences may be attributed to incorrect estimates of arroyo inflow, to variation in monthly rate of seepage including bank storage and release, or to small errors in the measurements of one or more of the various records involved. Analysis of the major discrepan[illegible] indicates that measurements of inflow at San Mar[illegible]

Table 26.—*Estimated inflow to Elephant Butte Reservoir at San Marcial*

[Computed from data of storage changes, releases, evaporation, rainfall, and estimated seepage and arroyo inflow, for comparison with recorded San Marcial flow, table 161. Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1915	14	13	62	262	403	301	63	28	0	15	21	32	1,214
1916	53	53	164	223	456	196	19	79	19	209	121	45	1,639
1917	56	50	45	103	249	386	173	13	2	0	15	34	1,126
1918	33	26	59	51	119	74	27	6	2	24	24	42	487
1919	41	34	96	314	541	171	231	60	0	22	36	53	1,608
1920	47	84	77	134	653	597	111	28	0	2	42	32	1,807
1921	37	28	80	28	201	532	146	133	33	6	25	32	1,281
1922	37	39	52	68	329	267	14	4	53	0	15	25	903
1923	41	34	47	56	396	180	11	94	110	98	109	74	1,150
1924	42	67	62	400	567	119	30	0	28	13	0	21	1,349
1925	6	38	43	102	58	19	7	25	26	42	0	48	414
1926	44	42	71	137	412	240	24	0	7	4	8	35	1,024
1927	41	44	36	142	322	165	150	62	181	111	50	39	1,343
1928	43	50	47	41	262	111	0	9	7	7	9	26	612
1929	32	31	50	78	273	132	13	219	279	109	60	52	1,328
1930	37	51	68	191	122	64	88	46	0	4	18	37	726
1931	43	56	45	51	100	19	12	8	60	63	22	48	527
1932	47	72	111	268	475	236	135	52	3	17	31	33	1,480
1933	46	44	51	12	72	300	46	33	42	18	42	33	739
1934	46	50	29	29	17	12	16	26	57	10	13	0	305
1935	42	37	32	28	150	305	50	110	64	38	47	51	951

during flood stages are probably more inaccurate than measurements of reservoir release or content, and that the former measurements are usually high. These large differences are most frequent in the years 1919 to 1924 and in 1932. In 1921 they are to be noted in almost every month. Comparison of the recorded and deduced inflows for the months when it appears probable that the former may be considerably in error is given in table 28.

There are indications in some months of errors also in the records other than those at San Marcial. The monthly differences which show these are, with few exceptions, under 10,000 acre-feet. In some cases a negative San Marcial inflow is shown, and in others a small inflow is shown when the recorded flow is zero. Comparison of the recorded and deduced inflows for the months when differences exceeding 10,000 acre-feet indicate the probability of errors in records other than those at San Marcial is given in table 29.

Table 27.—*Comparison of estimated and recorded inflow to Elephant Butte Reservoir at San Marcial*

[Estimated inflow derived from data of storage changes, releases, evaporation, rainfall, and estimated seepage and arroyo inflow. Unit 1,000 acre-feet]

Year	Recorded inflow	Estimated inflow	Difference
1915	1,354	1,214	−140
1916	1,649	1,639	−10
1917	1,055	1,126	+71
1918	411	487	+76
1919	1,579	1,608	+29
1920	2,222	1,807	−415
1921	1,625	1,281	−344
1922	963	903	−60
1923	1,224	1,150	−74
1924	1,438	1,349	−89
1925	419	414	−5
1926	1,047	1,024	−23
1927	1,349	1,343	−6
1928	591	612	+21
1929	1,465	1,328	−137
1930	731	726	−5
1931	490	527	+37
1932	1,400	1,480	+80
1933	716	739	+23
1934	244	305	+61
1935	1,030	954	−76
Mean	1,095	1,048	−47

It is difficult from this study to point out specific months or periods when the difference between recorded

Table 28.—*Comparison of deduced and recorded flow at San Marcial for months when recorded flow is indicated to be in error*

[Unit 1,000 acre-feet]

Year and month	Recorded flow	Deduced flow	Departure of recorded from deduced flow
1919			
May	487	541	−34
1920			
June	863	597	+266
July	176	111	+65
			+331
1921			
February	44	28	+16
April	44	28	+16
May	216	201	+15
June	649	532	+117
July	206	146	+60
August	158	133	+25
September	62	33	+29
October	26	6	+20
November	38	25	+13
December	55	32	+23
			+334
1922			
January	58	37	+21
February	49	39	+10
March	57	52	+5
April	82	68	+14
May	344	329	+15
June	311	267	+44
July	50	14	+36
			+145
1923			
June	221	180	+41
1924			
June	134	119	+15
July	50	30	+20
			+35
1929			
August	275	219	+56
1932			
April	235	268	−33
May	431	475	−44
June	212	236	−24
			−101
Total	5,533	4,746	+787

TABLE 29.—*Comparison of deduced and recorded flow at San Marcial for months when records other than San Marcial are indicated to be in error*

[Unit 1,000 acre-feet]

Year and month	Recorded flow	Deduced flow	Departure of recorded from deduced flow
1919			
September	7	−14	+21
1920			
September	6	−12	+18
1922			
September	0	53	−53
October	0	−57	+57
November	0	15	−15
1925			
June	4	19	−15
November	40	−97	+137
1934			
June	0	12	−12
July	0	16	−16
Total	57	−65	+122

and deduced San Marcial flows may be considered a definite reflection on the accuracy of the San Marcial record. It appears, however, that for the months and periods given in table 28 there is some justification for questioning the San Marcial record and for substituting, in these months and periods, the deduced flow.

Middle Valley Depletion and Tributary Inflow Using Deduced San Marcial Flow.—Following the procedure previously outlined for estimating the past consumption of inflow and the tributary inflow, Otowi Bridge to San Marcial, new values were derived using the deduced San Marcial flow for the months and periods given in table 28. The changes in the consumption and side inflow estimates are indicated in table 30. This shows a total increase in the consumption figures for the corrected periods of 194,000 acre-feet and a total reduction in the tributary inflow figures of 572,900 acre-feet. The correspondingly revised 46-year means for consumption and tributary inflow are given in table 31.

Comparison of the mean annual figures for consumption of inflow and for tributary inflow, Otowi Bridge to San Marcial, as derived by use of the recorded San Marcial flow (tables 22 and 23), with those obtained by use of the deduced flow for San Marcial (table 31) shows a difference of 4,200 acre-feet for the consumption means and 12,500 acre-feet for the tributary inflow means. The relative insignificance of these differences, coupled with the uncertainties entering into the derivation of both the consumption of inflow and the deduced San Marcial flow, appears to give little justification for using the latter or any of the deductions not based on the recorded San Marcial flow.

Correction of Past Flow at Otowi Bridge and San Marcial.—Since there is relatively little irrigation from Rio Grande between the Lobatos and Otowi Bridge

TABLE 30.—*Estimated consumption of inflow and tributary inflow, Otowi Bridge to San Marcial, corrected for deduced San Marcial flow*

[Unit 1,000 acre-feet]

Year and month	Estimated consumption of inflow using San Marcial flow			Estimated tributary inflow using San Marcial flow		
	As recorded	As deduced	Correction	As recorded	As deduced	Correction
1919						
May	100.0	99.0	−1.0	17.0	70.0	+53.0
1920						
June	110.0	160.0	+50.0	268.0	52.0	−216.0
July	91.0	100.0	+9.0	83.0	27.0	−56.0
			+59.0			−272.0
1921						
February	17.0	23.0	+6.0	14.4	3.9	−10.5
April	63.0	63.0	0	35.1	18.7	−16.4
May	95.0	95.0	0	52.0	47.0	−5.0
June	105.0	190.0	+85.0	82.0	50.0	−32.0
July	82.0	82.0	0	180.0	120.0	−60.0
August	59.0	72.0	+13.0	25.0	13.0	−12.0
September	42.0	70.0	+28.0	9.2	8.3	−.9
October	32.0	42.0	+10.0	10.5	.6	−9.9
November	29.0	29.0	0	16.9	4.2	−12.7
December	25.0	28.0	+3.0	28.7	8.5	−20.2
			+145.0			−179.6
1922						
January	14.0	18.0	+4.0	19.0	1.5	−17.5
February	17.0	17.0	0	15.6	5.8	−9.8
March	46.0	46.0	0	26.8	21.9	−4.9
April	72.0	72.0	0	46.5	33.0	−13.5
May	97.0	97.0	0	40.0	25.0	−15.0
June	97.0	115.0	+18.0	39.0	13.0	−26.0
July	70.0	82.0	+12.0	37.6	14.0	−23.6
			+34.0			−110.3
1923						
June	95.0	95.0	0.0	55.0	14.0	−4[illegible]
1924						
June	92.0	95.0	+3.0	22.0	10.0	−12.0
July	55.0	55.0	0	49.6	29.6	−20.0
			+3.0			−32.0
1929						
August	60.0	60.0	0	173.0	117.0	−56.0
[illegible]32						
April	45.0	30.0	−15.0	3.0	21.0	+18.0
May	136.0	99.0	−37.0	30.0	47.0	+17.0
June	90.0	96.0	+6.0	6.0	36.0	+30.0
			−46.0			+65.0
Total	1,886.0	2,080.0	+194.0	1,382.9	810.0	−572.9

TABLE 31.—*Estimated mean consumption of inflow and mean tributary inflow, Otowi Bridge to San Marcial, 1890–1935, using deduced San Marcial flow*

[Deduced flow used for periods shown by table 28]

Month	46-year means in acre-feet	
	Consumption of inflow	Tributary inflow
January	12,800	12,300
February	16,800	16,800
March	45,000	31,300
April	83,500	36,200
May	109,000	49,900
June	97,900	43,600
July	65,600	48,300
August	38,900	25,600
September	33,900	22,000
October	33,000	22,400
November	29,800	17,300
December	23,600	30,600
Annual	589,800	346,20[illegible]

gaging stations and since the river is confined to a narrow canyon for much of the intervening distance, it was considered that corrections to past flow for present development in the San Luis section as applied to the Lobatos record should be applicable, without change, to the Otowi Bridge record. The corrections of table 17 were therefore applied to the Otowi Bridge run-off given by table 158 in Appendix A to derive the figures of table 32.

In order to carry the corrections for present development through to San Marcial, it became necessary to take into account the relation between Otowi Bridge flow and the Middle Valley consumption of inflow as previously developed and shown by the curves of figure 17. These curves were first entered with the recorded Otowi Bridge flow (table 158) and then with the corresponding Otowi Bridge flow corrected for present San Luis Valley development (table 32). The difference between the two curve values so obtained gave corrections which were applied to the Middle Valley consumption figures of table 22 to give those of table 33, "Estimated consumption of inflow to the Middle Valley, Otowi Bridge to San Marcial, under present irrigation development in San Luis Valley." In these new consumption values, adjustment was made where necessary to conform to the total available inflow; that is, the new Otowi Bridge flow plus side inflow. The corrections for San Luis Valley development given by table 17, less the corresponding change in Middle Valley consumption given by the difference between the values of tables 22 and 33, gave the corrections which were applied to the San Marcial record (table 161, Appendix A) to derive the figures of table 34, "Estimated run-off of Rio Grande at San Marcial, N. Mex., under present irrigation development in San Luis Valley."

Return Water

In the main river valleys of the upper basin a supply of considerable magnitude is water which, once diverted for irrigation, returns to the stream as direct drainage or as inflow from the ground-water basin. This "return water" has its source (1) in losses from canals or other conduits during conveyance of water from points of

TABLE 32.—*Estimated run-off of Rio Grande at Otowi Bridge, N. Mex., under present irrigation development in San Luis Valley*

[Drainage area 11,303 square miles.[1] Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890	33.0	35.0	72.0	268.0	602.0	245.0	87.0	62.0	38.0	38.0	45.0	52.0	1,577.0	126.1
1891	41.0	44.0	99.0	305.0	616.0	314.0	116.0	69.0	34.0	115.0	51.0	51.0	1,855.0	148.3
1892	39.0	46.0	102.0	376.0	515.0	196.0	41.0	15.0	8.0	19.0	31.0	24.0	1,411.0	112.8
1893	25.0	29.0	30.0	180.0	348.0	166.0	27.0	18.0	20.0	33.0	31.0	26.0	933.0	74.6
1894	26.0	26.0	48.0	118.0	222.0	38.0	17.0	22.0	22.0	10.0	43.0	49.0	641.0	51.2
1895	32.0	31.8	93.3	302.0	260.0	221.0	82.0	65.1	31.0	36.1	48.6	51.8	1,254.7	100.3
1896	35.9	37.5	87.2	182.0	155.0	28.8	23.3	13.9	23.8	31.3	39.6	35.0	693.3	55.4
1897	35.7	35.1	90.8	279.0	517.0	368.0	72.3	25.4	57.5	196.0	39.9	51.2	[illegible]	142.2
1898	[illegible]	[illegible]	[illegible]	33.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1899	[illegible]	[illegible]	[illegible]	52.0	[illegible]	[illegible]	37.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1900	35.8	31.3	55.8	44.5	202.0	128.0	19.3	10.1	42.6	28.8	34.3	27.0	659.5	52.7
1901	23.4	33.5	41.6	84.4	287.0	110.0	42.8	49.8	36.5	32.2	41.5	31.5	814.2	65.1
1902	29.6	27.2	33.7	98.6	68.6	25.2	16.7	34.2	28.8	21.2	26.4	27.2	435.4	34.8
1903	26.1	29.7	84.2	172.0	380.0	548.0	107.0	26.6	27.3	26.8	32.2	27.6	1,487.5	118.9
1904	20.9	26.2	29.3	35.3	30.2	17.0	15.1	93.0	159.0	303.0	53.4	35.4	817.8	65.4
1905	40.5	48.6	139.0	201.0	613.0	425.0	52.7	35.7	23.2	27.0	42.0	38.9	1,686.6	134.8
1906	32.0	32.0	82.0	158.0	602.0	389.0	122.0	66.0	50.0	101.0	77.0	52.0	1,733.0	138.6
1907	50.0	46.0	97.0	339.0	410.0	509.0	455.0	173.0	74.0	46.0	50.0	44.0	2,293.0	183.3
1908	47.0	52.0	96.0	136.0	202.0	130.0	54.0	74.0	35.0	31.0	32.0	32.0	921.0	73.6
1909	36.0	37.0	55.0	211.0	479.0	365.0	86.7	75.8	145.0	53.2	29.1	62.5	1,635.3	130.8
1910	36.4	33.3	183.0	258.0	351.0	116.0	13.0	20.1	20.0	21.0	37.8	36.3	1,125.9	90.0
1911	43.7	37.5	95.6	147.0	408.0	277.0	273.0	53.5	48.3	478.0	128.0	90.5	2,080.1	166.3
1912	43.6	44.8	91.7	120.0	675.0	426.0	118.0	45.0	33.3	28.2	34.3	27.5	1,687.4	134.9
1913	35.8	35.9	41.9	124.0	169.0	87.0	40.8	17.8	26.8	41.9	50.3	62.2	733.4	58.6
1914	45.9	47.8	87.4	156.0	321.0	178.0	132.0	80.0	56.3	82.3	49.0	34.4	1,279.1	102.3
1915	34.0	42.0	69.0	218.0	424.0	439.0	80.5	58.2	32.4	31.9	34.4	36.7	1,509.1	120.7
1916	42.1	46.6	191.0	250.0	500.0	347.0	124.5	99.0	40.7	181.0	81.8	55.6	1,959.3	156.6
1917	38.1	46.5	62.8	145.0	271.0	465.0	222.0	30.6	23.8	17.8	25.4	28.2	1,374.2	109.9
1918	28.7	26.6	58.8	69.4	189.0	143.0	60.5	26.4	34.0	28.0	41.0	43.5	749.9	60.0
1919	36.7	38.6	82.2	261.0	475.0	180.0	146.0	79.9	35.1	48.3	49.6	60.1	1,492.5	119.3
1920	46.5	74.7	81.8	125.0	838.0	626.0	181.0	54.7	31.3	32.7	49.5	39.4	2,180.6	174.4
1921	34.1	44.1	80.0	60.3	237.0	471.0	108.0	166.0	72.7	28.4	41.8	51.5	1,403.9	112.2
1922	45.5	49.2	77.1	99.0	416.0	309.0	61.0	27.7	14.5	15.9	39.9	44.2	1,199.0	95.9
1923	42.3	45.9	59.8	89.4	424.0	227.0	71.2	62.0	102.0	116.0	91.5	77.0	1,408.1	112.6
1924	44.6	46.5	42.5	306.0	590.0	205.0	56.4	30.2	22.6	26.5	34.5	50.4	1,463.2	117.0
1925	48.1	45.1	73.6	147.0	124.0	63.0	54.7	68.8	47.6	81.1	60.7	67.6	881.3	70.5
1926	46.8	36.6	58.6	159.0	428.0	315.0	51.0	21.1	21.6	25.9	31.5	40.3	1,235.4	98.8
1927	33.1	34.1	67.7	175.0	461.0	224.0	139.0	50.3	167.0	127.0	78.1	63.1	1,619.4	129.5
1928	49.7	48.1	65.1	84.4	322.0	113.0	34.7	24.6	15.3	21.1	36.6	33.7	838.2	67.0
1929	38.7	44.3	72.5	118.0	346.0	176.0	69.6	162.0	139.0	104.0	58.0	46.4	1,374.5	109.9
1930	48.2	59.1	53.6	215.0	153.0	116.6	82.6	63.3	25.9	39.7	39.1	39.1	915.2	73.2
1931	36.6	43.4	50.1	69.3	134.0	49.5	22.6	22.6	62.0	78.0	43.7	53.5	653.3	52.2
1932	41.2	64.6	139.0	327.0	539.0	266.0	143.0	49.5	29.3	33.1	34.2	37.6	1,693.5	135.4
1933	42.2	39.5	54.5	58.0	186.0	196.0	46.5	31.2	31.2	30.2	38.7	41.7	795.8	63.6
1934	39.2	45.5	54.9	89.1	47.4	15.3	13.5	14.5	22.9	21.4	30.4	28.3	412.4	33.0
1935	34.2	29.3	47.1	68.8	198.0	392.0	113.3	84.1	63.8	51.6	51.1	33.6	1,166.9	93.3
Mean	37.3	40.6	75.2	170.0	350.8	234.4	87.2	53.0	46.4	65.0	46.9	43.9	1,250.7	100.0
Percent of annual	2.98	3.25	6.01	13.59	28.05	18.74	6.97	4.24	3.71	5.20	3.75	3.51	100.0	......

[1] Exclusive of closed basin area, San Luis Valley.

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TABLE 33.—*Estimated consumption of inflow to the Middle Valley, Otowi Bridge to San Marcial, under present irrigation development in San Luis Valley*

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890	11.0	15.0	44.0	119.0	130.0	94.0	79.0	44.0	30.0	39.0	28.0	24.0	657.0
1891	12.0	17.0	50.0	80.0	120.0	99.0	81.0	46.0	29.0	43.0	33.0	28.0	638.0
1892	12.0	17.0	70.0	199.0	103.0	92.0	45.0	15.0	8.0	19.0	28.0	18.0	626.0
1893	10.0	15.0	30.0	109.0	97.0	173.0	30.0	18.0	20.0	28.0	24.0	19.0	[illegible]
1894	11.0	14.0	38.0	73.0	93.0	35.0	19.0	22.0	22.0	12.0	32.0	29.0	[illegible]
1895	11.0	16.0	48.0	79.0	95.0	93.0	77.0	46.0	26.0	29.0	29.0	24.0	573.0
1896	12.0	16.0	48.0	77.0	88.0	27.0	27.0	15.0	22.0	27.0	27.0	22.0	408.0
1897	12.0	16.0	46.0	105.0	105.0	98.0	66.0	26.0	34.0	54.0	32.0	26.0	620.0
1898	11.0	16.0	38.0	79.0	91.0	104.0	79.0	34.0	17.0	23.0	32.0	24.0	548.0
1899	10.0	16.0	59.0	130.0	89.0	29.0	40.0	24.0	51.0	27.0	44.0	23.0	542.0
1900	12.0	15.0	40.0	46.0	94.0	84.0	20.0	10.0	31.0	27.0	30.0	20.0	429.0
1901	10.0	16.0	36.0	67.0	95.0	80.0	46.0	41.0	29.0	27.0	27.0	21.0	495.0
1902	11.0	14.0	31.0	70.0	63.0	25.0	17.0	33.0	25.0	21.0	23.0	20.0	353.0
1903	10.0	14.0	47.0	77.0	99.0	109.0	80.0	27.0	25.0	25.0	25.0	20.0	558.0
1904	10.0	14.0	29.0	35.0	31.0	17.0	16.0	50.0	146.0	62.0	30.0	22.0	462.0
1905	12.0	17.0	53.0	80.0	110.0	109.0	53.0	84.0	22.0	25.0	29.0	22.0	566.0
1906	11.0	15.0	40.0	76.0	183.0	124.0	82.0	45.0	33.0	43.0	32.0	26.0	710.0
1907	13.0	17.0	48.0	179.0	128.0	188.0	205.0	72.0	42.0	33.0	29.0	23.0	977.0
1908	13.0	17.0	50.0	75.0	89.0	84.0	54.0	46.0	32.0	31.0	25.0	21.0	537.0
1909	11.0	16.0	40.0	135.0	249.0	189.0	73.0	47.0	48.0	34.0	26.0	25.0	893.0
1910	12.0	15.0	69.0	124.0	129.0	81.0	12.0	21.0	20.0	21.0	29.0	22.0	555.0
1911	20.0	16.0	48.0	75.0	110.0	95.0	98.0	42.0	33.0	64.0	62.0	33.0	696.0
1912	12.0	17.0	48.0	73.0	230.0	109.0	82.0	39.0	29.0	25.0	26.0	20.0	710.0
1913	12.0	16.0	36.0	73.0	89.0	72.0	43.0	18.0	24.0	31.0	29.0	25.0	468.0
1914	13.0	17.0	47.0	76.0	111.0	90.0	89.0	49.0	46.0	41.0	29.0	22.0	630.0
1915	12.0	16.0	44.0	83.0	96.0	210.0	74.0	44.0	28.0	27.0	26.0	23.0	685.0
1916	13.0	17.0	58.0	78.0	99.0	140.0	83.0	51.0	31.0	51.0	32.0	25.0	678.0
1917	13.0	17.0	42.0	73.0	95.0	108.0	93.0	30.0	23.0	18.0	23.0	20.0	557.0
1918	11.0	14.0	42.0	58.0	91.0	86.0	60.0	27.0	34.0	25.0	27.0	24.0	499.0
1919	12.0	17.0	46.0	79.0	100.0	90.0	92.0	48.0	29.0	33.0	29.0	26.0	601.0
1920	13.0	20.0	46.0	73.0	280.0	110.0	91.0	42.0	29.0	29.0	29.0	23.0	765.0
1921	12.0	17.0	48.0	57.0	94.0	103.0	82.0	57.0	39.0	25.0	28.0	25.0	567.0
1922	13.0	17.0	46.0	70.0	97.0	96.0	61.0	27.0	14.0	16.0	36.0	35.0	528.0
1923	12.0	17.0	42.0	[illegible]	101.0	93.0	66.0	44.0	45.0	45.0	34.0	26.0	593.0
1924	13.0	18.0	36.0	84.0	109.0	92.0	56.0	30.0	22.0	27.0	38.0	41.0	566.0
1925	30.0	17.0	45.0	75.0	81.0	60.0	63.0	56.0	33.0	40.0	30.0	27.0	557.0
1926	20.0	39.0	65.0	76.0	110.0	104.0	52.0	21.0	21.0	24.0	45.0	24.0	601.0
1927	12.0	16.0	44.0	77.0	150.0	93.0	159.0	42.0	51.0	47.0	32.0	27.0	750.0
1928	14.0	17.0	44.0	67.0	99.0	80.0	31.0	70.0	15.0	20.0	33.0	22.0	512.0
1929	13.0	17.0	44.0	73.0	97.0	90.0	64.0	60.0	49.0	45.0	31.0	25.0	608.0
1930	14.0	18.0	40.0	78.0	87.0	81.0	62.0	44.0	24.0	36.0	27.0	23.0	534.0
1931	12.0	17.0	39.0	62.0	83.0	47.0	25.0	23.0	37.0	39.0	27.0	24.0	435.0
1932	12.0	18.0	52.0	95.0	136.0	89.0	90.0	41.0	26.0	27.0	26.0	22.0	634.0
1933	12.0	16.0	40.0	56.0	91.0	92.0	47.0	31.0	27.0	28.0	27.0	23.0	488.0
1934	12.0	17.0	40.0	68.0	49.0	16.0	14.0	17.0	22.0	21.0	19.0	20.0	315.0
1935	12.0	16.0	38.0	62.0	92.0	96.0	81.0	50.0	37.0	33.0	29.0	22.0	570.0
46-year mean	12.6	16.8	45.1	83.2	109.6	93.0	64.3	37.4	32.2	31.8	30.2	24.0	580.2

TABLE 34.—*Estimated run-off of Rio Grande at San Marcial, N. Mex., under present irrigation development in San Luis Valley*

[Drainage area 24,176 square miles.[1] Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890	30.0	29.0	62.0	161.0	502.0	213.0	30.0	49.0	31.0	0	25.0	42.0	1,174.0	113.9
1891	38.0	63.0	152.0	293.0	896.0	345.0	80.0	39.0	89.0	109.0	24.0	38.0	2,165.0	210.0
1892	36.0	44.0	56.0	210.0	529.0	145.0	42.0	1.0	2.0	0	6.0	12.0	1,083.0	105.0
1893	29.0	26.0	17.0	81.0	298.0	0	0	0	0	5.0	5.0	20.0	481.0	46.6
1894	20.0	28.0	36.0	109.0	173.0	33.0	16.0	0	3.2	52.0	11.0	27.0	505.2	49.0
1895	31.0	52.8	137.0	244.0	199.0	180.0	130.0	158.0	18.0	19.0	25.0	45.0	1,238.8	120.2
1896	39.0	42.0	45.8	163.0	114.0	9.8	28.7	7.3	9.7	46.6	19.4	42.1	567.4	55.0
1897	25.5	28.3	56.8	189.0	670.0	270.0	51.0	6.1	119.0	337.0	174.0	169.0	2,095.7	203.3
1898	63.7	70.4	69.2	239.0	154.0	110.0	116.0	12.8	3.7	1.0	13.2	25.4	878.4	85.2
1899	24.9	23.6	23.5	40.1	31.0	1.0	28.4	6.4	1.9	2.7	21.5	21.8	226.8	22.0
1900	39.6	34.1	36.2	3.3	115.0	121.0	0.1	0	56.1	2.1	7.4	9.1	424.0	41.1
1901	20.0	22.5	12.1	33.7	225.0	80.2	58.3	65.5	38.6	18.0	30.1	21.2	625.2	60.6
1902	22.7	17.4	8.0	39.1	25.8	6.4	0	49.2	13.3	0.8	7.6	15.3	205.6	19.9
1903	20.2	28.9	53.8	100.0	292.0	500.0	53.8	3.1	2.4	2.8	9.5	20.9	1,085.1	105.2
1904	16.8	19.9	9.1	1.0	0	0	10.5	57.0	54.7	511.0	55.8	41.8	777.6	75.4
1905	36.1	60.9	201.0	261.0	790.0	567.0	36.8	19.1	5.3	7.3	45.4	35.3	2,064.2	200.2
1906	33.5	36.7	50.9	147.0	449.0	290.0	91.0	30.2	22.5	70.8	76.8	84.1	1,391.5	135.0
1907	54.6	61.7	86.5	178.0	293.0	365.0	290.0	114.0	122.0	46.5	53.5	47.7	1,721.5	167.0
1908	47.6	52.0	66.4	111.0	158.0	72.5	48.0	76.7	3.7	0.8	27.9	39.4	704.0	68.3
1909	89.6	81.3	48.6	80.0	246.0	200.0	42.1	41.7	126.0	37.7	39.6	65.8	998.4	96.8
1910	60.3	44.0	128.0	144.0	235.0	52.1	1.1	7.3	3.0	0.6	11.9	28.2	713.5	69.2
1911	26.2	32.7	91.0	90.5	304.0	209.0	317.0	51.2	27.2	451.0	112.0	69.0	1,780.8	172.7
1912	46.8	46.4	74.7	101.0	476.0	363.0	115.0	17.8	4.6	4.0	24.6	21.0	1,294.4	125.5
1913	26.4	38.1	31.3	79.1	119.0	78.1	6.9	0.2	4.9	22.1	36.2	48.9	500.2	48.5
1914	42.1	45.1	63.9	103.0	216.0	126.0	153.0	62.2	11.1	73.5	37.2	38.0	981.1	95.2
1915	30.2	40.0	50.2	255.0	358.0	265.0	119.0	36.2	10.9	8.0	21.7	33.4	1,227.6	119.1
1916	45.8	44.1	161.0	219.0	437.0	228.0	84.7	68.8	12.4	177.0	76.1	48.9	1,582.8	153.5
1917	41.6	42.9	37.7	78.6	199.0	377.0	199.0	4.1	5.7	0	6.5	21.8	1,013.9	98.3
1918	24.0	18.8	39.6	80.5	121.0	73.2	20.4	1.7	0	10.0	25.3	39.7	404.2	39.2

[1] Exclusive of closed basin area, San Luis Valley.

TABLE 34.—*Estimated run-off of Rio Grande at San Marcial, N. Mex., under present irrigation development in San Luis Valley*—Con.

[Drainage area 24,176 square miles. Unit 1,000 acre-feet]

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Annual run-off in percent of mean
1919	35.4	39.4	72.6	262.0	392.0	148.0	254.0	73.8	6.8	29.3	36.0	60.1	1,409.4	136.7
1920	49.3	84.4	81.2	124.0	654.0	784.0	173.0	35.9	2.9	4.7	34.1	31.9	2,05[illegible]4	199.7
1921	35.0	41.5	69.8	38.4	195.0	450.0	206.0	134.0	42.9	13.9	30.7	53.2	1,310.4	127.1
1922	51.5	47.8	57.9	75.5	359.0	252.0	37.6	0	0	0	4.0	14.7	900.0	87.3
1923	39.9	39.1	54.0	60.9	331.0	189.0	33.8	62.1	107.0	79.6	98.0	75.2	1,169.6	113.4
1924	56.0	64.1	64.9	346.0	334.0	135.0	50.0	7.2	2.9	0	0.8	16.1	1,267.0	122.9
1925	19.4	32.8	36.4	95.2	57.9	6.6	2.3	16.3	31.0	45.0	39.3	53.6	435.8	42.3
1926	42.2	29.1	45.0	102.0	422.0	253.0	27.2	2.6	3.9	3.2	6.9	33.4	971.5	94.2
1927	36.7	27.9	36.4	132.0	342.0	168.0	113.0	63.8	198.0	101.0	67.3	56.9	1,343.0	130.3
1928	48.6	46.0	41.7	31.2	227.0	89.0	0.6	9.4	5.0	1.0	7.3	29.8	536.6	52.0
1929	29.5	34.6	51.0	76.8	274.0	126.0	44.1	275.0	300.0	123.0	69.2	49.4	1,451.6	140.8
1930	44.8	52.9	59.2	178.0	123.0	76.5	78.3	50.1	4.8	4.3	16.0	35.1	723.0	70.1
1931	39.2	42.8	39.6	52.1	92.8	7.1	8.0	6.9	62.0	66.6	32.8	53.9	503.8	48.9
1932	45.7	66.0	97.2	235.0	433.0	183.0	157.0	65.7	11.2	15.8	22.6	35.3	1,367.5	132.6
1933	45.1	39.6	44.5	18.8	102.5	254.0	55.2	37.9	42.3	15.9	29.0	47.2	730.0	70.8
1934	46.9	45.3	33.7	42.5	4.4	0.2	0	31.7	25.5	1.9	2.6	27.8	262.5	25.5
1935	44.9	41.1	32.4	27.5	179.0	397.0	52.0	108.0	64.6	35.2	47.2	47.6	1,076.5	104.4
Mean	37.3	41.2	61.6	123.5	289.9	191.5	75.0	42.7	37.2	55.8	34.2	41.1	1,031.0	....
Percent of annual	3.62	4.00	5.97	11.98	28.12	18.57	7.27	4.14	3.61	5.41	3.32	3.99	100.0	....

diversion to points of use, (2) in surface drainage from the land after irrigation, and (3) in seepage to the underground basin. Beginning a few miles below Del Norte in San Luis Valley, Rio Grande receives varying amounts of return flow along many sections of its course to Fort Quitman, Tex. Return flow above Alamosa is available for rediversion and use in San Luis Valley. During the irrigation season the flow near Lobatos is largely return flow except for a few indivertible peaks which pass during short storm and flood periods. This flow is lost to San Luis Valley but becomes available for the Middle Valley section. In each of the subvalleys of the latter much of the return water reaches the river at the lower end and becomes available for rediversion in the succeeding valley. Below the San Acacia diversion at the head of Socorro Valley the return flow is lost for use in the Middle Valley but passes on to the Elephant Butte Reservoir and ultimate use in the Elephant Butte-Fort Quitman section. In the latter the return water of each subvalley becomes available to that next lower as far as the Tornillo heading of the Rio Grande Project. Below this, return water is available to the Hudspeth County Conservation and Reclamation District.

In estimating the water supply for the major units of the upper basin under given future conditions of irrigation development, the return water is an important consideration. In the following paragraphs, therefore, such data as are available with respect to its past and present volume and occurrence are presented.

The San Luis Section

In the analysis of return water in the San Luis Valley three units are considered: (1) the Rio Grande area from the Del Norte gage to Alamosa, (2) the Conejos area, and (3) the southwest area, excluding the Conejos area. In the first unit the return water may be taken as the residual quantity when the outflow at Alamosa is subtracted from the inflow at the Del Norte gage and appropriate allowance is made for intervening diversions. The return flow so derived will include that in definite channels, such as the Rio Grande drain from the north, the Bowen drain from the south, and Pinos and San Francisco Creeks, together with that coming in as ground-water seepage. Pinos and San Francisco Creeks are largely diverted, and accordingly their inflow to the river is itself chiefly return water. The necessary data for this derivation are available for the years 1928 to 1936, inclusive. Rio Grande flow at the Del Norte, Monte Vista, and Alamosa gages is given by tables in Appendix A. The diversions, 1928 to 1935, were compiled and furnished through the Colorado State Engineer. Those for 1936 were obtained under the Rio Grande joint investigation. The computation of the return flow in this unit, by months, for 1936, is shown in table 35. It will be noted that a division was made to give the return flow in two sections, Del Norte to Monte Vista and Monte Vista to Alamosa. The results similarly derived for the years 1928 to 1935, together with the 1936 data, are summarized in table 36. From this table it would appear that in the last 3 years there has been a marked increase in return flow between Del Norte and Alamosa. To a considerable extent it varies, as should be expected, with the amount of the diversions. For example, in 1931, a year of very low water supply, the total of the diversions was only 307,500 acre-feet, and the return flow dropped to 11,800 acre-feet, or 3.8 percent of the diversions, from a figure of 38,400 acre-feet in 1930, or 7.7 percent of the total diversions of 499,100 acre-feet in that year. However, in 1934, another very dry year, with total diversions of only 309,200 acre-feet, the return flow amounted to 37,700 acre-feet or 12.2 percent of the diversions. This, taken with the return flow of 86,200 and 76,000 acre-feet for diversions of 670,900 and 479,600 acre-feet, respectively, in 1935 and 1936, is strongly indicative of a recent increase in return flow. The return figures of 1935 and 1936 represent, respectively, 12.8 and 15.8 percent of the diversions. Experience with respect to return water in general suggests that these percentages are very low and the explanation lies in the large diversions to the closed basin, from which there is little return to the river except by the one outlet drain of the Rio Grande Drainage District. Also Monte Vista and Empire Canals which divert near Monte Vista carry water far to the south so that return flow therefrom reaches Rio Grande below Alamosa. As shown by table 37, in the 9-year period, 1928 to 1936, the diversions from Rio Grande to the closed basin averaged 58.5 percent of the total diversions between the Del Norte and Alamosa gages.

The percentage of return flow in terms only of the diversions contributing to the return, may be closely approximated for the total river section from Del Norte gage to the mouth of Trinchera Creek as follows, using 1936 data:

	Acre-feet
(1) Inflow:	
Rio Grande near Del Norte	472,000
Rio Grande drain (estimate based on past records, no data for 1936)	20,000
	492,000
(2) Outflow:	
Diversions to closed basin	278,000
Rio Grande at Alamosa less diversions below	60,000
Return flow below Alamosa from Rio Grande diversions (32,000 of table 40 reduced by ratio of Rio Grande diversions, 163,000, to total diversions, 355,000)	20,000
	358,000
(3) Diversions from Rio Grande:	
Del Norte to Alamosa, excluding diversions to closed basin	202,0
Below Alamosa	9,0
	211,000
(4) Return flow (3) − (1) + (2)	77,000
Return in percent of diversions	36.5

This return of 36 percent of diversions conforms closely to the relative volume of return water as experienced in general.

In table 36 it will be noted that in the river section between the Del Norte and Monte Vista gages there are frequently, in many months of the year, losses of water rather than gains. This is explained by the fact that in the upper portion of this section, the river is traversing the apex of the Rio Grande alluvial fan. The material of this fan is coarse in texture and a considerable volume of water percolates from the stream channel to ground water. This is discussed in the section of Part II of this report which deals with ground water in San Luis Valley.

Based upon data for 1934, 1935, and 1936, the average monthly distribution of the return flow between Del Norte and Alamosa is given by table 38.

For estimate of the return water in the second San Luis Valley unit, the Conejos area, diversion data are available only for 1936 and the records for that year represent, in the main, water commissioners' reports that are based in many instances on estimates only. Using these data, the return water in the area served by the Conejos River and its tributaries was derived as shown in table 39. The return of 150,000 acre-feet, or 44.5 percent of the diversions, appears to be exceptionally high. It may be due, in part, to over estimates of the diversions but it is not, however, inconsistent with

TABLE 35.—*Return water between Del Norte and Alamosa gages, San Luis Valley, 1936*

[Unit 1,000 acre-feet]

Month	Rio Grande near Del Norte (1)	Rio Grande near Monte Vista (2)	Difference (1)−(2) (3)	Diversions Del Norte to Monte Vista (4)	Return flow Del Norte to Monte Vista (4)−(3) (5)	Rio Grande at Alamosa (6)	Difference (2)−(6) (7)	Diversions Monte Vista to Alamosa (8)	Return flow Monte Vista to Alamosa (8)−(7) (9)	Total difference (3)+(7) (10)	Total diversions (4)+(8) (11)	Total return flow Del Norte to Alamosa (5)+(9) (12)
January	9.3	9.3	0		0	9.4	−0.1		0.1	−0.1		0.1
February	10.0	11.1	−1.1	0.7	1.8	11.7	−.6		.6	−1.7	0.7	2.4
March	13.9	5.0	8.9	8.3	−.6	4.9	.1	4.6	4.5	9.0	12.9	3.9
April	67.3	17.3	50.0	51.4	1.4	2.8	14.5	20.2	5.7	64.5	71.6	7.1
May	141.2	42.3	98.9	105.0	6.1	5.0	37.3	44.0	6.7	136.2	149.0	12.8
June	89.1	21.0	68.1	71.3	3.2	2.9	18.1	25.9	7.8	86.2	97.2	11.0
July	39.6	6.5	33.1	34.6	1.5	2.6	3.9	7.8	3.9	37.0	42.4	5.4
August	37.6	5.4	32.2	38.2	6.0	3.2	2.2	8.2	6.0	34.4	46.4	12.0
September	27.1	3.9	23.2	28.1	4.9	1.5	2.4	6.7	4.3	25.6	34.8	9.2
October	15.1	3.4	11.7	15.9	4.2	1.6	1.8	5.1	3.3	13.5	21.0	7.5
November	12.4	11.7	.7	1.5	.8	10.9	.8	2.1	1.3	1.5	3.6	2.1
December	9.7	11.5	−1.8		1.8	12.2	−.7		.7	−2.5		2.5
Total	472.3	148.4	323.9	255.0	31.1	68.7	79.7	124.6	44.9	403.6	479.6	76.0

Total return flow is 15.8 percent of diversions.

TABLE 36.—*Return water between Del Norte and Alamosa gages, San Luis Valley, 1928–36*

[Unit 1,000 acre-feet]

	January	February	March	April	May	June	July	August	September	October	November	December	Year
1928													
Rio Grande near Del Norte	18.1	17.3	22.4	49.0	168.0	165.0	108.0	48.8	25.0	22.1	17.9	15.1	676.7
Rio Grande at Alamosa	17.8	17.3	23.1	12.7	28.9	23.3	3.1	2.2	1.3	1.4	10.1	11.7	152.9
Diversions Del Norte to Alamosa				31.4	132.1	143.6	105.3	54.6	30.6	26.1	6.0		529.7
Return flow—Del Norte to Monte Vista				−5.8	−7.6	−12.2	−8.5	.6	1.8	−.3	−4.0		[1] −36.0
Return flow—Monte Vista to Alamosa				.9	.6	14.1	8.9	7.4	5.1	5.7	2.2		[1] 44.9
Return flow—Del Norte to Alamosa	−.3	0	.7	−4.9	−7.0	1.9	.4	8.0	6.9	5.4	−1.8	−3.4	5.9
1929													
Rio Grande near Del Norte	13.8	12.2	16.0	50.6	186.0	220.0	117.0	104.0	82.7	57.7	23.4	14.1	897.5
Rio Grande at Alamosa	11.6	11.1	16.4	14.8	18.2	35.8	3.9	50.1	69.4	40.6	29.2	19.8	310.9
Diversions Del Norte to Alamosa				47.0	172.2	178.2	128.4	73.8	30.5	[2] 4.2			[2] 634.3
Return flow—Del Norte to Monte Vista				3.5	−3.9	−8.9	2.7	12.2	5.8				[3] 11.4
Return flow—Monte Vista to Alamosa				7.7	8.3	2.9	12.6	7.7	1.4				[3] 40.6
Return flow—Del Norte to Alamosa	−2.2	−1.1	.4	11.2	4.4	−6.0	15.3	19.9	7.2	[3] −12.9	5.8	5.7	[3] 47.7
1930													
Rio Grande near Del Norte	12.3	12.2	15.4	56.6	108.0	140.0	75.6	58.6	23.6	24.5	12.7	12.1	551.6
Rio Grande at Alamosa	12.9	17.8	14.6	7.6	5.2	3.3	7.6	3.5	1.0	1.4	7.7	8.3	90.9
Diversions Del Norte to Alamosa				39.4	105.3	143.2	78.2	68.1	29.4	29.9	5.6		499.1
Return flow—Del Norte to Monte Vista				−10.4	0	−.9	3.9	7.1	2.8	3.0	1.2		[1] 6.7
Return flow—Monte Vista to Alamosa				.8	2.5	7.4	6.3	5.9	4.0	3.8	−.6		[1] 30.1
Return flow—Del Norte to Alamosa	.6	5.6	−.8	−9.6	2.5	6.5	10.2	13.0	6.8	6.8	.6	−3.8	38.4
1931													
Rio Grande near Del Norte	8.3	9.3	12.3	28.2	73.8	99.4	35.4	18.7	23.1	30.4	12.2	10.2	361.3
Rio Grande at Alamosa	7.7	12.5	16.9	2.4	1.7	3.3	2.9	1.5	1.2	.9	3.6	11.0	65.6
Diversions Del Norte to Alamosa			1.5	29.5	78.0	97.0	40.8	22.1	27.3	16.3			307.5
Return flow—Del Norte to Monte Vista				−1.5	−3.5	−5.7	1.5	.5	1.4	−14.1	−6.7		[1] −28.1
Return flow—Monte Vista to Alamosa				5.2	4.4	6.6	6.8	4.4	4.0	.9	−1.9		[1] 30.4
Return flow—Del Norte to Alamosa	−.6	3.2	6.1	3.7	.9	.9	8.3	4.9	5.4	−13.2	−8.6	.8	11.8
1932													
Rio Grande near Del Norte	11.4	11.3	16.5	66.6	214.0	236.0	146.0	106.0	30.6	26.3	10.9	9.5	885.1
Rio Grande at Alamosa	10.5	12.5	18.3	3.3	24.8	63.7	24.1	2.5	1.9	1.9	11.5	15.1	190.1
Diversions Del Norte to Alamosa				61.1	187.9	177.2	128.6	100.9	34.5	25.9			716.1
Return flow—Del Norte to Monte Vista			−4.8	−6.2	−8.7	−6.9	−10.0	−10.7	1.4	−.4	1.1		[4] −45.2
Return flow—Monte Vista to Alamosa			6.6	4.0	7.4	11.8	16.7	8.1	4.4	1.9	−.5		[4] 60.4
Return flow—Del Norte to Alamosa	−.9	1.2	1.8	−2.2	−1.3	4.9	6.7	−2.6	5.8	1.5	.6	5.6	21.1
1933													
Rio Grande near Del Norte	10.2	8.6	14.4	23.6	81.2	169.0	79.3	39.4	27.1	24.2	14.7	12.9	504.6
Rio Grande at Alamosa	12.3	9.7	10.1	.7	2.0	7.0	2.7	2.3	1.3	1.0	4.2	13.4	66.7
Diversions Del Norte to Alamosa				24.4	78.4	172.6	80.5	45.1	31.2	27.5			459.7
Return flow—Del Norte to Monte Vista				−2.0	−2.6	4.4	−3.4	2.7	2.5	1.2	−4.6		[1] −1.8
Return flow—Monte Vista to Alamosa				3.5	1.8	6.2	7.3	5.3	2.9	3.1	−5.9		[1] 24.2
Return flow—Del Norte to Alamosa	2.1	1.1	−4.3	1.5	−.8	10.6	3.9	8.0	5.4	4.3	−10.5	.5	21.8
1934													
Rio Grande near Del Norte	13.2	11.1	15.1	67.2	103.0	28.3	14.7	15.9	17.9	14.4	11.3	8.3	330.4
Rio Grande at Alamosa	10.7	13.1	4.5	1.2	2.2	3.0	1.8	1.7	1.0	.6	.9	8.2	48.9
Diversions Del Norte to Alamosa			9.8	70.5	108.3	33.1	17.4	19.4	20.0	21.1	9.6		309.2
Return flow—Del Norte to Monte Vista		−3.3	−4.0	2.0	.2	1.5	.8	1.2	0	.6	−1.9	2.6	[5] −0.3
Return flow—Monte Vista to Alamosa		5.3	3.2	2.5	7.3	6.3	3.7	4.0	3.1	6.7	1.1	−2.7	[5] 40.5
Return flow—Del Norte to Alamosa	−2.5	2.0	−.8	4.5	7.5	7.8	4.5	5.2	3.1	7.3	−.8	−.1	37.7
1935													
Rio Grande near Del Norte	3.5	5.1	15.3	37.1	31.[illegible]	263.0	128.0	72.2	27.9	19.5	12.7	8.3	683.5
Rio Grande at Alamosa	7.3	6.9	.9	.9	3.2	60.0	6.5	1.6	1.5	3.1	5.8	11.1	98.8
Diversions Del Norte to Alamosa		4.8	12.8	36.5	72.7	238.4	150.2	82.7	36.2	23.8	12.8		670.9
Return flow—Del Norte to Monte Vista	2.9	−.6	−5.5	−3.0	−12.8	9.6	12.1	4.9	5.1	1.8	−.7	.9	14.7
Return flow—Monte Vista to Alamosa	−4.1	3.2	3.9	3.3	6.8	15.8	16.6	7.2	4.7	5.6	6.6	1.9	71.5
Return flow—Del Norte to Alamosa	−1.2	2.6	−1.6	.3	−6.0	25.4	28.7	12.1	9.8	7.4	5.9	2.8	86.2
1936													
Rio Grande near Del Norte	9.3	10.0	13.9	67.3	141.2	89.1	39.6	37.6	27.1	15.1	12.4	9.7	472.3
Rio Grande at Alamosa	9.4	11.7	4.9	2.8	5.0	2.9	2.6	3.2	1.5	1.6	10.9	12.2	69.7
Diversions Del Norte to Alamosa		.7	12.9	71.6	149.0	97.2	42.4	46.4	34.8	21.0	3.6		479.6
Return flow—Del Norte to Monte Vista	0	1.8	−.6	1.4	6.1	3.2	1.5	6.0	4.9	4.2	.8	1.8	31.1
Return flow—Monte Vista to Alamosa	.1	.6	4.5	5.7	6.7	7.8	3.9	6.0	4.3	3.3	1.3	.7	44.9
Return flow—Del Norte to Alamosa	.1	2.4	3.9	7.1	12.8	11.0	5.4	12.0	9.2	7.5	2.1	2.5	76.0

[1] April to November inclusive, only.
[2] October diversions are incomplete.
[3] April to September inclusive, only.
[4] March to November inclusive, only.
[5] February to December, inclusive.

the relative degree of return to be anticipated under the conditions of "wild flooding" which prevail in this area during the short period of the spring run-off.

For the third unit, the southwest area exclusive of the Conejos area, the return-water estimate is limited to 1936 for the same reason as in the case of the Conejos area. Here, again, the available diversion records are largely those of the water commissioners. This unit comprises the area south and west of Rio Grande served by southern diversions from the river between Del Norte and Alamosa and by Rock, Alamosa, and La Jara Creeks. As shown by table 40, the return flow of this unit in 1936 is estimated to have been 31,600 acre-feet or 12 percent of the diversions.

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TABLE 37.—*Rio Grande diversions to the closed basin, San Luis Valley*

[Unit 1,000 acre-feet]

Year	1928	1929	1930	1931	1932	1933	1934	1935	1936	Mean
Total diversions between Del Norte and Alamosa gages	529.7	634.3	499.1	307.5	716.1	459.7	309.2	670.7	479.6	511.8
Diversions to the closed basin area	330.9	369.7	295.2	150.0	442.4	275.5	144.6	413.3	278.2	300.0
Closed basin diversions in percent of total	62	58	59	49	62	60	47	62	58	58.5

TABLE 38.—*Monthly distribution of return water between Del Norte and Alamosa gages, San Luis Valley*

Month	Return water in percent of total annual return	Month	Return w in percen total annu return
January	[1]−1.8	July	19.3
February	3.5	August	14.6
March	0.8	September	11.0
April	6.0	October	11.1
May	7.2	November	3.6
June	22.1	December	2.6

[1] Loss.

TABLE 39.—*Return water in the Conejos area, San Luis Valley, 1936*

[Unit 1,000 acre-feet]

Month	Conejos River near Mogote (1)	Los Pinos River near Ortiz (2)	San Antonio River at Ortiz (3)	Total inflow (1)+(2)+(3) (4)	Conejos River near La Sauses (5)	La Jara Drain (6)	Total outflow (5)+(6) (7)	Difference (4)−(7) (8)	Diversions below gages (9)	Return flow (9)−(8) (10)
January	2.1	[1]0.9	[1]0.2	3.2	4.0	([2])	4.0	−0.8		0.8
February	2.5	[1]1.0	[1].3	3.8	4.6	([2])	4.6	−.8		.8
March	3.9	[1]1.6	[1].4	5.9	3.8	([2])	3.8	2.1	8.6	6.5
April	47.6	36.3	15.2	99.1	54.3	([2])	54.3	44.8	52.0	7.2
May	87.9	32.4	4.0	124.3	65.2	0.2	65.4	58.9	125.7	66.8
June	34.3	8.4	.3	43.0	4.9	.5	5.4	37.6	77.6	40.0
July	8.8	2.3	.4	11.5	.2	.2	.4	11.1	22.1	11.0
August	13.8	2.9	.9	17.1	2.8	.4	3.2	13.9	20.8	6.9
September	9.9	2.0	.2	12.1	2.4	.5	2.9	9.2	11.3	2.1
October	9.4	3.3	.5	13.2	5.4	.6	6.0	7.2	12.9	5.7
November	7.6	3.0	.9	11.5	7.1	.6	7.7	3.8	6.8	3.0
December	4.1	[1]1.7	[1].4	6.2	5.4	([2])	5.4	.8		−.8
Total	231.4	96.8	23.7	350.9	160.1	3.0	163.1	187.8	337.8	150.0

[1] Estimated.
[2] No record.

NOTE.—Total return flow is 44.5 percent of diversions.

TABLE 40.—*Return water in the southwest area exclusive of the Conejos unit, San Luis Valley, 1936*

[Unit 1,000 acre-feet]

Month	Diversions to the area from the Rio Grande (1)	Rock Creek near Monte Vista (2)	Alamosa Creek below Terrace Reservoir (3)	La Jara Creek near Capulin (4)	Rio Grande at Alamosa (5)	La Jara Drain (6)	Total inflow (1) to (6) inclusive (7)	Outflow Rio Grande above Trinchera Creek (8)	Difference (7)−(8) (9)	Diversions (10)	Return flow (10)−(9) (11)
January		[1]0.1	2.1	[1]0.2	9.4	([2])	11.8	[1]9.4	2.4		−2.4
February		[1].2	1.9	[1].2	11.7	([2])	14.0	[1]12.7	1.3		−1.3
March	5.4	[1].2	1.9	[1].2	4.9	([2])	12.6	[1]10.1	2.5	7.3	4.8
April	25.0	[1]1.3	13.2	[1]1.3	2.8	([2])	43.6	[1]4.6	39.0	42.1	3.1
May	51.4	2.2	24.2	1.4	5.0	0.2	84.4	11.2	73.2	86.5	13.3
June	34.7	.8	13.6	.5	2.9	.5	53.0	3.7	49.3	57.3	8.0
July	12.4	.5	6.8	2.0	2.6	.2	24.5	.3	24.2	22.8	−1.4
August	17.7	1.2	7.0	.7	3.2	.4	30.2	4.8	25.4	25.3	−0.1
September	11.1	.4	4.6	.5	1.5	.5	18.6	4.3	14.3	15.3	1.0
October	3.8	.4	1.9	.6	1.6	.6	8.9	6.9	2.0	6.2	4.2
November	1.3	.4	1.8	.4	10.9	.6	15.4	15.5	−.1	1.8	1.9
December		[1].2	1.8	[1].2	12.2	([2])	14.4	14.9	−.5		0.5
Total	162.8	7.9	80.8	8.2	68.7	3.0	331.4	98.4	233.0	264.6	31.6

[1] Estimated.
[2] No record.

NOTE.—Total return flow is 12.0 percent of diversions.

An analysis of the 1936 return flow to the section of the Rio Grande between the Alamosa and Lobatos gages is given in table 41. Exclusive of the inflow of Trinchera, Conejos and Culebra creeks, totaling 168,400 acre-feet, this shows a net return in the section of 53,000 acre-feet, 38,800 acre-feet from Alamosa to Trinchera Creek and 14,200 acre-feet from Trinchera Creek to the Lobatos gage. Including the inflow of the three creeks, the total return in the section was 221,400 acre-feet. For the years 1930 to 1935 data are available to derive the total return in this section, but the lack of a record in these years of Rio Grande flow above Trinchera Creek prevents segregation of the return to the two sections, above and below Trinchera Creek. An es-

TABLE 41.—*Return water between Alamosa and Lobatos gages, San Luis Valley, 1936*

[Unit 1,000 acre-feet]

Month	Rio Grande at Alamosa (1)	Rio Grande above Trinchera Creek (2)	Difference (1)−(2) (3)	Diversions below Alamosa (4)	Return flow Alamosa to Trinchera Creek (4)−(3) (5)	Rio Grande near Lobatos (6)	Total inflow Trinchera Creek to Lobatos (6)−(2) (7)	Trinchera Creek at mouth (8)	Conejos River and Culebra Creek at mouths [1] (9)	Net return flow Trinchera Creek to Lobatos (7)−(8+9) (10)	Net return flow Alamosa to Lobatos (5)+(10) (11)
January	9.4	[2] 9.4	0		0	15.4	6.0	[1] 0.7	4.0	1.3	1.3
February	11.7	[2] 12.7	−1.0		1.0	19.8	7.1	[1] 1.0	4.6	1.5	2.5
March	4.9	[2] 10.1	−5.2		5.2	16.0	5.9	[1] .7	3.8	1.4	6.6
April	2.8	[2] 4.6	−1.8		1.8	60.4	55.8	[1] .3	54.3	1.2	3.0
May	5.0	11.2	−6.2	1.5	7.7	78.7	67.5	.2	65.2	2.1	9.8
June	2.9	3.7	−.8	3.4	4.2	11.0	7.3	0	4.9	2.4	6.6
July	2.6	.3	2.3	3.0	.7	1.1	.8	0	.2	.6	1.3
August	3.2	4.8	−1.6	1.2	2.8	9.0	4.2	.4	2.9	.9	3.7
September	1.5	4.3	−2.8		2.8	7.7	3.4	.6	2.4	.4	3.2
October	1.6	6.9	−5.3		5.3	13.9	7.0	1.2	5.4	.4	5.7
November	10.9	15.5	−4.6		4.6	24.7	9.2	2.0	7.1	.1	4.7
December	12.2	14.9	−2.7		2.7	23.3	8.4	[1] 1.1	5.4	1.9	4.6
Total	68.7	98.4	−29.7	9.1	38.8	281.0	182.6	8.2	160.2	14.2	53.0

[1] From May to November the flow of Culebra Creek was only 106 acre-feet; 10 in July and 96 in August. [2] Estimated.

timate of the net return requires also that Trinchera Creek inflow be estimated. The data are given in table 42. This table indicates a mean return flow, exclusive of the creek inflow, Alamosa to Lobatos, for the 7-year period 1930–36, amounting to 57,200 acre-feet, with a range from 29,100 acre-feet in 1931 to 100,800 acre-feet in 1932.

For the remainder of San Luis Valley, comprising the closed basin and southeast area, few return-flow data are available. In the closed basin there is no return to Rio Grande except by the Rio Grande drain. Otherwise, return from irrigation travels toward the sump and is lost by evaporation or through transpiration by native vegetation. In the southeast area the irrigable lands far exceed the area which can be served by the water supply of the streams, which are completely regulated. With reuse of return flow in the lower areas, there is, therefore, little return to Rio Grande.

TABLE 42.—*Return water between Alamosa and Lobatos gages, San Luis Valley, 1930–36*

[Unit 1,000 acre-feet]

Year	Rio Grande at Alamosa (1)	Rio Grande near Lobatos (2)	Difference (1)−(2) (3)	Diversions below Alamosa (4)	Total inflow Alamosa to Lobatos (4)−(3) (5)	Trinchera Creek at mouth (6)	Conejos River at mouth (7)	Net return flow Alamosa to Lobatos (5)−(6+7) (8)
1930	90.9	270.4	−179.5	4.9	184.4	[1] 6.0	119.5	58.9
1931	36.6	126.5	−89.9	7.4	67.3	[1] 4.0	34.2	29.1
1932	190.1	596.4	−406.3	12.5	418.8	[1] 10.0	308.0	100.8
1933	86.7	257.0	−170.3	7.5	177.8	[1] 6.0	110.9	60.9
1934	48.9	98.8	−49.9	9.1	59.0	[1] 4.0	20.8	34.2
1935	98.8	360.1	−261.3	13.5	274.8	[1] 8.5	203.0	63.3
1936	68.7	281.0	−212.3	9.1	221.4	8.2	160.1	53.1
Mean	89.9	281.3	−191.4	9.1	200.5	6.7	136.6	57.2

[1] Estimated.

NOTE.—Culebra Creek inflow probably negligible; taken as zero.

The Middle Section

From the results of the 1936 investigation some data are available to furnish an idea of return flow in the Middle Rio Grande Conservancy District. As brought out in the ground-water investigation of this area, the flow in riverside drains of the district is made up almost entirely of direct seepage from the river. The flow in the interior drains may therefore be taken as representing the total return flow from irrigation plus intercepted underflow from the mesas. No determination of the latter has been made but in the report of the ground-water investigation it is estimated at 50,000 to 100,000 acre-feet for the valley from Pena Blanca to San Marcial, a distance of 150 miles.

The flow of the interior drains of the conservancy district as measured in 1936 is given by divisions in table 43. The 1936 irrigated acreage for each division

TABLE 43.—*Discharge of interior drains of Middle Rio Grande Conservancy District, 1936*

[Unit acre-feet]

Month	Division: Cochiti	Division: Albuquerque	Division: Belen	Division: Socorro	District total	Combined flow of Albuquerque and Belen divisions in percent of annual flow
January	400	3,500	4,900	2,700	11,500	6.3
February	440	2,700	4,100	2,500	9,740	5.1
March	400	3,400	4,300	3,000	11,100	5.8
April	330	5,500	6,100	3,400	15,330	8.7
May	470	6,600	7,500	4,300	18,870	10.6
June	400	7,800	6,700	3,100	18,000	10.9
July	430	8,300	6,300	2,700	17,830	10.8
August	340	7,400	6,200	2,300	16,240	10.2
September	430	6,800	6,200	2,400	15,830	9.8
October	410	5,600	5,100	2,800	13,910	8.0
November	430	4,400	5,300	2,600	12,730	7.3
December	430	3,500	5,100	2,700	11,730	6.5
Year	4,890	65,400	67,700	34,500	172,490	100.0
Acreage irrigated	5,208	22,819	23,896	7,237	59,159	
Drain flow acre-feet per irrigated acre	0.94	2.86	2.84	4.77	2.92	
Percent of gross diversions	6.5	27.7	28.1	52.8	28.0	

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FIGURE 19.—Riverside drain in Middle Rio Grande Conservancy District, New Mexico. Check structure diverts water into canal for irrigation.

FIGURE 20.—Interior drain, Middle Rio Grande Conservancy District, New Mexico.

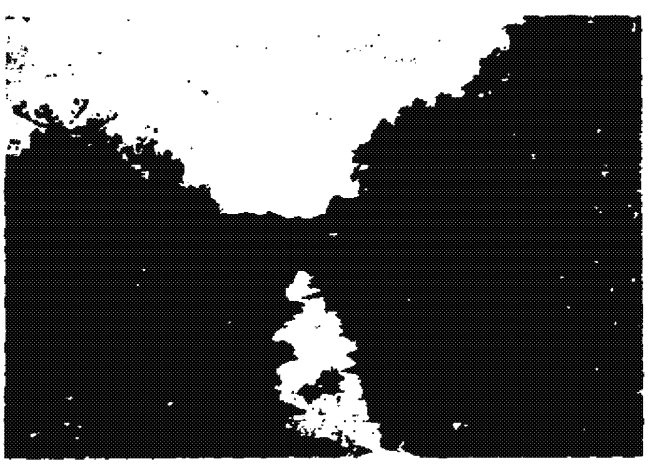

FIGURE 21.—A riverside drain through bosque, Middle Rio Grande Conservancy District, New Mexico.

is given also and the drain flow in acre-feet per irrigated acre. The latter figures for all divisions except Cochiti appear to be rather high, especially that of 4.77 acre-feet per acre for the Socorro division. This division is very narrow, and probably its interior drains receive some direct seepage from the river. Some waste may also be included in the drains at the points of measurement.

The monthly distribution of the drainage return as derived from the combined flow in the Albuquerque and Belen divisions is shown in the last column of table 43.

The data obtained in 1936 do not afford a comparison of the drainage return with net diversions. Gross diversions only are available, and because in the conservancy district a great amount of water is wasted back to the river below the points of diversion measurements (only a small portion of this waste was measured), there is a wide difference between gross and net diversions. The gross diversions to the divisions of the conservancy district as given by the 1936 measurements are shown in table 44. These figures represent the diversions to the division less the discharge of the canals flowing past the lower boundary of the division into the succeeding division. The total of the gross diversion for the district is 617,000 acre-feet, and the total drain flow of 172,490 acre-feet is 28 percent of the total gross diversion. The drain flow in percent of the gross diversions by divisions is given in the last line of table 43.

The Elephant Butte-Fort Quitman Section

Except for the Rio Grande Project, drainage data for this section are incomplete. On the project the discharges of the drains of each division, Rincon, Mesilla, and El Paso, have been measured for many years, and the data are available to derive the net diversions in each division. Comparison of drainage return and net diversions is therefore possible. Table 45 gives the net diversions and drainage return in acre-feet and in percent of diversions for each division and for the total project for the years 1930 to 1936, inclusive. It will be noted that the percentage return is high, the 7-year mean for the project being 50.3 percent. An important factor contributing to high return is seepage losses from the very large mileage of main canals and laterals required to irrigate the long narrow valleys.

TABLE 44.—*Gross river diversions in the Middle Rio Grande Conservancy District, 1936*

[Unit acre-feet]

Month	Division				District total
	Cochiti	Albuquerque	Belen	Socorro	
January	0	[1] 0	0	[1] 0	0
February	0	[1] 0	0	[1] 0	0
March	0	[1] 0	0	[1] 0	0
April	6,500	29,700	36,100	6,600	78,900
May	10,000	37,800	39,800	11,200	98,800
June	9,000	36,300	37,800	11,400	94,500
July	9,800	34,400	30,600	7,600	82,400
August	9,800	30,000	32,300	11,000	83,100
September	7,300	27,400	26,700	7,800	69,200
October	7,900	24,200	17,800	6,400	56,300
November	7,800	10,700	19,600	3,300	41,400
December	6,900	5,500	0	0	12,400
Year	75,000	236,000	240,700	65,300	617,000
Acreage irrigated	6,208	22,819	23,895	7,237	59,159
Diversions in acre-feet per irrigated acre	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] Estimated.

The monthly distribution of the drainage return as derived from the 1930–36 means for the total project drainage is as shown in table 46.

Ground Water

Another source of water supply in the upper basin is the water collected and stored in its underground reservoirs. These are charged by percolation from rainfall and from water applied in irrigation, and by seepage from canals and natural stream channels. Withdrawals or discharge from the ground-water basins may occur through pumping, the flow of artesian wells and springs, evapo-transpiration losses at the ground surface where the water table is high, artificial drainage, and underflow, of which the latter may appear as inflow to stream channels at lower elevations.

TABLE 46.—*Monthly distribution of drainage return, Rio Grande Project, 1930–36*

Month	Total project drainage return mean for years 1930–36, inclusive.		Month	Total project drainage return mean for years 1930–36, inclusive.	
	In 1,000 acre-feet	In percent of annual		In 1,000 acre-feet	In percent of annual
January	18.4	5.2	August	41.0	11.5
February	18.0	5.1	September	37.1	10.4
March	24.7	7.0	October	29.4	8.3
April	32.1	9.0	November	23.1	6.5
May	35.0	9.8	December	21.1	5.9
June	36.2	10.2			
July	39.5	11.1	Annual	355.6	100.0

The principal ground-water basins for consideration with respect to water supply in the upper basin are these underlying the San Luis Valley, the Middle Valley from Cochiti to San Marcial, and the Rincon, Mesilla and El Paso Valleys. In none of these areas has ground water been utilized to any appreciable extent as a primary or basic source of supply for irrigation, although the extensive control of ground water for the practice of subirrigation in western San Luis Valley areas might be considered as an exception to this statement. Moreover, there appears to be no immediate

TABLE 45.—*Net diversions and drainage return, Rio Grande Project, 1930–36*

[Unit 1,000 acre-feet except as otherwise noted]

Year	Divisions									Project total		
	Rincon			Mesilla			El Paso					
	Net diversion	Drainage return		Net diversion	Drainage return		Net diversion	Drainage return		Net diversion	Drainage return	
		Amount	Percent of diversions		Amount	Percent of diversions		Amount	Percent of diversions		Amount	Percent of diversions
1930	64.4	31.9	49.5	434.1	188.6	43.4	268.1	132.5	49.4	756.6	348.2	46.0
1931	64.0	36.7	57.3	410.7	196.5	47.9	237.0	131.2	55.4	711.7	364.4	51.2
1932	73.9	39.2	53.0	439.5	194.4	44.2	244.6	138.0	56.4	758.0	371.6	49.0
1933	69.4	41.0	59.1	416.3	205.4	49.4	243.4	137.2	56.4	729.1	383.6	52.6
1934	82.7	40.9	49.5	426.3	217.8	51.1	265.3	132.8	50.1	774.3	391.5	50.5
1935	51.3	26.8	52.3	298.7	167.1	56.0	198.8	109.5	55.1	548.8	303.4	55.3
1936	63.0	28.5	45.2	365.8	183.2	50.2	237.4	112.9	47.6	669.2	326.6	48.8
Mean	67.0	35.0	52.2	397.8	192.9	48.5	242.1	127.7	52.7	706.9	355.6	50.3

probability of extensive ground-water development as a basic supply, except as the recurrence of dry years may result in increased pumping in San Luis Valley, or Wagon Wheel Gap Reservoir, if constructed and accompanied by power development, may create a condition favorable to ground-water pumping in that valley. This investigation accordingly has been concerned with the relation of ground water to present utilization of surface supplies and to present losses by evaporation and transpiration in seeped areas, rather than with potentialities of ground water as a basic supply. It is to be observed, in general, that extensive development of ground water for irrigation would add no new water to the Upper Rio Grande Basin and that recharge of the ground-water basins would necessarily involve a draft on surface supplies which are now utilized otherwise. The chief element to be considered in such a development would be the redistribution of the availability and use of present supplies and the resulting effect upon the water supply of lower major units.

As a part of the Rio Grande joint investigation, the nature and occurrence of ground water in the San Luis and Middle Valleys was studied by the Ground Water Division of the Geological Survey and the report of that study constitutes part II of the present report. Some of the salient features of the study are reviewed in the following paragraphs.

San Luis Valley

The entire floor of San Luis Valley is underlain by a body of unconfined water at shallow depth. The only major development of this body of ground water, with the exception of its control for subirrigation in parts of the valley, has been the construction of stand-by irrigation wells in the agricultural area on the west side of the valley, where the wells are used in periods of water shortage. Beneath the shallow ground waters, and separated from them by a confining bed, lies a large body of artesian water, occupying numerous strata in the valley fill. The artesian water has been developed extensively for domestic, stock, and irrigation purposes, more than 6,000 flowing wells having been drilled. The principal features of the 1936 investigation were the measurements of water levels and fluctuations of the shallow ground water and an inventory of the discharge of artesian wells.

Unconfined or shallow ground water.—The shallow valley fill which contains the unconfined ground water is present under the valley floor as a continuous deposit ranging in thickness from 10 to 90 feet. Beneath it are the impermeable beds which form the upper confining surface of the artesian basin. At the edges of the valley floor these impermeable beds "feather out" and there are marginal strips of unconfined ground water. This water, moving laterally toward the center of the valley, is a common source of supply for both the shallow and artesian basins.

The yield of shallow wells in the valley ranges widely in accordance with the character of the sediments of the valley fill. An investigation of wells sunk for irrigation pumping in nearly every part of the valley showed, in general, that the successful wells are all on the west side of the valley, on or near the alluvial fans. The greatest concentration of irrigation wells is on the Rio Grande alluvial fan. Another group is east of the Monte Vista Canal in the Bowen-Carmel area and there are a few scattered wells on either side of Rio Grande in the vicinity of Parma. The average yield of wells in these areas is about 850 gallons per minute; some wells report yields up to 1,600 gallons per minute. In the central and eastern parts of the closed basin, practically all attempts to pump for irrigation have failed, chiefly because of the inability of the sediments to yield water readily.

The form of the water table in the closed basin as shown by ground-water contours plotted for October 1936 shows a close resemblance to the general form of the land surface. The water table slopes from the west, north, and east toward the trough of the valley, and the lowest point is about 6 miles south of San Luis Lake. Here the contours indicate a closed depression with the water table sloping toward it on all sides. From the Rio Grande alluvial fan the movement is toward the northeast, east, and southeast, but there is indication that along the south side of this fan, and north of the river between Monte Vista and Alamosa, the movement is toward the Rio Grande. With the latter exception, the October 1936 contours indicate that none of the ground water of the closed basin is moving out of the area.

Except on steep alluvial slopes and fans, where it may be 100 feet or more, the depth to ground water over most of the valley floor does not exceed 10 feet. Depths-to-water contours for July 1936 show less than 5 feet over approximately 70 percent of the closed basin and from 5 to 8 feet over 20 percent of it. In the Bowen-Carmel district and the general area east to the river, they show less than 5 feet in most places, with an increase to the west where the alluvial fan of Gato and Alamosa Creeks begins.

Fluctuations of the water table maintain a balance between the annual amount of water replenishing the underground supply and the annual amount withdrawn or discharged. In San Luis Valley the fluctuations follow closely the seasons of the year, but they are not uniform throughout the valley. In the western areas, where subirrigation is practiced, there is a sharp and pronounced rise of the water table at the beginning of the irrigation season, usually about April 1. At the end of the irrigation season there is a gradual decline which continues until the beginning of the next season. In the northern, central, and eastern parts of the closed basin, cropped lands give way to meadow and brush lands. Water is applied to most of the meadowlands but not to lands supporting other native vegetation. However, such vegetation is comprised of plants that "feed" on ground water, resulting in a lowering of the water level during the growing season. A gradual rise ensues through the winter, after which percolation from spring thaws brings about a sharp rise. The water level then remains high until the "transpiration draft" is resumed. Lowering of the water table due to standby irrigation pumping in 1936 was quite marked on the Rio Grande alluvial fan and in the Bowen-Carmel area. The decline began in June and there was no appreciable recovery until well into September.

The sources of ground-water recharge in San Luis Valley are stream flow, irrigation diversions, artesian well flow, and precipitation on the valley floor. All streams entering the valley must flow across the bordering alluvial slopes, the texture of which is conducive to high percolation, and large losses to ground water result. Measurements of Rio Grande losses in a short section below the Del Norte gage, situated close to the apex of the Rio Grande alluvial fan, range as high as 100 second-feet or more. The highest measured loss between Del Norte and Monte Vista in 1936 was 2,345 acre-feet during March and April, equivalent to a continuous flow of 19 second-feet. Similarly, on Conejos River between the Mogote gage and Conejos, losses have been measured in certain periods of the year that ranged up to 22 second-feet.

During the irrigation season practically the entire flow of Rio Grande and other streams entering the valley from the west is diverted for irrigation, largely on the Rio Grande alluvial fan and that of Gato and Alamosa Creeks. With the types of soil and the methods of subirrigation prevailing, there is abundant opportunity for ground-water recharge from irrigation in these areas. Without doubt there is now a much larger recharge to the ground water than occurred in days before irrigation was practiced. This is evidenced by the extensive system of drains built to lower the water level and to carry away excess ground water.

Very little of the artesian well flow passes out of the valley as stream flow, and much of it goes to recharge ground water. A substantial part of this recharge is by leakage from wells inadequately cased.

A rough measure of ground-water recharge from rainfall penetration in the central portion of the closed basin was afforded by data on the rise in the water table and the specific yield of water bearing materials at seven wells situated outside of the influence of any recharge from irrigation. In the period from July 20 to October 15, 1936, the recorded precipitation at Garnett was 5.78 inches. In the same period the average rise of the water table in the wells was 0.94 foot. On the basis of the average specific yield of 30.5 percent, the recharge to ground water amounted to 3.7 inches, or 64 percent of the rainfall as recorded at Garnett. Since the texture of the soil and the amount and intensity of rainfall range widely throughout the valley, it follows that ground-water recharge from rainfall penetration must also range widely.

Discharge of ground water in the shallow valley fill of San Luis Valley is by evaporation and transpiration, underflow, artificial drainage, and pumping. Conditions in the valley, especially in the central and eastern portions of the closed basin, are favorable for the disposal of large quantities of ground water by evaporation and transpiration.

As previously stated, discharge by underflow to Rio Grande occurs in the section between Del Norte and Alamosa. The data of tables 35 and 36 in the preceding section dealing with return water furnish some conception of its amount. The return flow indicated by these tables includes some creek and surface drain inflow. Eliminating this in the 1936 table, using available records and best estimates of its amount, gives seepage gains for the year of 17,200 acre-feet between Del Norte and Monte Vista and of 35,500 acre-feet between Monte Vista and Alamosa. The largest monthly gain in the section in 1936 was 10,040 acre-feet in August, equivalent to a continuous flow of 163 second-feet.

Of the ground-water discharge through the net work of drains on the valley floor, much is rediverted for irrigation and the remainder is ultimately discharged either to Rio Grande or to the sump in the closed basin.

The quantity of ground water withdrawn by pumping varies notably from year to year. Practically all of the pumps have been installed as standby irrigation plants, and this development has occurred largely within the last five years. When there is a shortage in stream flow, as in 1936, pumping is at a maximum. A reconnaissance in 1936 showed that there were 176 irrigation pumping plants in the valley. Many of them were just being installed. From reported discharges by owners or operators, the total output of all plants pumping continuously was estimated at 660 acre-feet per day.

Confined or artesian water.—Flowing wells can be obtained in the San Luis Valley over an area embracing 1,430 square miles or, measured at its extremities, an area 66 miles north and south and 32 miles east and west. All the essentials of an ideal artesian system are present in the valley.

Corresponding principally to the distribution and character of the sediments in the aquifers, the valley may be divided into fairly well defined sections of high flow and low flow on the basis of the average yields of the wells. Three localities in particular have appreciably higher flows than the average. These are (1) the district southwest of Alamosa in the vicinity of Henry station and westward to the Fountain neighborhood; (2) an area several sections in extent, the center of which is about 6 miles northeast of Alamosa; and (3) an area extending southward from the vicinity of Russell Lakes to Veteran School. The largest and strongest flows of the valley occur in the last named area.

Contrary to the usual history of artesian basins, the area of flow in San Luis Valley has increased over a period of development covering the last 30 years. This is shown by comparison of the area of flow in 1906, as delineated by Seibenthal, with the area determined by the field work of 1936. The increase is readily apparent on the gentler alluvial slopes, such as the Rio Grande fan, but not where slopes rise steeply from the valley floor. Thus the boundary of the flow area has moved westward more than a mile in some places along the Rio Grande alluvial fan and southward about 2 miles near Manassa. The explanation lies in the shift of irrigation development toward the west, and the resulting increase in recharge to the artesian basin from irrigation diversions.

As in the case of the shallow ground-water basin, recharge to the artesian basin is from stream flow, irrigation diversions, and precipitation. For the artesian basin, however, the area of recharge is confined to the marginal rim of the valley overlying the upturned edges of the artesian aquifers.

Water is naturally discharged from the artesian basin by springs and artificially by wells. There are several springs in the valley along the boundary of the area of flow. The discharge of McIntire Springs, one of the larger, remains practically constant at close to 19 second-feet throughout the year. On the other hand, the discharge of Diamond Springs, about 4 miles southwest of La Jara, has increased progressively during the last 30 years from probably less than 1 second-foot to more than 24 second-feet, thereby furnishing strong additional evidence of the increase in recharge of the artesian basin due to irrigation development. Other springs on the west side of the valley are those comprising the source of Spring Creek and Russell Springs. Table 47 lists the artesian springs and gives their average discharge as measured in 1936. The indicated total average discharge of 65.7 second-feet represents an annual discharge of 47,600 acre-feet.

An estimate of the total artesian water discharged annually by wells in the valley is afforded by the inventory of wells which was made in 1936. On the basis of this inventory, it is estimated that there are 6,074 artesian wells in the valley, with an average annual discharge of about 119,000 acre-feet. Of this number, 1,380 wells in the towns of Alamosa, Center, La Jara, Monte Vista, and Sanford discharge annually about 8,700 acre-feet. The discharges of the wells range from a trickle to 350 gallons per minute, with an average of about 12 gallons per minute. If all wells in the valley were allowed to flow unrestricted, the annual discharge would be about 142,000 acre-feet.

TABLE 47.—*Discharge of artesian springs in San Luis Valley, 1936*

Springs	Number and dates of measurements	Average discharge second-feet
Russell	1, Nov. 22	3.6
Spring Creek	1, Nov. 27	9.7
Washington		(1)
Diamond	3, Apr. 14, May 6, June 3	24.5
McIntire	4, Mar. 27, May 12, June 3, July 11	18.9
Smaller unnamed	Estimated	9.0
Total		65.7

[1] Trickle.

Middle Valley

The ground-water investigation in the Middle Valley covered the valley area from about 15 miles south of White Rock Canyon to about 7 miles north of San Marcial. The principal feature was the measurement of water levels and fluctuations in approximately 1,000 observation wells. Certain studies were made and a small amount of experimental work was carried on in an endeavor to clarify some of the basic problems connected with the source, motion, and disposal of the ground water, but the time and work involved in the location and periodic measurement of the large number of wells left little opportunity in the one season for the special and experimental type of investigation needed for such clarification.

Movement of ground water.—Observations on the movement of ground water are based on the maps of part II, plates 6 to 9, inclusive, which give the water-table altitudes by contours and the depths below ground surface by areal divisions, as derived from the data of well readings during October 1936. Lacking the requisite data for derivation of annual means, the October readings were used because all available evidence indicated that the water table during that month was at approximately its mean position for the year. The most obvious characteristic of the ground-water flow is its predominant downstream movement. From the vicinity of Algodones, where the water table has an altitude of 5,080 feet, to a point 17 miles south of Socorro, the water table falls 585 feet, an average of 5 feet per mile. This corresponds, of course, to the fall of the river in the same distance. The lateral slopes of the water table, and consequently the lateral movements of the ground water vary considerably in different parts of the valley, depending principally on the spacing of the drains. In general, the lateral slope of the water table varies more or less inversely with the width of the valley. It is most pronounced in the Socorro division, where it is as high as 22 feet to the mile, and least pronounced in the Belen division. Throughout most of the length of the river, the water table slopes from the riverside drains to the interior drains.

Due to the great variation throughout the valley in the transverse direction of water movement according to the spacing and distribution of drains and canals, no short generalized areal description of the movement of ground water is possible. In a section at the upper end of the Albuquerque division, the water table slopes from the edge of the mesa to the river, and indicates an accretion to the river from the arroyos and mesa slopes and to some extent by leakage from the Bernalillo and Algodones acequias. However, from this section to the lower end of the Middle Rio Grande Conservancy District at the north line of the Bosque del Apache Grant there is every variation in direction of ground-water movement: to interior drains from mesa sides and riversides; from the river to riverside drains or beyond them to interior drains; from the mesa or border canals to interior drains, or to riverside drains where there are no intermediate interior drains; and from canals to drains; etc. In the Bosque del Apache Grant, which is an undrained area, the water table slopes rather uniformly southward; it shows comparatively little distortion, and lateral flow is small.

Water-table fluctuations.—The determination of normal seasonal fluctuations of the water table was not possible in the few months of the present investigation. It was found, however, that the seasonal fluctuations in irrigated and unirrigated areas are opposite in trend. As in the case of portions of San Luis Valley, the irrigated areas receive water in the growing season in excess of their demand and consequently the water table rises in summer. It then falls to a lower position in winter. In the unirrigated areas the vegetation demands more water in summer than can be supplied by ground-water flow, and hence in these areas the water table falls in summer. It rises in winter, when there is no draft by native vegetation. These typical changes are shown by the average fluctuation in the various districts of the valley between July and October 1936 given in table 49. The Bosque del Apache area, unirrigated except by overflow from the Socorro main canal at the northern border, showed a rise in the water table, July to October of 0.86 foot. In none of the Middle Valley districts listed is all of the land irrigated. Hence the declines of the water table given in table 49 are not entirely representative of the change in irrigated areas. However, the more heavily irrigated areas show the greater declines, ranging up to 1.62 feet for the Barr district.

Source of ground water.—Ground water in the Middle Valley has several sources. Part of it comes by underflow from the mesas on either side of the valley, part from seepage from the river, part from seepage from canals, and part from seepage from irrigated lands. To determine the source or sources of the ground water in any particular locality is difficult. A substantial amount must come as underflow from the higher lands bordering the floodplain of the river. This probably occurs as a general seepage throughout the length of the valley and as concentrations near the arroyos which intermittently receive larger quantities of water. The water-table map shows steep gradients from the debouchures of the large arroyos, notably Tijeras, in the upper part of the Barr district, and Hell Canyon, above Peralta. The volume of this increment to the ground water of the floodplain has not been determined. An approach to the problem is discussed in a subsequent paragraph after consideration of ground-water conditions prior to drainage. It is concluded there that available data indicate an average annual flow from the hillsides to the valley of about 0.25 second-foot per lineal mile of border, or a total on both sides of the valley throughout its length of about 50,000 acre-feet. It is concluded further that the maximum flow that should be assumed, based on minimum accretions to the interior drains, probably does not exceed 100,000 acre-feet per year.

Rio Grande is, without doubt, itself the source of most of the water in the riverside drains. In the cultivated area beyond the riverside drains, some of the ground water also comes from the river. In general, the latter condition is likely to occur where intermediate drains lie within a mile of the riverside drains, a situation most prevalent in the Socorro division. As shown by the quality of water investigation, the water in the interior drains of the Socorro division has, on the whole, a lower mineral content than that in the interior drains of the remainder of the Middle Valley.

Some water-table divides in the interior of the valley follow approximately irrigation canals, indicating that the latter are another source of ground water. Data are largely lacking to define either the degree or the amount of their contributions.

It is doubtful whether any significant part of the ground water has its origin in the scant precipitation on the valley floor. This doubt applies particularly to the summer period. Precipitation does, however, have a noticeable effect in reducing ground-water consumption, and this effect is manifested in fluctuations of the water table.

There seems little doubt that in most areas of the Middle Valley seepage from irrigated lands is the main source of ground water. This is indicated by the pronounced drop in ground-water levels in irrigated districts as measured in 1936 between July, when irrigation was intense, and October, when irrigation had decreased but the canals were all operating.

From present information it would seem that gains and losses between riverside drains and the lands are of the same order of magnitude so that the discharge of the riverside drains, excluding surface waste into them, represents approximately the quantity of water withdrawn by seepage from the river, while the discharge of the interior drains represents water derived fro immediate sources other than the river that are sav from evaporation and transpiration.

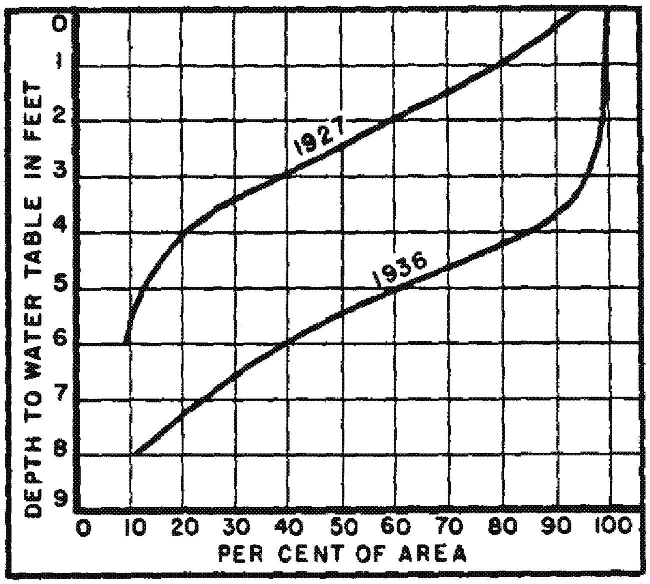

FIGURE 22.—Proportion of land with ground water over various depths, Middle Rio Grande Valley, 1927 and 1936.

Depth to ground water.—Based on data of the October 1936 well readings, the depths to ground water throughout the Middle Valley are summarized in table 48 which gives the acreage in each subdivision of the valley with ground water at various depths. In order to derive a comparison between 1936 ground-water conditions and those which obtained before drainage construction, and particularly to establish the average lowering of the water table due to the latter, the 1936 depths to ground water were compared to the average of those for 1926–27 as given in the 1928 Burkholder report of the Middle Rio Grande Conservancy District. The comparison is shown in table 49. This table also gives the average rise or fall of the water table in the various valley subdivisions from July to October 1936.

The average lowering of the water table under the entire valley from 1927 to 1936 was 3 feet. Depths to water of less than 3 feet are shown for October 1936 in 4 percent of the total valley area; between 3 and 4 feet in 11 percent of the area; between 4 and 6 feet in 46 percent; between 6 and 8 feet in 28 percent; and more than 8 feet in 11 percent. The data for the valley as a whole are shown graphically in figure 22. The bes drained districts are indicated to be the Coralles, th Peralta-Tome, and the San Acacia-Lemitar-Socorro.

Conditions before drainage.—A cooperative ground-water investigation in the Middle Valley conducted in the period 1917–22 also furnishes some data for

TABLE 48.—*Areas in the Middle Valley having ground water at given depths in October 1936*

District		Depth to water, in feet								Total acreage		
		Above surface	0–1	1–2	2–3	3–4	4–6	6–8	Over 8	Surveyed	Not surveyed	Total
Algodones-Bernalillo	acres	0	21.00	12.00	311.00	622.00	3,385.00	1,915.00	777.00	7,043.00	0	7,043.00
	[1] percent	0	.29	.17	4.21	8.84	48.16	27.23	11.10	100.00	0	
Corrales	acres	0	0	0	0	352.00	1,722.00	688.00	355.00	3,117.00	631.00	3,748.00
	percent	0	0	0	0	11.28	55.24	22.10	11.38	100.00	20.25	
Alameda-Albuquerque	acres	0	0	31.00	597.00	2,072.00	6,535.00	2,901.00	1,853.00	13,990.00	1,468.00	15,457.00
	percent	0	0	.22	4.27	14.80	46.70	20.73	13.28	100.00	10.48	
Atrisco-Pajarito-Isleta	acres	0	0	0	11.00	1,832.00	7,025.00	2,850.00	528.00	12,246.00	1,887.00	14,133.00
	percent	0	0	0	.10	14.96	57.36	23.27	4.31	100.00	15.41	
Barr	acres	0	13.00	178.00	408.00	1,322.00	1,730.00	402.00	490.00	4,543.00	0	4,543.00
	percent	0	.28	3.90	9.00	29.10	38.10	8.85	10.77	100.00	0	
Peralta-Tome	acres	0	0	0	92.00	933.00	9,775.00	7,760.00	1,490.00	20,050.00	0	20,050.00
	percent	0	0	0	.46	4.66	48.75	38.70	7.43	100.00	0	
Los Lunas-Belen	acres	0	0	64.00	236.00	1,960.00	11,215.00	7,225.00	3,120.00	23,820.00	674.00	24,494.00
	percent	0	0	.27	.99	8.24	47.10	30.30	13.10	100.00	2.82	
San Juan	acres	69.00	363.00	424.00	376.00	583.00	3,815.00	2,645.00	224.00	8,499.00	0	8,499.00
	percent	.81	4.27	4.98	4.43	6.86	44.88	31.15	2.62	100.00	0	
San Francisco	acres	154.00	133.00	235.00	408.00	1,843.00	1,437.00	580.00	554.00	5,344.00	0	5,344.00
	percent	2.88	2.49	4.40	7.64	34.48	26.87	10.87	10.37	100.00	0	
San Acacia-Lemitar-Socorro	acres	0	182.00	186.00	322.00	1,107.00	3,395.00	2,928.00	2,516.00	10,636.00	0	10,636.00
	percent	0	1.71	1.75	3.03	10.40	31.85	27.62	23.65	100.00	0	
San Antonio	acres	0	0	0	91.00	415.00	2,520.00	2,087.00	923.00	6,036.00	0	6,036.00
	percent	0	0	0	1.51	6.88	41.75	34.56	15.30	100.00	0	
Bosque del Apache Grant	acres	358.00	814.00	1,772.00	2,040.00	1,476.00	544.00	230.00	208.00	7,442.00	448.00	7,890.00
	percent	4.81	10.93	23.80	27.42	19.83	7.32	3.09	2.80	100.00	6.03	
Valley total [2]	acres	223.00	712.00	1,130.00	2,852.00	13,041.00	52,564.00	31,981.00	12,830.00	115,323.00	4,660.00	119,983.00
	percent	.19	.62	.98	2.46	11.30	45.64	27.69	11.12	100.00	4.04	

[1] The percentage given in this and subsequent lines, including that for unsurveyed area, is the percentage of the surveyed area.
[2] Bosque del Apache area not included in totals.

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TABLE 49.—*Comparison of depths to ground water in the Middle Valley in 1927 and 1936*

District	Year	Percentage of area with depth to ground water over—								Unsurveyed area in percent of surveyed	Average depth to water, in feet	Average lowering of water table, in feet	Average change in 1936 from July to October, in feet	Acreage in each district		
		8 feet	6 feet	4 feet	3 feet	2 feet	1 foot	0 foot	Above ground surface					Surveyed	Unsurveyed	Total
Algodones-Bernalillo	1927	......	20.97	39.71	......	70.21	86.49	95.23	4.77	1.72	3.58	......	......	11,983	197	12,180
	1936	11.10	38.33	86.49	95.33	99.54	99.71	100.00	......	......	5.72	2.14	−0.33	7,043	0	7,043
Corrales	1927	......	2.86	26.69	......	51.71	69.52	91.64	8.36	0	2.48	......	......	3,038	0	3,038
	1936	11.38	33.48	88.72	100.00	......	......	......	......	20.25	5.73	3.25	−.30	3,117	631	3,748
Alameda-Albuquerque	1927	......	8.02	13.18	......	37.19	62.56	88.48	11.52	0	1.99	......	......	14,675	0	14,675
	1936	13.28	34.01	80.71	95.51	99.78	100.00	......	......	10.48	5.61	2.62	−.68	13,989	1,468	15,457
Atrisco-Pajarito-Isleta	1927	......	7.22	24.80	......	72.60	89.25	96.87	3.13	1.17	3.09	......	......	15,823	186	16,009
	1936	4.31	27.58	84.94	99.90	100.00	......	......	......	15.41	5.41	2.32	−.86	12,246	1,887	14,133
Barr	1927	......	0	7.60	......	41.05	72.59	91.18	8.82	0	1.91	......	......	4,185	0	4,185
	1936	10.77	19.62	57.72	86.82	95.82	99.72	100.00	......	0	4.80	2.89	−1.62	4,543	0	4,543
Peralta-Tome	1927	......	9.33	13.56	......	47.99	69.52	93.24	6.76	0	2.22	......	......	20,541	0	20,541
	1936	7.43	46.13	94.88	99.54	100.00	......	......	......	0	5.99	3.67	−.19	20,050	0	20,050
Los Lunas-Belen	1927	......	10.54	22.39	......	75.39	94.24	99.88	.12	.37	3.23	......	......	25,047	92	25,139
	1936	13.10	43.40	90.50	98.74	99.73	100.00	......	......	2.82	5.97	2.74	−.40	23,820	674	24,494
San Juan	1927	......	1.51	21.69	......	68.22	91.34	96.97	3.03	.39	2.87	......	......	6,198	26	6,224
	1936	2.62	33.77	78.65	85.51	89.94	94.92	99.19	.81	0	5.10	2.23	.05	8,499	0	8,499
San Francisco	1927	......	11.52	25.65	......	39.26	51.91	75.48	24.52	0	2.12	......	......	4,616	0	4,616
	1936	10.37	21.24	48.11	82.59	90.23	94.63	97.12	2.88	0	4.50	2.38	1.39	5,344	0	5,344
San Acacia - Lemitar - Socorro	1927	......	12.47	24.36	......	53.55	72.79	88.78	11.22	4.76	2.66	......	......	13,437	640	14,077
	1936	23.65	51.27	83.12	93.52	96.54	98.29	100.00	......	0	6.13	3.47	.22	10,636	0	10,636
San Antonio	1927	......	4.81	21.63	......	63.31	87.10	97.65	2.35	37.34	2.83	......	......	5,016	2,620	7,636
	1936	15.30	49.86	91.61	98.49	100.00	......	......	......	0	6.16	3.33	−.07	6,036	0	6,036
Bosque del Apache Grant	1927	......	0	11.55	......	60.04	80.12	93.07	6.93	31.55	2.37	......	......	6,290	1,985	8,275
	1936	2.80	5.89	13.21	33.04	60.46	84.26	95.19	4.81	6.02	2.60	.23	.86	7,442	448	7,890
Valley total	1927	......	9.54	21.69	......	59.32	79.56	93.85	6.15	4.56	2.75	......	......	124,559	3,761	128,320
	1936	11.12	38.81	84.45	95.75	98.21	99.19	99.81	.19	4.04	5.69	2.94	......	115,323	4,663	119,983

NOTE.—Bosque del Apache area not included in totals. Depths for 1936 are from measurements taken in October; those for 1927 are average for 1926–27.

comparison with ground-water conditions of 1936 and gives further information on conditions prior to drainage of the valley. A complete and detailed comparison of the data cannot be made because it was impossible to determine accurately the locations of many of the observation wells of the earlier investigation. In a few areas, however, enough old wells were found to furnish a key for locating the remainder in those areas. One of the areas which was best "covered" with wells in the 1917–22 investigation was that between Albuquerque and Alameda, and a contour map for this area showing the average position of the water table in the period 1918–22 was drawn, based on the data obtained in that period. The outstanding characteristic of this map is the perpendicularity of the contours to the river. It is indicated that in this area there was little movement of ground water into or from the river during the period 1918–22. This condition, if typical for the valley, is of much importance, for it indicates that previous to drainage the amount of ground-water seepage from the river was small. Rough ground-water contour maps of the Belen and Albuquerque divisions for months showing high and low ground-water stages in the period 1918–22, plotted according to locations on the old maps, indicate flat lateral gradients, and the undrained Bosque del Apache Grant shows the same flat lateral gradients today. Typical ground-water profiles across the valley, given in the report of the 1917–22 investigation show average gradients near the river of 0.0006. With a transverse valley coefficient of transmissibility of 50,000 (a figure to which present meager data point), this gradient would indicate a ground-water flow of 0.25 second-foot per lineal mile of river, and if the length of the valley between Pena Blanca and San Marcial is taken as 150 miles, the total seepage from the river on both sides would then have been 75 second-feet, or about 50,000 acre-feet a year.

A tentative opinion as to the amount of ground-water inflow from the borders of the valley prior to drainage can also be formed from the earlier data. The 1918–22 map of the Albuquerque-Alameda area shows that the ground-water contours approach the hillsides only slightly deflected from the perpendicular. The contours in the Bosque del Apache area also approach the hillsides near to the perpendicular, and little flow from the mesas is indicated in this area where control is good. The general average of water-table gradients from the mesa to the flood plain, as shown by the profiles of the 1917-22 investigation, is 0.00065. This indicates, therefore, about the same flow from the mesas that was indicated as probably coming from the river, that is, about 50,000 acre-feet in the 150 miles between Pena Blanca and San Marcial. This figure might be increased somewhat to allow for concentrated flow near the debouchures of arroyos on which data are scarce, but it does not seem that the aggregate inflow could have exceeded 100,000 acre-feet. The ground-water flow from the mesas is presumably about the same now as it was before the construction of drains. The figure of 100,000 acre-feet per year would represent a flow from the hillsides of about 0.5 second-foot per mile, and this in turn represents about half the minimum accretion to interior drains per mile as measured in the Isleta-Belen section during the winter of 1936–37 when there was little, if any, irrigation.

If these figures of river and mesa seepage are approximately correct, the much larger apparent loss of water in the valley in former years must have been due chiefly to other causes, and there must have been other and more important sources of water to support the transpiration of native vegetation. Losses from the river other than by seepage were by diversions for irrigation, by evaporation in the river channel to an extent probably greater than now obtains, and by losses suffered through spreading of the water and consequent infiltration during floods. Of these, diversions for irrigation must have been, by far, most important.

Rincon, Mesilla, and El Paso Valleys

Ground-water data for these valleys are very meager and no study of ground-water conditions in them was included in the Rio Grande joint investigation. These valleys comprise the Rio Grande Project, which is well provided with open drains that satisfactorily maintain ground-water levels at the depths below ground surface required to prevent waterlogging and seeping of the lands.

Periodic measurements of the depths to ground water in 55 to 88 wells in Mesilla Valley have been made by the Bureau of Reclamation in every year since 1924. The observations were made and the results were used chiefly to derive the annual increment or decrement of ground water as a necessary factor in computing the annual consumptive use of water in the valley by the inflow-outflow method. The data were made available to the Bureau of Agricultural Engineering and were used by the bureau in its study of the consumptive use of water in Mesilla Valley as reported in part III of this report.

Average depths to ground water in Mesilla Valley as shown by the January observations have been between 9 and 10 feet throughout the period from 1924 to date.

Quality of Water

In the Upper Rio Grande Basin drainage from the irrigation of upper lands returns to the river and is rediverted to lower lands, and this process is repeated many times in the length of river valleys from the upper to lower limits of the basin. Also the major portion of the water supply reaches the river in the upper portions of the basin with very little contribution from downstream tributaries. Under these conditions the salt concentration of the downstream irrigation waters becomes increasingly higher. Quality of water, as well as quantity of water, becomes, therefore, an important consideration, particularly with respect to the waters that are available to the lowest lands in the basin, such as those in the Tornillo unit of the Rio Grande Project and in the Hudspeth District. With higher salinity of the irrigation water, more abundant applications are needed to prevent the accumulation of salts in the soil and resultant deleterious effects upon plant growth.

In view of these conditions, a comprehensive investigation of the quality of water was made a part of the Rio Grande joint investigation. Samples of water for analysis were taken at frequent intervals from streams, drains, and ground water throughout the basin. These samples were taken under the supervision of the Geological Survey by the field men and members of other agencies cooperating in the investigation. The analyses were made by the Geological Survey, the means employed consisting of conductance tests at field laboratories at Albuquerque and Alamosa, and complete determinations at Washington. Assembly and compilation of the analytical data, together with the summarization and interpretation of them, were done by the Bureau of Plant Industry. A cooperative quality-of-water investigation confined chiefly to conditions along the main stem of Rio Grande had been conducted since 1930 by the Bureau of Plant Industry, Bureau of Reclamation, Geological Survey, International Boundary Commission, and the Colorado State Engineer. The data obtained by this earlier investigation were also assembled by the Bureau of Plant Industry and included with those of the 1936 investigation. The interpretive digest by the Bureau of Plant Industry is included in this report as part IV. The more detailed analytical data are published separately. In the following paragraphs data and results of the investigation as given in the interpretive report are summarized.

The Rio Grande from Del Norte to Fort Quitman

Total yearly quantities and weighted mean concentrations of salts in the water of Rio Grande passing the nine principal gaging stations from Del Norte to Fort Quitman are given in tables 50, 51, and 52. Table 50 gives the 1936 data for all nine stations; table 51, the means for 3 years, 1934–36, for Lobatos, Otowi Bridge, and San Marcial; and table 52, the means for 6 years 1931–36, for the five stations from Elephant Butte Dam to Fort Quitman. These tables indicate clearly the progressive increase in total salt concentration of the river water from the upper to the lower limits of the basin. In 1936, the mean concentration ranged from 0.11 ton of salt per acre-foot of water at Del Norte to 2.84 tons per acre-foot at Fort Quitman. The latter figure is equivalent to approximately 2,100 parts per million. As shown in both tables 50 and 51, a progressive increase in the total tonnage of salts carried occurs from Del Norte to San Marcial. Below San Marcial there is little change through the reservoir and then, as shown by the 6-year means of table 52, there is a small increase in tonnage to Leasburg Dam, a slight decrease to El Paso, a decided decrease to Fabens, and a smaller one to Fort Quitman. In the period 1931–36 the river has apparently lost 147,000 tons of salts annually between Elephant Butte Reservoir and Fort Quitman. There was, however, an annual gain of 18,000 tons between the reservoir and El Paso, so that between the latter station and Fort Quitman there was an annual loss of 165,000 tons of salts. In comment on this the report of the Bureau of Plant Industry states:

It is obviously not to be inferred that all of the dissolved solids shown to be lost from the stream between those two points are deposited in the soils of the El Paso Valley division. The data available do not appear to warrant definite quantitative conclusions as to where these dissolved solids are deposited. But painstaking consideration of the available data and reviewing of the computations by which the summaries have been obtained leads to the belief here stated; namely, that there is a very substantial quantity of soluble solids deposited annually somewhere along the Rio Grande between El Paso and Fort Quitman.

It is to be noted not only that the quantities of total dissolved solids passing the stations differ greatly but also that the quantities of each constituent differ even more, so that the composition of the dissolved solids changes appreciably from station to station. Probably the most striking of these changes is the progressive increase downstream in the quantity of the chloride constituent. For 1936, the only year for which data are available for all nine stations, the quantity of chloride increased from [illegible],300 tons at the Del Norte station to 137,000 tons at the Fort Quitman station. The increase in sodium, from 4,000 tons to 92,000 tons, was also large.

The San Luis Section.

With respect to the waters of San Luis Valley, the data show that the tributary streams contain relatively very little dissolved material. The water leaving the valley in Rio Grande seldom contains more than half a ton of salts per acre-foot and frequently less than a quarter of a ton. The water in the drains north of the river is also of relatively low salinity. Two stations on San Luis Lake showed conductances ranging from 64 to 108. In some of the drains south of the river the salinity is relatively high and doubtless from this area most of the salt is derived that the river carries out of the valley. Data on the ground waters indicate that those around the margins of the valley are of low salinity with low sodium percentages, being similar in character to the inflowing surface waters. In the lower sections of the valley there are two areas in which the shallow

TABLE 50.—*Totals and weighted mean concentrations of salts in the Rio Grande in 1936 at 9 control stations*

Item	Gaging and sampling stations								
	Del Norte	Lobatos	Otowi Bridge	San Marcial	Elephant Butte outlet	Leasburg Dam	El Paso (Courchesne)	Fabens-Tornillo[1]	Fort Quitman
River discharge, in 1,000-acre-feet units	472	281	1,072	867	747	593	474	224	150
Dissolved solids, in 1,000-ton units	52	74	352	653	590	596	560	423	426
Concentrations:									
Tons per acre-foot	0.11	0.26	0.33	0.75	0.79	0.86	1.18	1.93	2.84
Conductance, $K \times 10^5$ at 25° C	8.5	26.5	30.5	79.4	86.3	91.5	129.9	245.2	332.0
Sum, milliequivalents	2.27	5.71	7.49	17.31	17.87	19.23	27.28	44.17	66.27
Constituents, in 1,000-ton units:									
Calcium (Ca)	7.2	10.6	63.9	88.7	76.3	76.3	63.8	42.1	38.8
Magnesium (Mg)	2.1	2.7	12.2	18.2	15.9	15.5	13.3	10.2	9.3
Sodium (Na)	4.4	8.0	80.2	98.2	90.8	91.1	103.4	87.0	92.5
Bicarbonate (HCO_3)	13.7	18.0	94.1	106.7	82.3	81.0	69.8	38.1	24.8
Sulphate (SO_4)	9.7	18.3	89.8	232.7	232.2	220.7	187.8	121.0	99.3
Chloride (Cl)	2.8	3.9	15.5	66.0	55.4	64.5	91.1	105.3	136.9
Nitrate (NO_3)	.2	------	.9	.8	.1	1.5	2.1	.7	.8

[1] Discharge is sum of diversion to Tornillo Canal and River flow at Tornillo Bridge. Samples taken at head of Tornillo Canal.

TABLE 51.—*Annual totals and weighted mean concentrations of salts in the Rio Grande at 3 control stations above Elephant Butte Reservoir; means for 1934 to 1936, inclusive*

Item	Gaging and sampling stations		
	Lobatos	Otowi Bridge	San Marcial
River discharge, in 1,000-acre-feet units	247	851	714
Dissolved solids, in 1,000-ton units	67	293	591
Concentrations:			
Tons per acre-foot	0.27	0.34	0.83
Conductance, $K \times 10^5$ at 25° C	27.9	31.8	97.2
Sum, milliequivalents	5.84	7.76	18.63
Constituents, in 1,000-ton units:			
Calcium (Ca)	9.3	[illegible]	[illegible]
Magnesium (Mg)	[illegible]	[illegible]	[illegible]
Sodium (Na)	[illegible]	[illegible]	[illegible]
Bicarbonate (HCO_3)	16.3	80.9	90.4
Sulphate (SO_4)	16.3	71.6	214.6
Chloride (Cl)	3.6	11.9	57.4
Nitrate (NO_3)	.2	1.1	1.4

TABLE 52.—*Annual totals and weighted mean concentrations of salts in the Rio Grande at 5 control stations below Elephant Butte Reservoir; means for 1931 to 1936, inclusive*

Item	Gaging and sampling stations				
	Elephant Butte outlet	Leasburg Dam	El Paso (Courchesne)	Fabens-Tornillo[1]	Fort Quitman
River discharge, in 1,000-acre-feet units	766	745	523	257	172
Dissolved solids, in 1,000-ton units	620	647	638	496	473
Concentrations:					
Tons per acre-foot	.81	.87	1.22	1.93	2.75
Conductance $K \times 10^5$ at 25° C	87.1	91.0	127.2	212.0	296.7
Sum, milliequivalents	18.32	19.97	28.71	46.51	65.81
Constituents, in 1,000-ton units:					
Calcium (Ca)	78.3	81.8	70.3	47.8	40.8
Magnesium (Mg)	17.0	17.9	15.5	11.4	10.0
Sodium (Na)	96.6	104.0	124.3	104.4	111.6
Bicarbonate (HCO_3)	94.4	95.8	81.4	46.9	28.5
Sulphate (SO_4)	234.7	259.0	210.1	135.3	107.2
Chloride (Cl)	56.7	72.4	112.7	126.8	160.9
Nitrate (NO_3)	.3	1.3	1.7	.7	.6

[1] Discharge is sum of diversion to Tornillo Canal and river flow at Tornillo Bridge. Samples taken at head of Tornillo Canal.

TABLE 53.—*Mean conductance of irrigation water and water in riverside and interior drains of Middle Rio Grande Conservancy District, N. Mex., 1936*

Divisions	Mean conductance, $K \times 10^6$ at 25° C.		
	Irrigation water	Riverside drains	Interior drains
Cochiti and Albuquerque	37.9	52.7	88.5
Belen	53.2	71.1	163.0
Socorro	89.0	110.7	155.0

TABLE 54.—*Salinity of ground waters of the Middle Rio Grande Valley, 1936*

Item	Division of Middle Rio Grande Conservancy District		
	Albuquerque	Belen	Socorro
SUBSOIL WATERS			
Conductance tests only:			
Number of stations	138	156	70
Mean conductance	158	274	337
Detailed analyses:			
Number of stations	35	37	20
Mean conductance	146	276	319
Percent sodium	42	52	56
Percent chloride	13	20	24
DEEP WELLS			
Detailed analyses:			
Number of stations	11	11	12
Mean conductance	74	157	150
Percent sodium	32	58	55
Percent chloride	11	19	20

or subsoil waters are generally rather saline. Toward the middle of the valley the deeper water is generally "soft"—i. e., it has a high sodium percentage—and in the area north of the eastern edge of the Rio Grande delta the deeper waters are both soft and rather saline.

The Middle Section

The waters contributed by tributary streams of the Middle section above Galisteo Creek on the east side are of low salinity, with conductances ranging from 5 to 72. Those of Rio Chama are likewise of low salinity, with conductances less than 80. The low-water charges of Jemez Creek, Rio Puerco, and Rio S. are comparatively saline, with conductances ranging up to 400 or more. The dissolved salts carried by these 3 streams consist largely of sulphates of calcium, sodium, and magnesium. Comparison of the mean conductance of the irrigation water and of that in the riverside and interior drains of the Middle Rio Grande Conservancy District as found in 1936 is shown in table 53. There is a progressive increase southward in the salinity of the irrigation and riverside drain water, but not in the interior drain water between Belen and Socorro divisions. This exceptional situation with respect to the interior drain water probably is accounted for by the fact that the Socorro division is narrow and its interior drains are in a position to receive more direct seepage from the river than do those in other divisions. A summary of the data on the salinity of ground water in the Middle Valley is given by table 54.

The Elephant Butte-Fort Quitman Section

The total quantities and mean concentrations of salts in the drain waters of the Rincon, Mesilla, and El Paso divisions of the Rio Grande project are shown in table 55. The similar quantities for the river water at stations above and below each division are also sh for purposes of comparison. The data are derived from the detailed analyses made in the period 1929–36, and they represent mean values for that period. Summarizing the conditions as shown by table 55, the river brings into the area annually from Elephant Butte Reservoir about 766,000 acre-feet of water carrying about 620,000 tons of dissolved solids. It takes away from the area, past Fort Quitman, about 172,000 acre-feet of water carrying about 473,000 tons of dissolved

TABLE 55.—*Totals and mean concentrations of salts in river and drain water of divisions of Rio Grande Project, New Mexico and Texas; means for 1930–36*

Divisions	Mean annual discharge		Mean concentrations		Range of constituent percentages [1]					
	Water acre-feet	Total dissolved solids tons	Conductance	Total dissolved solids tons per acre-foot	Ca	Mg	Na	HCO_3	SO_4	Cl
River at Elephant Butte Outlet	766,000	620,000	87	0.81	41	15	44	32	51	17
Rincon: Totals of 4 drains	36,400	48,100	109–142	1.32	41–49	12–13	38–47	26–36	40–46	23–28
River at Leasburg Dam	745,000	647,000	91	.87	41	14	45	31	49	20
Mesilla: Totals of 12 drains	206,000	383,000	108–442	1.87	17–44	10–15	41–73	15–37	32–43	22–53
River at El Paso (Courchesne)	523,000	638,000	127	1.22	35	12	53	26	43	31
El Paso:										
Totals of 7 drains above Fabens	79,900	331,000	180–419	4.15	27–36	10–13	51–63	13–23	27–42	35–60
Tornillo drain (4 drains tributary)	52,900	243,000	299–945	4.59	27–36	7–12	52–66	5–16	17–30	54–76
			517		32	9	59	9	22	69
Division totals	133,000	574,000	180–945	4.32	27–36	7–13	51–66	5–23	17–42	35–76
River at Fort Quitman	172,000	473,000	296	2.75	26	11	63	12	29	59

[1] Percent of sum of milligram equivalents of cations for calcium, magnesium, and sodium and of sum of milligram equivalents of anions for bicarbonate, sulphate, and chlo

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solids. Between these two stations on the river the irrigation and drainage of the contiguous agricultural lands results not only in changing the concentration of the dissolved solids of the stream waters but also in changing, and appreciably, the composition of those dissolved solids. The change of concentration is upward at successive stations along the stream and it is accompanied by higher concentrations in the drain waters and in the subsoil waters as sampled from observation wells. The changes in composition are in the direction of higher percentages of sodium and of chloride, with lower percentages of the other four major constituents.

TABLE 56.—*Salinity of ground water in observation wells and contiguous drains in divisions of Rio Grande Project, New Mexico and Texas, 1936*

Division	Salinity in terms of conductance $K \times 10^5$ at 25° C.			
	Observation wells		Drains	
	Number sampled	Mean conductance	Number sampled	Mean conductance
Rincon	4	200	4	145
Mesilla	16	237	7	206
El Paso:				
Above Fabens	11	705	3	448
Below Fabens	44	570	3	497

The salinity of ground waters in the divisions of the Rio Grande Project, as indicated by conductance determinations of well samples taken in 1936, is shown in table 56. The mean conductance of water of the drains contiguous to the observation wells, as derived from samples taken during the same period as that in which the well samples were taken, is also shown for comparison.

Control of Salinity

In the problem of high concentration of salts in the irrigation water and the conditions under which such water may be used without harmful effects on plant growth, the controlling factor to be considered is the concentration of the soil solution within the root zone of the plants. When irrigation water is applied to land, some of the water, usually the major portion of it, is evaporated from the soil or transpired by plants, chiefly the latter. The surplus, if any, passes away either by downward percolation, or by moving laterally as subsoil drainage. Because of the losses by evaporation and transpiration, the residual water becomes more concentrated with soluble material. Thus the "soil solution" in irrigated land is normally more concentrated than the water with which the soil is irrigated, but the degree of greater concentration depends upon what proportion of the water applied to the soil surface ultimately percolates through the root zone and escapes below. As the proportion of the volume of root-zone percolation to the volume of water applied increases, the difference between the concentration of the soil solution and that of the irrigation water diminishes. Consequently, if injurious concentrations of salinity in the soil solution are to be avoided, more irrigation water must be applied if it is highly saline than would be needed if it were less saline. Hence, as a practical consideration in the control of salinity, a definite determination is needed of the application of irrigation water required in order that a given concentration of the soil solution shall not be exceeded.

The essential elements in this problem are listed in the report of the Bureau of Plant Industry. They include:

(1) Consumptive use, i. e., the quantity of water, in depth per unit area, required to support crop growth and meet evaporation losses.

(2) Irrigation requirement; i. e., the quantity of water, in depth per unit area, required, not only for consumptive use, but also to provide sufficient percolation through the root zone to keep the concentration of the soil solution below a given maximum.

(3) Concentration of the irrigation water either in respect to total dissolved solids or in respect to any constituent regarded as potentially most likely to cause trouble.

(4) Concentration of the soil solution in the root zone, measured by the same standards, or as to the same constituent as used for the irrigation water.

Several equations have been developed to express the relationship between these elements, but as the quantitative factors involved are yet somewhat indefinite, it has been considered best, in this report, to proceed more or less arbitrarily in assuming allowances to maintain the desired salt balance. The basis on which these allowances have been assumed appears later in this report in connection with consideration of water uses and requirements.

PART I
SECTION 3.—IRRIGATION DEVELOPMENT

History of Development

Recorded history of the Rio Grande Valley begins with its discovery by the Spanish explorers under Coronado in 1540. As reported by his expedition, Indians were living in pueblos in what is now known as the Middle Valley in New Mexico, cultivating land and bringing water to it by irrigation ditches as their ancestors long had done. An outline of the early development of irrigation is given by Follett in his 1896 report to the International Boundary Commission, as follows:

> Before the middle of the sixteenth century the Spaniards entered New Mexico and the valley of the Rio Grande and there found the Pueblo Indians, living in their many-storied towns and cultivating the land of the valleys, bringing water onto it by acequias, or irrigating ditches, many of which are still in use to this day. How long these Indians had been on the ground is unknown, but they were even then old inhabitants, and raised not only grain and fruit, but even flowers, as one poetical and doubtless homesick Spaniard wrote that roses bloomed along the acequia bank "as bloomed the roses of beautiful Aragon." There are some 17 or 18 of these settlements of Pueblo Indians in New Mexico, each holding a land grant 2 leagues square and each with its own pueblo, containing from 200 to 600 people. There were at least this number of pueblos when the Spaniards came to the country, and probably several more, as the ruins of three or four still exist. The inhabitants of each pueblo were then much more numerous than now. In other words, prior to the middle of the sixteenth century, 350 years ago, there were some 15,000 to 20,000 people living from products raised by irrigation in the Rio Grande drainage above the Jornado del Muerto, and the area of irrigated land probably exceeded 30,000 acres.
>
> While the Spaniards first entered New Mexico from Sonora and the Gulf of California, the first attempts at colonization were made from El Paso as a base, the Spanish conquest of Mexico having extended to the Rio Grande. This first attempt was made in 1598, and the first Spanish capital of New Mexico was then established at Chamita, in the Espanola Valley, just above the mouth of the Chama. This was abandoned in 1605, and the inhabitants and capital transferred to Santa Fe, where they and their descendants remained until 1680, engaged principally in mining. Then the Pueblo Indians revolted and drove the Spaniards from the country. In 1692 it was reoccupied by the Spaniards and permanently held. Bernalillo was founded about 1700 and Albuquerque in 1706. Settlements were made along the Rio Grande, both in the Albuquerque and Espanola Valleys, and also up the Chama, the Abiquiu grant on the latter stream being made to the inhabitants of that town in 1739. El Rito, some 20 miles northeast of Abiquiu, was occupied in 1730.
>
> The Mexicans did not penetrate to the San Luis Valley, judging from the water rights there granted, until after 1850, the oldest water claim in that valley being that of the San Luis People's Canal, on Culebra Creek, whose appropriation dates back to 1852. For the 10 or 12 years after 1852 the settlements in the San Luis Valley were confined to the country on the Costilla and Culebra and to the Conejos Valley, the town of Conejos being founded in 1855. In 1866 and 1867 settlements were started on the Rio Grande, San Luis, and Saguache, while the next 3 years saw farms opened and small ditches taken out on the Carnero, the La Garita, Alamosa, and La Jara, but all of these, except those at Conejos, were confined to the little valleys back in the hills around the margin of the San Luis Valley proper. On these farms the principal product was hay. This the Mexicans fed in winter to their stock, to which the main valley furnished abundant pasturage for the greater portion of the year.
>
> About 1873 or 1874 the Americans began to move into the San Luis, but still the farm lands were confined to the small side valleys. The first settlement in the San Luis Valley proper, outside of Conejos, was made by the Mormons, who founded Manassa in 1878 or 1879. About this time the Denver & Rio Grande Railroad built into the valley. The main industry was still cattle raising, however, until about 1882. Then commenced the era of large canal building, which continued for 10 years. During this time were built the Rio Grande, Monte Vista, Empire, San Luis Valley, Costilla, Prairie, and Farmers' Union Canals, besides many others. All those named head on the Rio Grande between Del Norte and Alamosa, and, stretching 30 or 40 miles north and south from the river, cover the whole of the western half of the valley with their network of laterals.

The San Luis Section

In the San Luis section, as indicated in the Follett report, irrigation began on Rio Grande tributaries, such as Culebra and La Jara Creeks and Conejos, San Antonio, and Costilla Rivers. Diversions for small ditches could be accomplished more easily from the smaller streams than from Rio Grande. A summary of the decreed water priorities in San Luis Valley to 1871 shows only 36 second-feet on Rio Grande as against 2,054 second-feet on tributaries. Subsequent to the building into the valley of the Denver & Rio Grande Railroad, construction began in 1879 on the Rio Grande Canal, the largest in the valley today. As noted by Follett, this was the forerunner of an intensive development in the following decade during which were built most of the larger canals which are now diverting water from Rio Grande. The great activity in this period is strikingly demonstrated by the fact that decreed water rights bearing dates between 1881 and 1890 total nearly 8,000 second-feet on the streams of the southwest area, Rio Grande, Alamosa, and La Jara Creeks, Conejos and San Antonio Rivers. Substantial development was made also in all other portions of the valley. From 1890 to 1900 development seems to have been confined largely to the area served by Rio Grande, as indicated by decreed rights to nearly

3,000 second-feet that were initiated for this area while ... water was decreed in other parts of the valley. ... record indicates that development had proceeded ... this time to the extent of greatest possible diversion of the natural stream flow and that storage developments were contemplated.

A serious condition soon complicated the situation. It was brought about by the rise in ground-water levels to such an extent that lands in the lower parts of the valley were becoming seeped. With continued large diversions from Rio Grande to the porous and shallow soils in the closed basin, the underground basin had filled rapidly; the water table had risen from depths ranging from 40 feet on the east to 100 feet on the west to a position practically at the surface on the east, bordering the sump, and to a level within 10 to 15 feet of the surface on the west.

Under the large network of canals built between 1880 and 1890, land was first brought in about 8 miles northeast of Monte Vista. Activities were extended from that locality to the north and east until in a short time the whole central portion of San Luis Valley as far north as Hooper became one flourishing wheat field.

A method of subirrigation peculiar to this region was developed and is still practiced as it is claimed to be e...ntial to the successful growth of crops under the ...d water-supply conditions which prevail. By it t... ground water is built up to within 1 to 3 feet of the surface and water is then allowed to run slowly through small ditches spaced about 8 rods apart. Water from these ditches seeps outward, supplying moisture to the plants. This method really constitutes in part a substitution of underground storage for "headwater" or stream storage in an effort to adjust the water supply to the irrigation demand. It results, however, in overdiversion during the spring run-off, in unduly high water tables, and in excessive evaporation and transpiration losses.

The rise in ground water and the seeping of lower lands soon began to force abandonment of acreages along the eastern side of the closed basin, with concomitant substitution of lands farther west. This gradual process of abandonment at the east and extension westward proceeded at a rate of half a mile to a mile per year, so that by 1910 or 1915 the once prosperous agricultural areas near Mosca and Hooper were under brush and salt grass, the farm houses abandoned, and the fences broken down. As years went by the irrigated zone shifted to the westward until it reached the extreme west side of the valley, while the broad stretch of once-occupied lands to the eastward was l... revert to its natural state, badly damaged, howe... y alkali.

Drainage to reclaim seeped lands in various parts of the valley began about 1911 and by 1921 eight drainage systems serving about 90,000 acres had been constructed. Of these, the Sylvestre, Gibson and Rio Grande are in the closed basin and the Parma, Carmel, McLean, Monte Vista Town, and Norton are in the southwest area. Drainage of the western area in the closed basin has developed waters which have aided in a progressive reoccupation of part of the neighboring lands to the eastward, but large areas between the present irrigated area and the old eastern boundary are still open for reclamation by irrigation and drainage, the only basic requirement being an available water supply.

Decreed water rights initiated in the period 1900 to 1920 total about 3,400 second-feet for the valley. Of these, 1,100 second-feet were for the Conejos-San Antonio area and 1,000 second-feet for the Trinchera area. Since 1920 little water has been decreed. Development has included the works constructed by the Del Norte Irrigation District to irrigated bench lands lying north of Rio Grande between Del Norte and Monte Vista, the dam for the Continental Reservoir and additional drainage systems. The latter include the drains of the San Luis Valley Irrigation District in the closed basin and the systems of the Waverly, Bowen, Morgan, Adams Lane, Manassa Town, and San Luis Valley Drainage District in the southwest area.

Although the development of storage to regulate the water supply for San Luis Valley was considered in the early 1890's, construction on any large scale was prevented by the "embargo" of 1896. This was an order by the Secretary of the Interior directing the Commissioner of the General Land Office to suspend action on all applications for rights-of-way across public lands in Colorado and New Mexico for use of Rio Grande water. It was issued expressly to prevent further depletion of the flow of Rio Grande in the Elephant-Butte-Fort Quitman section, and as a result of complaints by Mexico of water shortages and the subsequent investigation and report by Follett to the International Boundary Commission. This departmental order held until 1907, when it was modified to permit approval of applications for rights-of-way involving the diversion of storage of water in amounts not exceeding 1,000 acre-feet and of applications in connection with which there might be a showing that the rights of the applicants had been initiated prior to the beginning of active operations, on March 1, 1903, as stated, by the Reclamation Service for the Rio Grande Project. With this modification the embargo remained in effect until 1925, when it was lifted entirely.

Most of the reservoir development in the San Luis section that could be accomplished under the embargo took place between 1900 and 1915. The Rio Grande and Santa Maria Reservoirs in the upper Rio Grande watershed, with a combined capacity of about 93,000 acre-feet, were completed in 1913. La Jara and Terrace Reservoirs on La Jara and Alamosa Creeks were completed in 1910 and 1912, respectively. These have a combined capacity of about 32,000 acre-feet. Other reservoirs completed in this period include the Sanchez on Culebra Creek and Mountain Home and Smith on Trinchera Creek. The Continental Reservoir in the upper Rio Grande drainage, capacity 27,000 acre-feet, was completed in 1928.

Acreage irrigated.—For administrative purposes of the Colorado State engineer in distribution of the surface waters in accordance with rights decreed by the courts, the San Luis section comprises irrigation division no. 3 subdivided into eight water districts, nos. 20, 21, 22, 24, 25, 26, 27, and 35. The positions and approximate boundaries of these districts are shown on plate 1. The irrigation division is administered by a division engineer and each water district by a water commissioner reporting to the division engineer. These officials distribute the available water supply according to the various decrees and render weekly reports of the amount of water distributed, the latest priority receiving water, and other pertinent data. The division engineer makes an annual report embodying data on the ditches, reservoirs, quantity of water diverted, storage operations, acreage and crops irrigated, operation and maintenance costs, and the general conditions which have prevailed during the year. Except for Federal census data and the reports of a few surveys made in connection with engineering investigations, these reports of the division engineer have been the only available source for deriving the total acreage irrigated in the valley in the past. Such checks as could be made of the data on irrigated acreage in these reports indicate that they may be more or less inaccurate. This may be attributed in part to differences in interpretation of what areas were actually irrigated, involving, for example, the question as to whether or not certain extensive acreages of pasture were irrigated, but in the main it is attributable to the conditions and methods under which the data are obtained by the water commissioners. They do not make an actual survey, but rely upon information furnished by the water users. In general, the data from the water commissioner's reports appear to give totals higher than the actual irrigated acreage. Regardless of whether these data represent correct totals for each year, it is believed that they may be used to furnish an index of the trend of irrigation in the valley. In a report on "Investigations in the Middle Rio Grande Valley" submitted in 1932 by E. B. Debler, hydraulic engineer of the Bureau of Reclamation, the annual data on the irrigated acreages in San Luis Valley as given by the water commissioner's reports were compiled by water districts for the period 1880 to 1930. This compilation has been reproduced, with the addition of data for the years 1931 to 1935, as table 57 of this report.

In the period 1925–34 four special field surveys were made of the irrigated acreage in San Luis Valley. The first was made in 1925–26 by R. J. Tipton for the Colorado State engineer. The other three were made in connection with investigations by the New Mexico State engineer; in 1927 by E. P. Osgood; in 1932 by J. H. Bliss; and in 1934 by Russell Dallas. The data of these surveys are shown in table 58.

The Middle Section

Follett's historical outline previously quoted furnishes some information on the beginning of agricultural and irrigation development in the Middle Valley. A more detailed account of events during the Spanish occupation of significance in tracing irrigation development is given in the 1928 report to the Middle Rio Grande Conservancy District by J. L. Burkholder. The following statements are quoted from pages 23 to 25 of that report:

> The first Spaniards to visit New Mexico were treasure seekers under Coronado. They accomplished little in the way of developing the country and, disappointed in their quest for the fabulous wealth of "Cibola", returned to Mexico in 1542.
>
> It was not until 1598 that a real colonizing expedition under Don Juan de Onate came into the valley and founded a settlement near the mouth of the Rio Chama at the Indian pueblo of Yugewinge. This settlement was christened San Juan de los Caballeros and was the first capital of the new empire. Here, with the assistance of 1,500 Indians, Onate built a canal or "acequia" which was probably the first Spanish ditch in the country.
>
> A few years later (probably 1609) this settlement was abandoned and a new capital was established at the Ciudad Real de la Santa Fe de Francisco de Assizi, where it remains today under the short name of Santa Fe.
>
> Exploration and colonization were carried on from Santa Fe for a period of about 75 years, but in 1680 the Indians rose in revolt and drove the Spaniards out of the country. They retired to Paso del Norte (the El Paso of today) and remained there for 12 years. In 1692, under Don Diego de Vargas, they put down the Indian rebellion and returned to Santa Fe and the Rio Grande valley.
>
> At this time many vast Spanish land grants were made, in recognition of services rendered during the pueblo rebellion, and the real development of the country began. Perhaps because of the location of Santa Fe, which was the capital and headquarters for the entire country, this development took place generally from north to south, the country near Santa Fe being settled first.
>
> In almost regular progression down the river to the south, settlement and development followed. Bernalillo was founded about 1700 on a land grant from the Spanish Crown.
>
> The Villa de San Felipe de Albuquerque, named for King Philip of Spain and his viceroy, the Duke of Albuquerque, was settled in 1706 on the site of the old "hacienda" of Don Luis Carbajal, which had been destroyed by the Indians during the uprising of 1680.
>
> In 1739 certain residents of Albuquerque, dissatisfied with conditions there, moved a few miles to the southward and established the settlement known as Nuestra Senora de la Conception

TABLE 57.—*Acreages irrigated in San Luis Valley, as derived from water commissioner's reports*

Year	Water districts								Total irrigation division no. 3
	No. 20	No. 21	No. 22	No. 24	No. 25	No. 26	No. 27	No. 35	
1880	26,205	15,100	24,100	8,650	34,100	16,660	4,000	2,640	131,475
1881	29,670	17,800	31,200	8,700	35,340	17,270	4,000	2,640	146,620
1882	44,115	18,300	33,700	8,700	35,950	17,600	4,000	2,640	165,085
1883	56,315	19,900	44,400	8,800	36,810	18,725	4,000	2,640	191,590
1884	58,785	22,000	45,400	8,800	39,120	20,380	4,000	2,670	201,155
1885	51,935	24,000	51,700	8,800	39,450	20,655	4,000	2,670	213,210
1886	66,045	29,300	56,400	8,800	39,930	21,230	4,000	2,890	228,595
1887	72,675	38,200	57,400	8,800	40,950	22,210	4,000	2,890	247,125
1888	88,630	42,000	59,400	8,800	43,600	22,505	4,000	4,040	272,975
1889	97,535	42,000	60,000	8,800	45,950	22,505	4,000	4,520	285,310
1890	112,480	44,000	60,000	10,000	45,950	22,505	4,000	4,780	303,715
1891	166,480	46,000	55,000	10,000	46,750	21,430	4,000	4,780	354,440
1892	216,685	45,000	50,000	10,000	47,550	20,290	4,000	4,780	398,305
1893	179,785	44,000	45,000	10,000	46,200	19,160	4,000	4,780	352,925
1894	166,085	42,000	50,000	10,000	44,760	18,020	4,000	4,780	339,635
1895	164,795	41,550	55,000	9,500	42,940	16,550	4,040	4,430	339,105
1896	139,795	37,940	60,525	7,050	46,295	20,205	2,670	4,180	318,760
1897	162,229	39,929	[1] 60,000	6,199	45,408	12,360	4,586	[1] 4,500	335,211
1898	134,277	28,604	[1] 45,000	10,537	23,941	19,857	[1] 3,000	[1] 4,000	269,216
1899	200,544	[1] 45,000	[1] 50,000	10,637	44,591	3,755	1,569	[1] 5,000	361,096
1900	209,650	58,934	[1] 55,000	10,541	46,098	23,606	[1] 3,000	[1] 6,000	412,829
1901	258,000	17,600	[1] 60,000	10,528	44,686	23,658	2,000	10,000	426,472
1902	96,920	22,342	[1] 30,000	11,067	14,519	5,155	1,303	6,245	187,551
1903	[2] 175,000	30,121	43,920	11,045	43,075	11,275	3,230	[1] 6,000	323,666
1904	126,234	14,412	[1] 35,000	6,739	16,141	5,479	3,531	[1] 4,000	211,536
1905	232,246	28,456	[1] 70,000	8,407	[1] 15,000	16,143	2,585	[1] 5,000	377,837
1906	249,931	31,000	73,004	16,655	16,180	20,116	1,555	[1] 5,000	413,441
1907	267,057	30,675	74,798	17,068	26,797	24,273	1,801	11,900	454,369
1908	278,099	38,485	66,730	16,800	25,338	14,275	1,532	[1] 5,000	444,259
1909	208,302	31,942	104,748	20,412	[3] 22,744	25,021	4,282	[1] 4,000	421,451
1910	248,097	34,146	93,442	35,910	20,281	24,709	5,397	3,478	465,460
1911	247,077	61,732	87,524	18,292	19,738	25,604	4,241	4,700	468,998
1912	271,656	59,794	117,081	13,846	17,604	29,396	6,250	4,162	519,789
1913	251,752	61,009	97,951	15,226	18,936	28,499	5,452	[1] 10,000	488,825
1914	300,287	51,444	85,730	15,294	19,600	31,636	6,025	16,928	526,944
1915	280,280	50,842	88,365	12,627	26,011	30,932	4,244	20,060	513,361
1916	304,271	55,140	98,760	12,945	21,218	27,920	4,132	12,535	536,921
1917	316,375	44,212	97,555	29,908	15,991	37,765	4,208	14,820	561,334
1918	225,446	40,140	97,040	10,516	22,151	26,575	2,146	11,776	435,790
1919	310,259	38,669	101,457	25,928	23,511	37,527	4,766	16,058	558,175
1920	329,561	41,387	99,760	13,799	21,810	37,222	7,604	16,401	567,544
1921	325,249	39,858	89,420	22,347	40,609	53,057	5,100	40,802	616,442
1922	342,148	42,196	99,270	17,904	21,035	35,127	6,740	24,349	588,769
1923	379,349	41,821	135,365	16,794	9,650	45,583	5,229	8,943	642,734
1924	337,767	40,806	136,840	31,987	22,276	19,766	8,195	17,539	615,178
1925	334,581	44,537	128,180	31,536	17,776	46,763	6,827	11,640	621,836
1926	356,904	47,003	117,038	32,423	[3] 32,267	50,320	8,902	11,707	653,564
1927	452,568	55,984	106,863	33,203	62,216	47,802	5,485	15,550	779,671
1928	370,098	61,146	103,390	33,811	63,866	49,067	7,546	14,211	703,135
1929	403,772	53,859	104,368	34,645	49,418	58,067	7,158	25,190	736,477
1930	426,340	43,920	102,050	35,589	34,245	44,682	6,696	28,871	722,393
1931	325,249	39,858	89,420	22,346	40,609	53,507	5,100	40,802	616,891
1932	412,984	57,297	87,104	30,886	47,116	30,918	5,752	33,730	705,787
1933	409,313	44,647	86,831	32,400	26,573	25,376	3,074	29,720	660,334
1934	278,494	28,737	92,477	[illegible]	26,346	44,344	[illegible]	20,241	638,756
1935	339,109	45,310	107,333	[illegible]	27,372	46,960	3,403	22,323	599,024

[1] Estimated to complete total for the division.
[2] Available records showing approximately 37,000 acres for district 20 in this year are believed to be incomplete. The figure given is an estimate based on general conditions applying in this year.
[3] Published figures are higher by 60,000 acres in 1909 and by 30,000 acres in 1926 because of the inclusion of pasture land on the Baca grant. For other years, subsequent to 1903 at least, figures for such pasture lands are not included.

Data for 1880 to 1896 are from the Follett report, S. Doc. 229, 55th Cong., 2d sess., but were largely supplied to Follett by San Luis Valley water commissioners. Other data except as noted are from biennial reports of the Colorado State engineer or from reports of the division engineer, irrigation division no. 3.

de Tome Dominquez. This settlement still exists under the shorter name of Tome, and it is interesting to note that one of the reasons for the dissatisfaction of the original settlers with Albuquerque was the shortage of water for their fields.

In 1716 a grant of land known as the San Clemente Grant was made to Ana Snadoval y Manzanares, daughter of Mateo Sandoval y Manzanares, one of the original colonists driven out by the pueblo rebellion of 1680. The present town of Los Lunas, some 20 miles south of Albuquerque, is located on this grant.

The Belen area developed from another land grant made in about 1642 and the La Joya Grant to the south followed.

The Socorro area was developed many years later. There were Indian pueblos in this locality in pre-Spanish time and the Spaniards established several missions at these pueblos, but after the rebellion of 1680 these few small settlements were exposed to continual attack by the hostile Apaches, who murdered or drove the settlers, and it was not until the building of the railway n the Rio Grande Valley some 200 years later that the real elopment of this country took place.

TABLE 58.—*Irrigated area, San Luis Valley, Colo., reported by surveys of Tipton, Osgood, Bliss, and Dallas*

Authority	Year of survey	Irrigated area in acres
Tipton	1925–26	494,200
Osgood	1927	507,471
Bliss	1932	534,806
Dallas	1934	[1] 428,737

[1] 70,184 acres irrigated in 1932 were not irrigated in 1934 because of water shortage

As each community was settled it built its own irrigating ditch or "acequia", since all of these settlements were agricultural communities, dependent upon irrigation, without which no crops could be grown in this country.

From the date of discovery by the Spanish Conquistadores in 1539, the Middle Rio Grande Valley was claimed by Spain and was ruled by Spanish governors under the jurisdiction of the colonial government of Mexico until 1821, when Mexico established her independence.

When Mexico revolted and became independent, this upper country became Mexican territory and so remained until it was ceded to the United States of America under the treaty of Guadalupe Hidalgo in 1848. This treaty, which marked the end of the Mexican War, guaranteed to the inhabitants of the ceded area the same rights and privileges to which they had been accustomed. Consequently the customs of the Spanish colonies have been preserved to a considerable extent in New Mexico.

Information on the development and extent of irrigation in the Middle section prior to Follett's investigation, and indeed even to 1918, is meager. As described further under the heading of acreage irrigated, estimates by New Mexico engineers fix a peak development about 1880, with a sharp decline from that date to 1896. Subsequently a further but more gradual decline is indicated to about 1925. This decline is attributed to a progressive increase in seeped and water-logged areas which, at the time of organization of the Middle Rio Grande Conservancy District in 1925, occupied almost two-thirds of the agricultural area later incorporated in that District. The seeped condition is affirmed to have been the result of decreased flow in Rio Grande which caused deposition of silt and a consequent raising of the river bed and of the contiguous water table. The decrease in river flow is asserted to have been due in part to depletions in San Luis Valley.

As early as the late 1890's it was realized by many people in the Middle Valley that drainage and an improved irrigation system were necessary, and some years later a small drainage district was attempted south of Albuquerque. However, these early attempts at reclamation were unsuccessful, due partly to lack of proper organization. In 1923 the Legislature of New Mexico passed a conservancy act and the decree of organization of the Middle Rio Grande Conservancy District was entered by the appropriate court on August 26, 1925. The plan of the district for flood control, drainage, and irrigation in the Middle Valley was approved in 1928, and active construction began in 1930. Completion of the works, including El Vado reservoir on Rio Chama, with a capacity of 198,000 acre-feet, was accomplished in 1935.

Acreage irrigated.—As reported by Follett in 1896, there were at that time on Rio Grande and its tributaries in New Mexico above San Marcial, 572 ditches having a total capacity of 5,106 second-feet and conducting water to 150,410 acres. Of the total, 104,650 acres were irrigated from tributaries of Rio Grande and 45,760 from the main stream. The main stream acreage involved 14,060 acres in Espanola Valley and 31,700 acres from Cochiti to San Marcial.

The next available information on irrigated acreages in the Middle section is given in a report by Herbert W. Yeo to the Bureau of Reclamation, covering the results of an investigation made by him in 1910. The follo[illegible] data are derived from this report:

Valley subdivision:	*Acreage in 1910*
Rio Grande tributaries above San Marcial	60, 390
Soccoro Valley	10, 060
Lower Albuquerque Valley	22, 860
Upper Albuquerque Valley	12, 300
Espanola Valley	5, 335
Total	110, 945

The Follett and Yeo acreage and ditch data for the Middle Valley unit from Cochiti to San Marcial show:

Year	Number of ditches	Capacity, second-feet	Acreage irrigated	Authority
1890	71	1, 779	31, 700	Follett.
1910	79	2, 145	45, 220	Yeo.

During 1918 the New Mexico State engineer completed a survey of the valley from Cochiti to San Marcial as a preliminary to drainage. The following statements are quoted from the report of this survey:

The total gross area of the valley, as determined by the survey, including all areas from the foot of the slopes as nearly as may be determined, is 206,012 acres, classified as follows:

	Acres
Cultivated (class I)	40, [illegible]
Cultivated (class II)	[illegible]
Alkali and salt grass	5[illegible]
Swamp	6, [illegible]
Timber	37, 594
River and river wash	27, 536
Other valley	33, 593
Total	206, 012

In cultivated (class I) of this classification are included all areas that are being cultivated and, by a superficial examination, do not show that crops are being impaired by a too high water table. It does not mean that the land is not suffering from a high water table or even endangered, nor that it will grow all crops without injury, but that there are no surface indications of a shallow soil.

In cultivated (class II) are included those cultivated areas which do show indications of a high water table either by evident saturated soil or the presence of alkali or by affected crops.

In alkali and salt grass are included those areas which are not being farmed, have visible quantities of alkali, or are overgrown with salt grass. It is usual that such areas have the water table within a very few inches of the surface and during periods of high water table it may be at, or even above, the ground surface.

The swamp areas are those that have the ground water exposed and are indicated by the water surface, marsh and rushes. This class is very closely related to alkali and salt grass areas as the two may oscillate to a certain extent with fluctuations of the ground water within the same year or from year to year.

The timbered areas are those overgrown with timber or brush, usually cottonwoods, willows, or thorn bushes.

In the river and river wash areas are those actually occu[illegible] by the river or the washed channels through which the [illegible] flows at a higher river stage. These latter are usually free [illegible] vegetation and consist of washed sand or gravel.

In the other valley areas are included all lands that do not come under the other classifications and may be sand wastes or sand dunes or sage brush either above or below ditches, and village or town areas.

This report indicates that there were found in the Middle Valley area covered, 65 ditches with a carrying capacity of 1,957 second-feet.

Between 1924 and 1928 investigations in Rio Grande tributary areas were made by the New Mexico State engineer's office, and the Middle Valley area from Cochiti to San Marcial was under investigation by engineers of the Middle Rio Grande Conservancy District. From the data of these investigations it appears that in 1928 or thereabouts the irrigated acreage was approximately as follows:

Valley subdivision:	*Acreage irrigated 1928*
Rio Grande tributaries above San Marcial	91, 760
Middle Valley-Cochiti to San Marcial	45, 580

The 1928 Burkholder report of the Middle Rio Grande Conservancy District shows for 1927 a total of 67 ditches, with a carrying capacity of 2,038 second-feet, in the Cochiti-San Marcial area.

A summary of the foregoing data with respect to the acreage irrigated is given in table 59.

TABLE 59.—*Irrigated acreages in the Middle section comprising the Rio Grande drainage area in New Mexico above San Marcial*

Year	Acreage irrigated					Authority
	Tributary areas	Rio Grande			Total above San Marcial	
		Espanola Valley	Cochiti to San Marcial	Total		
1896	104, 650	14, 060	31, 700	45, 760	150, 410	W. W. Follett.
1910	60, 390	5, 335	45, 220	50, 555	110, 945	H. W. Yeo.
1918			47, 000			New Mexico State engineer.
1928	91, 760	5, 805	45, 580	51, 385	143, 145	New Mexico State engineer and chief engineer, Middle Rio Grande Conservancy District.

In a review of all available data on the history of irrigation development as pertaining particularly to the Middle Valley from Cochiti to San Marcial, C. R. Hedke, in a report of December 1924 to the New Mexico Interstate Compact Commission, presented an estimate of this development from 1600 to 1925. This estimate, as taken from the Hedke report, is shown in table 60. It will be noted that for 1880, 16 years before the Follett investigation, the deduction is made that there was a maximum of 124,800 acres "under development" from Cochiti to San Marcial. This is indicated to have declined to 50,000 acres in 1896 and 45,000 acres in 1910.

TABLE 60.—*Deduction by Hedke of irrigation development in Middle Rio Grande Valley, Cochiti to San Marcial, 1600–1925*

Time up to—	Number of ditches	Second-feet capacity	Acres under development	Acres failed	Remarks
1600	22	537	25, 555		Indian development.
1700	61	1, 445	73, 580		Indian with Spanish.
1800	70	1, 808	100, 380		Above with Spanish grants.
1850	80	2, 099	123, 315		Natural increase.
1880	82	2, 145	124, 800		Transcontinental traffic and Civil War demand, completed developments.
1896	71	1, 779	50, 000	74, 800	Due to short water supply, rising water table, railroad supply competition, and railroad labor demand.
1910	79	2, 121	45, 220	79, 580	Further shortage and further rising water table.
1918	65	1, 957	47, 000	77, 800	War period.
1925	60	1, 850	40, 000	84, 800	Estimated present condition.

As derived by C. R. Hedke and presented in report to New Mexico Interstate Compact Commission, December 1924.

The Elephant Butte-Fort Quitman Section

In the Follett account previously quoted there is only brief reference to the Elephant Butte-Fort Quitman section. In a report by R. G. Hosea submitted to the Rio Grande Survey Commission of New Mexico in 1928, the early history of this section is covered at some length as the result of considerable research by Hosea, and the following paragraphs are quoted or abstracted from his report:

The original Indian inhabitants of the El Paso Valley, the Mansos and Zumanas, were not an agricultural people; they had no permanent town and did not cultivate (or irrigate) their lands.

The first white settlement in the Lower Rio Grande Valley was founded December 8, 1659, by Fray Garcia de San Francisco y Zuniga—a mission dedicated to the Virgin of Guadalupe, and called El Passo. It was on the south side of the river about where the Mexican city of Juarez now stands. The first temporary buildings were replaced a little later by the church which is still standing in Juarez. The cornerstone was laid by Father Garcia in April 1662 and the building was dedicated January 15, 1668.

Two other missions were established prior to 1680 and a nucleus of Spanish settlers were living in the district at this time. In 1680 the Pueblo rebellion broke out in the country to the north and the Spanish colonists of New Mexico, driven out by the Indians, came to Paso del Norte under Otermin in September of 1680.

Otermin had with him 1,946 "persons of all kinds", including some 300 friendly Indians from Isleta, Sevilleta, Alamillo, Socorro, and Senecu, and more Indians came during the next year (1681). These Indians w re settled in three pueblos, Senecu, Isleta, and Socorro, near El Paso, in 1682, and the Spanish refugees were located at San Lorenzo at about the same time.

These settlements were consolidated at Guadalupe del Passo in 1684 for protection against the local Indians who had revolted. Food was very scarce, due to a drought and to Indian depredations, and the El Paso district came very near to being abandoned at this time.

This crisis passed, however, and in 1692–93 de Vargas reconquered most of the Pueblo Tribes of New Mexico, working north from El Paso as a base.

From 1700 to 1800 El Paso was the gateway to the northern colonies. In 1700 the population was 3,588, in 1779 it was 4,934, not including Indians in either of the above figures.

Up to 1827 there were no houses or cultivated fields on the east side of the river, but in that year Juan Ponce de Leon acquired a grant of land of 200 to 500 acres and built an adobe house near the present location of the Mills Building in the El Paso of today.

After the Mexican War a number of new settlers came to the district and in 1859 the city of El Paso was surveyed by Gen. Anson Mills. At this time El Paso had a population of about 300 inhabitants, of whom 200 were Mexicans, while across the river a town of 13,000 people was flourishing.

Four railroads built into El Paso almost simultaneously, the Southern Pacific, the Santa Fe, and the Mexican Central in 1881, and the Texas Pacific in 1882, and in 1883 El Paso became the county seat of El Paso County, Tex.

The Spanish colonists of the El Paso district practiced irrigation from the time of their first occupation of the country, and from that date the irrigated area increased gradually until 1680, when the refugees from the Indian rebellion in New Mexico arrived. At this time several hundred Indians and Spaniards settled at Senecu, Ysleta, Socorro, and San Lorenzo, and a large increase in the irrigated area took place.

In 1851 there was a considerable area in cultivation on both sides of the river. Major Emory in his report to President Franklin Pierce states that the lands for 20 miles below El Paso (now Ciudad Juarez) were irrigated. This area was probably about 32,000 acres.

In the Mesilla Valley evidences of Peublo Indian villages are still visible on the west edge of the valley, about 8 miles above El Paso, Tex., and on the mesa west of the Oscar Snow ranch. Pottery has been found in still other localities.

Early Spanish settlements in the southern Rio Grande Valley were for the most part confined to the immediate vicinity of El Paso, on account of the hostility of the Apaches and other Indians.

The first application for the right to colonize the country with American settlers was made in 1822 by Dr. John Heath, for the "Bracito" tract. This was a tract 5 leagues square, with its center on an island in the Rio Grande about 30 miles above El Paso. This application was granted by the Emperor Iturbide on April 21, 1823, and John Heath with an American colony proceeded to his land grant by way of Mexico. Before the colony had time to get out of old Mexico, Iturbide was killed and the country was thrown into a state of revolution. The new government refused to acknowledge the grant to Heath, and the colonists were persecuted, robbed, and finally driven out of the country.

In 1805 Don Juan Antonio Garcia petitioned the governor of the province of New Mexico for a grant of land to extend from Bracito to the marsh or lake of Trujillo. Testimony given in a land grant hearing in 1849 showed that he lived on this land for many years, cultivating it and raising stock, and was finally driven off by the Indians. Title to this tract was sold to Hugh Stephenson of El Paso and was confirmed and patented by the United States Government.

At the time of Mexican independence (1821) the jurisdiction of which Paso del Norte was the center included the Mesilla Valley probably as far north as Dona Ana and south to San Lorenzo, Senecu, Ysleta and Socorro del sur. The entire population was about 8,000, nearly all of which was located in Paso del Norte and its immediate vicinity.

First settlers near Las Cruces, numbering 116, and led by Don Jose Costales in 1839, petitioned the governor of the State of Chihuahua for a grant of land on the east bank of the river known as "El Canon de Dona Ana." The grant was made and the settlers took possession in 1843. To each colonist was given a plat of land in a square 780½ varas in length, and to those who were not heads of families a parallelogram of equal length and one-half the breadth. The records show that there were 107 men, 59 women, 48 boys, and 47 girls in this colony.

On August 4, 1853, Mexico made a grant to the civil colony of Mesilla on the west side of the river near Mesilla, then in Mexico and later acquired by the United States under the Gadsden purchase. This colony consisted of about 300 families or a total of 1,500 people.

The Santo Tomas de Yturbide Colony was founded about 1848, the Refugio Colony about 1852, and the Jose Manuel Sanchez Baca grant about 1853.

Just prior to the Civil War the El Paso district ranked with the Sahta Fe district in importance, and large areas of land were in cultivation in the Dona Ana Bend and the Mesilla Colony grants. In 1862 and 1865 disastrous floods in the Rio Grande changed the channel of the river and caused the abandonment of certain ditches and necessitated the construction of new ones. Such avulsions sometimes caused entire towns to be abandoned.

The Mesilla ditch, which originally had its intake on the west side of the Rio Grande, watered lands about Picacho, Mesilla, Bosque Seco, and old Santo Tomas. After the flood of 1865 most of the lands under this ditch were on the east side of the river and a new portion was built which connected the part remaining with the Las Cruces ditch at a point about halfway between Las Cruces and Dona Ana. Thereafter, both the Las Cruces and the Mesilla ditches used the same heading at El Tajo, near Hill, and the same ditch to El Partidor.

In 1870–80 the Mesilla Valley was very prosperous, but in the eighties a number of causes produced a slump in values and a contraction of the cultivated area. The railroad came in in 1881 and brought farm products from the Middle West. As the Indian menace decreased, the number of soldiers was decreased and the market furnished by the forts and Army posts became smaller.

The ever-shifting river bed made irrigation difficult and ditch maintenance expensive, and the summer water supply became very erratic and undependable. In 1903 the Acequia de las Amoles was destroyed, together with the village of the same name.

In the Rincon Valley the Pueblo Indian occupation is evidenced by abandoned villages, one of which is located on the east side of the Rio Grande above Derry and another at San Diego Mountain. The first permanent settlements were made at Santa Teresa and Colorado. The bold raids of the nomadic Apaches delayed the settlement of this valley.

In the Palomas Valley one old pueblo was located about a mile below Hot Springs, another about 2 miles above Las Palomas, and other evidences of early occupation have been seen.

The first settlement in this valley using water from the Rio Grande was at Las Palomitas above Las Palomas on the east side of the river. The Las Palomitas ditch was destroyed in 1887 and the town was later abandoned.

The town of Las Palomas, from which the valley derives its name, was one of the early settlements and receives water for irrigation from Palomas Creek.

In the area now occupied by the Elephant Butte Reservoir, the Pueblo Indians had villages along the edge of the valley as shown by the old pueblo at the edge of the mesa on the west side of the river and on the south side of Mulligan Gulch, and by another pueblo on the west side of the valley, about 1 mile above the present Elephant Butte Dam, and by other evidences of Pueblo Indian occupation.

The old Santa Fe-Chihuahua Trail traversed a portion of the upper part of the reservoir and passed down the west side of the Rio Grande to a point just below the lower end of Black Mesa. Opposite Paraje, the Rio Grande was crossed and the trail bore southeasterly and then southerly over the Jornada del Muerto. Paraje, during the occupation of Fort Craig, became in the seventies one of the largest towns between Albuquerque and Mesilla, as it was from Paraje that the difficult journey to the south across the Jornada del Muerto began.

The first Spanish settlements were probably established about the year 1820, after grant no. 33 to Pedro Armendaris was made, December 4, 1819, and after grant no. 34, also to Armendaris, was made, May 3, 1820. Settlements were made on these grants shortly after these dates.

In the early 1890's water shortages began to occur along Rio Grande in the Mesilla and El Paso Valleys, and people near Juarez, across the river from El Paso, complained to the Mexican Government. The matter was taken up through diplomatic channels, and in a claim for damages of $35,000,000 filed by Mexico against the United States it was alleged that the shortages were due to increasing diversions from the river by water users in Colorado and New Mexico. As a result, the International Boundary Commission was directed to make an investigation and report covering the whole upper Rio Grande situation. Under appointment from the commission this was done, as already noted by Follett. Follett's summary of his findings are quoted as follows:

1. The fact of a decrease in the flow of the river at El Paso exists, as claimed, and dates back to 1888 or 1889. Before those years the river went dry at intervals of about 10 years. Since 1888 it has been dry every year but two.

2. The use of water for irrigation has not materially increased in New Mexico since 1880, and hence is not the cause of this decreased flow.

3. The use of water in the San Luis Valley of Colorado has very largely increased since 1880, and at the present stage of development it takes from the river, in excess of what was taken in 1880, an amount of water equivalent to a flow of 1,000 second-feet, running for 100 days; at least this amount is taken and possibly more.

4. It is impossible to state specifically how much water was in the river prior to this increased use of water and since, as the records do not antedate this increased use, and as the flow since the records began varies within very wide limits.

5. This flow of 1,000 second-feet, if allowed to remain in the river, would do much toward preventing a dry river at El Paso. Hence—

6. The Mexican and American citizens of the El Paso Valley have suffered in common with their neighbors of the Mesilla Valley and those still farther up the river by this Colorado increased use of water. The suffering has been greater in the El Paso Valley than elsewhere.

7. All of the summer flow of the steams in the San Luis Valley, except their floodwaters, are now appropriated, and therefore the use of water therein for direct irrigation is not likely to materially increase in the future.

An immediate result was the promulgation of the "embargo" by the Department of the Interior. The ...e and operation of this embargo have been previ...y noted in this report.

Mexico continued to press its claims and through the efforts of the Department of State, the Department of the Interior undertook an investigation of the river and a study looking to some means of providing water to satisfy the Mexican demands. The investigation revealed the feasibility of constructing Elephant Butte Reservoir for the storage and regulation of Rio Grande flow passing San Marcial. It was reported that reasonable demands for water upon the part of Mexico could be satisfied, and that, with inflow rights properly protected, the reservoir could also furnish water for an area in New Mexico and Texas estimated at 155,000 acres. This was designated as the Rio Grande Project of the Reclamation Service, and the Leasburg unit was approved for construction by the Secretary of the Interior December 2, 1905. By an act of February 25, 1905, Congress authorized construction of the storage dam, and in March, 1907, appropriated $1,000,000 toward the construction as representing that part of the total cost involved in the provision of water for Mexico. A treaty between the United States and Mexico was signed May 21, 1906, and proclaimed by the President January 16, 1907. Under the terms of this treaty the United States guaranteed to Mexico, in return for relinquishment of all claims for damages, the annual delivery in perpetuity of 60,000 acre-feet of water in the bed of Rio Grande at the head of Acequia Madre, the Mexican canal opposite El Paso. The monthly distribution of this amount is specified in the treaty and there is a clause which provides that, "In case, however, of extraordinary drought or serious accident to the irrigation system in the United States, the amount delivered to the Mexican canal shall be diminished in the same proportion as the water delivered to lands under said irrigation system in the United States."

Notices of intention to appropriate Rio Grande waters for the Elephant Butte Reservoir and the Rio Grande Project were filed in the office of the territorial engineer of New Mexico by the Reclamation Service in 1906 and 1908. The notice of January 23, 1906, names 730,000 acre-feet and that of April 8, 1908, "all the unappropriated water of the Rio Grande and its tributaries." Both specify a storage reservoir of 2 million acre-feet capacity. The Secretary of the Interior approved construction of the Elephant Butte Dam on May 23, 1910, and the dam, providing a reservoir of 2,639,000 acre-feet capacity, together with the diversion dams and canal systems of the Rio Grande Project, was completed in 1916. About 1918 the necessity for drainage on the Project became apparent and by 1925 a complete system of open drains was constructed. Land owners on the Rio Grande Project represented by the Elephant Butte Irrigation District in New Mexico and the El Paso County Water Improvement District No. 1 in Texas have contracted with the Government for full repayment of construction costs of the Project, except for the million dollars appropriated by the Congress to cover the cost of supplying water to Mexico under the terms of the treaty of 1906. The total construction cost of the Project to date is about 15 million dollars.

In 1924 the Hudspeth County Conservation and Reclamation District No. 1, comprising 20,000 acres of El Paso Valley in Texas below the Rio Grande Project, was organized to consolidate into one canal system several ditches which had been built about 1915, and which were diverting water from Rio Grande at various points between the Rio Grande Project boundary and Guayuco Arroyo which now marks the lower or eastern terminus of the Hudspeth district canal system. Under a Warren Act contract between the Hudspeth district and the United States, the district has, since 1925, been making a direct diversion of drainage and waste waters of the Rio Grande Project.

Acreage irrigated.—It is stated in the Follett report that the combined capacity of all canals in El Paso Valley in the late sixties, as determined from evidences found in 1896, was 300 second-feet on the Mexican side of Rio Grande and 250 second-feet on the American side, and that 40,000 acres had been irrigated. If the areas irrigated were in proportion to the capacity of the ditches on the two sides, the area irrigated in Mexico was about 22,000 acres and that on the American side 18,000 acres. For the Mesilla and Rincon Valleys, Follett in 1896 reported 29 ditches with a total capacity of 974 second-feet. irrigating 36,950 acres.

In a 1928 report by Herbert W. Yeo, then State Engineer of New Mexico, a deduction of the irrigated acreages in the New Mexico and Texas areas of the Upper Rio Grande Basin is made for 1907 and 1928. The following paragraphs quote this report with respect to the derivation of the data for the Elephant Butte-Fort Quitman section:

For the area south of San Marcial, irrigated from the Rio Grande, maps and notes filed by the United States Bureau of Reclamation, at El Paso, have been consulted. This area includes the land within the present Elephant Butte Reservoir, the Palomas Valley, Rincon Valley, Mesilla Valley, and El Paso Valley.

For the area irrigated within Elephant Butte Reservoir the topographic maps of the reservoir were consulted. The surveys for the reservoir were made in 1903–4 and 1907–8.

Data concerning the area irrigated in the Palomas Valley were obtained from old residents of the valley (and are subject to their error) and from topographic maps made in 1903.

Information as to irrigated lands in the Rincon Valley is found on topographic maps made in 1912 by the United States Reclamation Service. At the time these maps were made the Reclamation Service had not constructed any irrigation works in Rincon Valley and the area irrigated was substantially the same as in 1907.

A survey of the irrigable lands in Mesilla Valley was made in 1903–4 by the United States Reclamation Service, and the maps show the area irrigated at that time. The acreage shown irrigated on these maps was practically the same in 1907. In addition to the above the United States Reclamation Service made a detailed survey in 1907 of the lands irrigated under the Dona Ana, Las Cruces, and Mesilla ditches.

The area irrigated in the El Paso Valley in 1908, as determined by Homer J. Gault, is shown on a map of the irrigable lands of the Rio Grande project in Texas which was made by the United States Reclamation Service.

Information concerning the irrigated acreage on the tributary streams south and west of San Marcial was gathered in 1928. Facts relative to the area cultivated in 1907 were given by residents on the various streams and from records on file in the Sierra County courthouse in Hillsboro. This information was later checked in the field and is believed to be fairly correct. The area irrigated on the various tributaries is limited by the water supply and the cultivated acreage has not varied appreciably for many years.

Based upon these data, the Yeo report gives the following figures for the irrigated acreage in the Elephant Butte-Fort Quitman section in 1907:

Valley subdivision:	Acreage irrigated in 1907
El Paso Valley (American side)	8,537
Mesilla Valley	26,229
Rincon Valley	4,370
Palomas Valley	150
Elephant Butte Reservoir area	2,080
Tributaries below San Marcial	4,475
Total	45,8

For his 1928 summary Yeo used the 1927 data for the Rio Grande Project and other valley areas below Elephant Butte Dam, as the 1928 data were not yet available. Substitution of the latter as obtained from the Rio Grande Project history for 1928 and use of Yeo's figures for tributaries below San Marcial give the following figures for the irrigated acreage in the Elephant Butte-Fort Quitman section in 1928:

Valley subdivision:	Acreage irrigated in 1928
Fort Hancock area (Hudspeth district and below)	13,600
El Paso Valley—in Mexico (estimated)	35,000
El Paso Valley—Rio Grande Project	55,460
Mesilla Valley—Rio Grande Project	76,057
Rincon Valley—Rio Grande Project	11,807
Palomas Valley	390
Tributaries below San Marcial	4,530
Total	196,844

To be comparable with the 1907 total, that for 1928 should exclude the estimate of Mexican acreage.

In 1914 the Bureau of Reclamation made a complete survey of the cropped and irrigated acreages in what is now the area included in the Rio Grande Project. The data reported by this survey, those of Follett and Yeo as previously outlined, and those available from Rio Grande Project records beginning with 1920 are brought together in table 61.

of smaller ditches. The Terrace Irrigation District, comprising about 14,000 acres, owns the Terrace Reservoir on Alamosa Creek, capacity 17,700 acre-feet, and operates the Terrace and Alamosa Canal systems. Some 6,455 acres were irrigated within the exterior boundaries of this district in 1936. Water from La Jara Creek is distributed in small canals diverting from both sides. La Jara Reservoir, capacity 14,000 acre-feet, on La Jara Creek, is owned and operated by a group of water users.

There is a small amount of irrigation in the mountain valleys of Conejos River. It totaled 1,151 acres in 1936. Below, on the valley floor, irrigation from the Conejos and San Antonio Rivers extends east to the San Luis Hills and north to join the area irrigated from La Jara Creek and Rio Grande. There are no irrigation districts or large canal associations in this area. The ditches, nearly all small, are numerous and are the result of efforts by individuals or small community groups. There are no reservoirs on the Conejos, Los Pinos or San Antonio Rivers. Cove Lake Reservoir, capacity 9,700 acre-feet, is in the southeast corner of the southwest area in Poncha Valley. Water is diverted to the reservoir by a canal from San Antonio River. This was originally a project of the Taos Valley Irrigation Co., now out of existence. Some 680 acres were irrigated from the reservoir in 1936.

According to the 1936 survey, the acreage irrigated under Alamosa and La Jara Creeks and the minor streams to the north was 49,018, of which a part received some water also from Monte Vista Canal. Under Conejos, Los Pinos and San Antonio Rivers in Colorado, 82,389 acres were irrigated, and the San Antonio and Los Pinos irrigated 541 acres in New Mexico. As shown by the 1936 data, there were 36 ditches diverting from Alamosa Creek, 28 from La Jara Creek, and 121 from Conejos River and its tributaries.

In the southeast area, the irrigation development is that dependent on the Trinchera stream system in the north and Culebra Creek and Costilla River in the south. Practically the entire area is included in the original Sangre de Cristo Grant, later divided into the Trinchera and Costilla estates. Below several hay ranches, Trinchera Creek and its tributaries are entirely controlled by Mountain Home and Smith Reservoirs of 20,100 and 6,200 acre-feet capacity respectively, owned and operated by Trinchera Irrigation District. The latter, comprising about 35,000 acres, succeeded the Trinchera Estates Development Co. in 1910. The acreages irrigated in 1936 were 11,447 within the district boundaries, 2,669 from the stream system above the district, and 4,539 south and west of the district. In addition to the condition of a surplus of arable land for which there is no water supply, high transportation and other losses in the use of the available supplies combine to leave practically no residual flow to Rio Grande from Trinchera drainage.

The waters of Culebra Creek and Costilla River are diverted by individual and community ditches along the upper valleys of these streams and through the irrigation system of the Costilla Estates Development Co. to the bench lands lying between the two streams at an elevation of from 100 to 200 feet above Rio Grande. Sanchez Reservoir of the Costilla Estates Development Co. is on Ventero Creek, tributary to Culebra. A canal conducts water from Culebra, Vallejos, and San Francisco Creeks via Torcido Creek to the reservoir. Although the capacity is 104,000 acre-feet, the water stored has seldom, if ever, approached this amount. Eastdale Nos. 1 and 2 Reservoirs, with capacities of 3,500 and 3,000 acre-feet respectively, and also owned by Costilla Estates Co., are constructed off the stream channels and receive water through canals diverting from Culebra Creek and Costilla River. Their purpose is to provide regulatory storage for the lands on the western side of the Costilla Estates project. The project extends into New Mexico, and the Costilla Reservoir, capacity 20,700 acre-feet, on Costilla River in New Mexico, is a part of it. However, most of the lands irrigated from Costilla River are in Colorado. The present system of the Costilla Estates Co. makes possible the use of water from both Culebra Creek and Costilla River on the area between the two streams. The acreage thus irrigated in 1936 was 32,455 in Colorado and 188 in New Mexico. Outside of the Costilla Estates project, 2,696 acres were irrigated from Costilla in New Mexico. The New Mexico acreage is not included as a part of the southeast area of the San Luis section. As in the case of the Trinchera area, the irrigable land under Culebra Creek and Costilla River is greatly in excess of the available water supply, so that little of it reaches Rio Grande.

Present development in the closed basin with respect to areas irrigated by diversions from Rio Grande, chiefly through the Rio Grande, Farmers Union, Prairie,

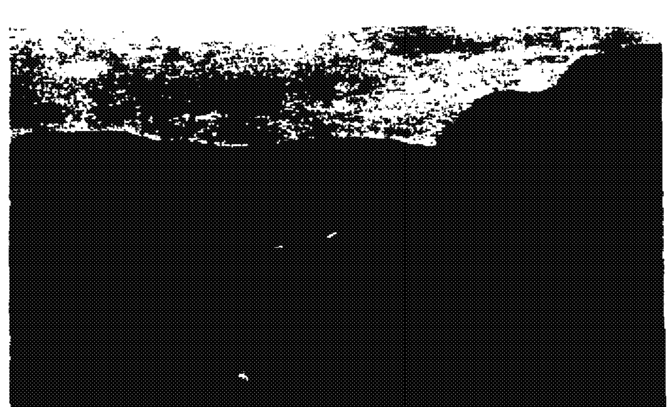

FIGURE 24.—Conejos River Valley. The lower reservoir site.

San Luis Valley, and Costilla canals, has been previously described. Other irrigated areas in the closed basin are those served by La Garita and Carnero Creeks on the west, Saguache Creek in the northwest, Kerber and San Luis Creeks on the north and numerous small creeks from Cotton to Zapato on the east. The area under La Garita and Carnero Creeks lies on the extreme western border of the valley. It is served by small community or private ditches. Practically the entire flow of the streams is applied to the land, but as the soils are open and porous, much of the water applied probably moves underground to lower lands under the Rio Grande canal to the east, or enters the artesian aquifer underlying the valley. In the lower areas waters from La Garita and Carnero Creeks are commingled with those brought from Rio Grande, so that it is difficult to segregate the acreage irrigated from any one source. Approximately 2,057 acres were irrigated from La Garita and 1,052 from Carnero Creek in 1936.

In the Saguache Creek area there were 12,086 acres irrigated in 1936 in the mountain valleys of Saguache Creek above Gunbarrel Road, and 29,576 acres in the vicinity of and below the town of Saguache. A terminal wasteway of the Rio Grande canal empties into Saguache Creek channel so that the acreage irrigated below this point may be served from two sources. By far the greater portion of the irrigated acreage in the Saguache area is wild hay land.

The acreage irrigated from Kerber and San Luis Creeks and the small creeks draining the short western slope of the Sangre de Cristo Range in the closed basin is practically all pasture or wild hay land. In 1936 the total acreage irrigated in this area was 46,453 of which 42,859 acres were pasture and wild hay. The low proportion of cultivated crops is an indication of the character of the water supply, as natural grass for hay or pasturage is grown more or less generally throughout the valley where the water supply is deficient, erratic, or unreliable, while cultivated crops are grown where the supply is, in the main, sufficient and certain. Very few of the east side streams are perennial down to or even near to the agricultural areas, and irrigation is largely confined to flooding hay land and to raising the ground-water level. The streams as far south as Deadman Creek would naturally be tributary to San Luis Creek, but only during periods of exceptionally high run-off do their surface waters reach so far, as they are spread over wild hay or largely absorbed by the loose gravelly soil which skirts the base of the mountains in which the creeks rise. From Deadman Creek to the southern boundary of the closed basin, the streams are practically all ephemeral in their lower reaches near the Sump area. These streams debouch from rocky canyons upon steep cones of gravel and coarse soil resulting in a large and rapid percolation of their flow to ground water. Any surface flow that remains is diverted to wild hay or meadow lands east of the Sump.

The Middle Section

The irrigated and other water-consuming areas in the Middle section as determined by the 1936 survey are shown by table 64.

TABLE 64.—*Irrigated and other water-consuming areas, middle section, 1936*

Subdivisions	Acreage irrigated	Other water-consuming acreage	Total
Tributary valleys	86,813	62,142	148,955
Espanola Valley	[1] 5,891	6,987	12,878
Cochiti to San Marcial	60,078	144,998	205,076
Total	152,782	214,127	366,909

[1] Includes 191 acres in Rinconada and Cieneguilla Valleys on Rio Grande above Embudo.

In the following paragraphs, the tributary areas are considered in downstream order from the Colorado-New Mexico State line.

On Costilla River the lands irrigated in New Mexico fall in three groups—those in the upper valley, those adjacent to the town of Costilla, and those under the Costilla Estates Development Co. The 1936 irrigated acreages in these groups were, respectively, 1,063, 1,633, and 188. As noted under development in the southeast area of San Luis section, Costilla Estates Development Co. owns Costilla Reservoir on Costilla River in New Mexico, but most of the lands irrigated under this development are in Colorado. The irrigation system of the company was constructed to serve about 15,000 acres in New Mexico.

East of Rio Grande, reaching from the Colorado line to Rio Colorado, there is an extensive smooth plain called Cerro Mesa. In the south-central portion of this mesa the Cerro community ditch diverts the waters of Latir Creek and smaller creeks to the south for irrigation near the settlement of Cerro. Some 2,402 acres were thus irrigated in 1936. At the southern end of Cerro Mesa the waters of Cabresto Creek and Rio Colorado are used near the settlements of Red River and Questa. Two community ditches are maintained on Cabresto Creek in conjunction with a small reservoir, Cabresto Lake. The acreage irrigated in 1936 from Rio Colorado near Questa and in the canyon above amounted to 2,846.

On San Cristobal Creek there is a small irrigated valley and on Rio Hondo, in the vicinity of Arroyo Hondo, a substantial acreage is irrigated from both Rio Hondo and Arroyo Seco. In 1936 the latter totaled 3,676 acres, and that on San Cristobal Creek was 576 acres. There is a ditch which diverts Arroyo Seco water to Taos Mesa and the acreage thus irrigated is included in that given below for Taos Mesa.

Taos Mesa extends for about 20 miles from Rio Hondo Canyon on the north to the Picuris Mountains on the south and lies between the Rio Grande Canyon on the west and the foot of the Sangre de Cristo Range on the east. Lands on this mesa are irrigated from Arroyo Seco, Rio Lucero, Rio Pueblo de Taos, Rio Fernando de Taos, and Rio Ranchos de Taos. The acreage shown to be thus irrigated in 1936 was 11,191. The arable lands of this mesa appear to far exceed the available water supply so that practically all of the latter is utilized. There is, however, no storage to permit utilization of flood flows in excess of diversion capacities. The Taos Indian Pueblo is located just north of the town of Taos. Its agricultural lands are under ditch systems which divert from Rio Lucero and Rio Pueblo.

On the Aguaje de la Petaca, a small stream joining Rio Grande from the west a few miles below the Rio Taos junction, there is an irrigation development originally organized by the Settlers Ditch & Reservoir Co. to irrigate about 5,000 acres. It is now organized as the Carson Irrigation District, comprising 9,400 acres. An earth and rock fill dam on Aguaje de la Petaca was completed in July 1936, forming a reservoir of 7,400 acre-feet capacity. This development is planned to serve about 4,800 acres of the total district area. No land was irrigated in 1936.

South of the Picuris Mountains is the drainage of Embudo Creek, joining Rio Grande from the east a short distance above Embudo. Along this stream and its tributaries, Rio Pueblo, Las Trampas, and Ojo Sarco, there are many narrow irrigated valleys shown by the 1936 survey to have included irrigated areas totaling 3,504 acres. The Picuris Indian Pueblo is located on Rio Pueblo.

In the mountain valleys of Rio Truchas, an eastern tributary of Rio Grande at the upper end of Espanola Valley, there were 1,449 acres irrigated in 1936.

Irrigation development on Rio Chama, a western tributary which drains an area of 3,200 square miles and joins Rio Grande just above the town of Espanola, comprises valley lands on the main stream, chiefly from the town of Chama to the vicinity of Park View and between Abiquiu and Rio Grande, and lands in the mountain valleys of numerous tributaries. Irrigation in the Rio Chama drainage is accomplished almost entirely by small individual or community ditches. The irrigated acreages as determined by the 1936 survey are given in table 65.

Joining Rio Grande just below the town of Espanola are Rio Santa Cruz from the east and Santa Clara Creek from the west. The Santa Cruz Irrigation District is situated in the Rio Santa Cruz Valley. In 1929 it completed a dam on Rio Santa Cruz about 1 mile

TABLE 65.—*Irrigated areas in Rio Chama drainage, 1936*

Subdivision:	Acreage irrigated
Chama and tributaries above El Vado Reservoir	7,921
Main stream and tributaries, except El Rito, El Vado to Abiquiu	5,725
El Rito	3,857
Main stream and tributaries, except Ojo Caliente, Abiquiu to mouth	2,395
Ojo Caliente and its tributaries, Tusas and Vallecitos	8,715
Total	28,613

above Chimayo forming Santa Cruz Reservoir of 4,600 acre-feet capacity. This development supplements irrigation by direct diversion along Rio Santa Cruz which has been carried on from a very early date. The acreage irrigated in 1936 on Rio Santa Cruz above the Santa Clara Pueblo Grant was 3,628. The water of Santa Clara Creek is used by the Santa Clara Indian Pueblo, which also diverts from Rio Grande and gets some water from Rio Santa Cruz as well.

Pojoaque Creek enters Rio Grande from the east at the San Ildefonso Indian Pueblo at the lower end of Espanola Valley and just above the Otowi Bridge gaging station on Rio Grande. It has two principal tributaries, Nambe and Tesuque Creeks. The Nambe and Tesuque Indian Pueblos are located on Nambe and Tesuque Creeks, respectively, and divert these streams for irrigation. San Ildefonso Pueblo irrigates from Pojoaque Creek. The 1936 acreage irrigated on Pojoaque Creek and its tributaries was 3,174. This does not include an area along Rio Grande but irrigated from Pojoaque Creek.

Santa Fe Creek joins Rio Grande near the Indian Pueblo of Cochiti at the upper end of Santo Domingo Valley. The city of Santa Fe is situated on this creek about 25 miles above its mouth just at the foot of the Sangre de Cristo Range at an elevation of 7,000 feet. The water of Santa Fe Creek is practically all used for municipal purposes in Santa Fe and some irrigation near the city. The New Mexico Power Co. owns three small reservoirs on the creek above Santa Fe which are operated for the municipal supply. Irrigation from Santa Fe Creek and tributaries in 1936 covered 1,496 acres.

There are a few small irrigated acreages along Galisteo Creek which is practically the last stream, except for arroyos of erratic flow, to enter Rio Grande from the east above Fort Quitman. In fact, the flow of Galisteo Creek itself is by no means perennial and the water reaching Rio Grande at its junction near the Indian pueblo of Santo Domingo is largely that brought down as the result of sudden storms in the summer. The total area irrigated along Galisteo Creek in 1936 amounted only to 39 acres.

FIGURE 25.—Looking up Rio Puerco near junction with Rio Grande, N. Mex.

Jemez Creek joins Rio Grande from the west just below the Angostura diversion of the Middle Rio Grande Conservancy District, or about 7 miles above Bernalillo. It drains the south slope of the high Jemez Mountains and has a drainage area of 1,000 square miles. However, most of the flow is either used in irrigation in upper valleys along the stream or sinks into the ground in a barren sandy stretch of more than 10 miles. Little water, therefore, other than that from spring run-off and summer storms, reaches Rio Grande. There are three Indian pueblos along Jemez Creek. In downstream order they are Jemez, Zia, and Santa Ana. The first two use Jemez Creek waters for irrigation but the irrigated lands of the Santa Ana Indians are 10 miles below the pueblo in the Rio Grande Valley and are served from the main river. There are other irrigated lands above Jemez pueblo and below it in the vicinity of San Ysidro. The 1936 survey showed 2,496 acres irrigated in the valleys of the Jemez Creek drainage.

There are no tributaries upon which there is irrigation between Jemez Creek and Rio Puerco. The latter, which joins Rio Grande from the west a short distance above San Acacia, or about 65 miles below Albuquerque, has a drainage area of 5,000 square miles. This area is, however, relatively low and there is little perennial flow from mountain snow fields to its upper valleys and practically no flow to Rio Grande other than that resulting from intermittent and torrential storms. There are two principal irrigation areas in the Puerco Basin, the Cuba and Bluewater. The upper Rio Puerco and its tributaries, La Jara Creek, Salado Creek, San Jose Arroyo, Rito de los Pinos, Rito de los Utes, Rito Lecho, and Nacimiento Creek, comprise the so-called Cuba Valley. In 1936 there were 4,600 acres irrigated in the various sub-valleys of the area. Since the streams are not perennial, water for irrigation may be available for only a few weeks in spring or following intermittent summer storms. There is, however, a fairly good annual precipitation, so that some crops can be grown with the irrigation supply indicated.

On Bluewater Creek, a southwestern tributary Rio Puerco, present irrigation development is under the Bluewater-Toltec Irrigation District. The District owns and operates the Bluewater Reservoir, capacity 57,500 acre-feet, on Bluewater Creek, and in 1936 the acreage irrigated on the project was 3,227.

Below the junction of Bluewater Creek with Rio San Jose, which is tributary to Rio Puerco, there are two Indian pueblos, Laguna and Acoma, which in 1936 diverted water from Rio San Jose for the irrigation of 5,072 acres. On tributary streams below Grants 2,073 acres were irrigated.

Including all other small irrigated areas with those of the Cuba and Bluewater districts, the total acreage irrigated in the Rio Puerco Basin in 1936 was 14,972.

Irrigation development in the main valleys along Rio Grande from Embudo to San Marcial is, for purposes of this description, divided to that of Espanola Valley, that under the Middle Rio Grande Conservancy District from Cochiti to the southern third of Socorro Valley, and that from the lower end of the Middle Rio Grande Conservancy District to San Marcial.

In the Espanola Valley from Embudo to White Rock Canyon there are about eight ditches which divert water for irrigation from Rio Grande. Although the are old and probably follow much the same course a irrigate the same lands as in the early days of the Spanish occupation, their headings in the river are still more or less temporary rock and brush wing dams which must be replaced with the passage of each flood or reoccurrence of high water. In a few instances, several small ditches have been combined into community ditches such as the Alcalde. The management of the ditches continues much as in early times; each landowner under a ditch contributes labor for its maintenance and a majordomo distributes the water. Included in the irrigation development of Espanola Valley is that of three Indian pueblos, San Juan, Santa Clara, and San Ildefonso. As previously noted, Santa Clara pueblo obtains water from Rio Santa Cruz and Santa Clara Creek and San Ildefonso pueblo from Pojoaque Creek, thus supplementing their Rio Grande supplies. The total acreage irrigated in Espanola Valley in 1936 was 5,700. Some of this was irrigated from tributary sources, rather than from the main river. There are two small areas in the Rio Grande Canyon above Embudo where a small amount of water is diverted for irrigation. These are Rinconada and Cieneguilla Valleys, in which 191 acres were irrigated in 1936.

In the area of the Middle Rio Grande Conservancy District there were, at the time of the formation of th district, nearly 70 old ditches diverting water from R. Grande by means of temporary headings. This network of ditches was largely rebuilt by the district and incorporated into a system which accomplishes the er diversion at six headings and embraces approximately 1,000 miles of canals. The district is divided into four irrigation divisions which are, in downstream order, Cochiti, Albuquerque, Belen, and Socorro. The diversion dams, headings, and main canals, as shown on the maps, plates 13 to 16, inclusive, are Cochiti Dam diverting to Cochiti and Sili main canals on the east and west sides of the river, respectively; Angostura Dam, diverting to Albuquerque main canal, east side; Atrisco heading opposite Albuquerque, diverting to Arenal main canal, west side; Isleta Dam diverting to Peralta and Belen High Line main canals, east and west sides, respectively; San Juan heading diverting to San Juan main canal, east side; and San Acacia Dam diverting to Socorro main canal, west side.

Most of the lands in the Middle Valley are privately owned. Title came originally through land grants made by the kings of Spain. However, in accordance with the Spanish custom of inheritance under which ownerships are subdivided and resubdivided with succeding generations, the original grants have been reduced to an extremely large number of very small, irregularly shaped tracts. This is strikingly shown on the maps which display the vegetative cover classifications in the Middle Valley. The management of the Middle Rio Grande Conservancy District is charged with furnishing service to approximately 30,000 properties.

The drainage system constructed by the district includes 334 miles of drains, of which 181 miles are riverside drains and 153 miles interior drains. El Vado Reservoir, 198,000 acre-feet capacity, on Rio Chama 60 miles above its confluence with Rio Grande, is owned by the Middle Rio Grande Conservancy District and operated as a supplemental source of supply for the lands of the district.

As stated in the Burkholder report, the gross area of the valley floor from Cochiti to San Marcial is 210,000 acres. Of this, the net irrigable area included in the Middle Rio Grande Conservancy District, as set forth in the approved plan for the district (table 5, p. 43 of the Burkholder report) is 123,267 acres, including 22,734 acres of Indian land. There are six Indian Pueblos with grants totaling 28,500 acres within the district. These are Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta. The irrigated and other

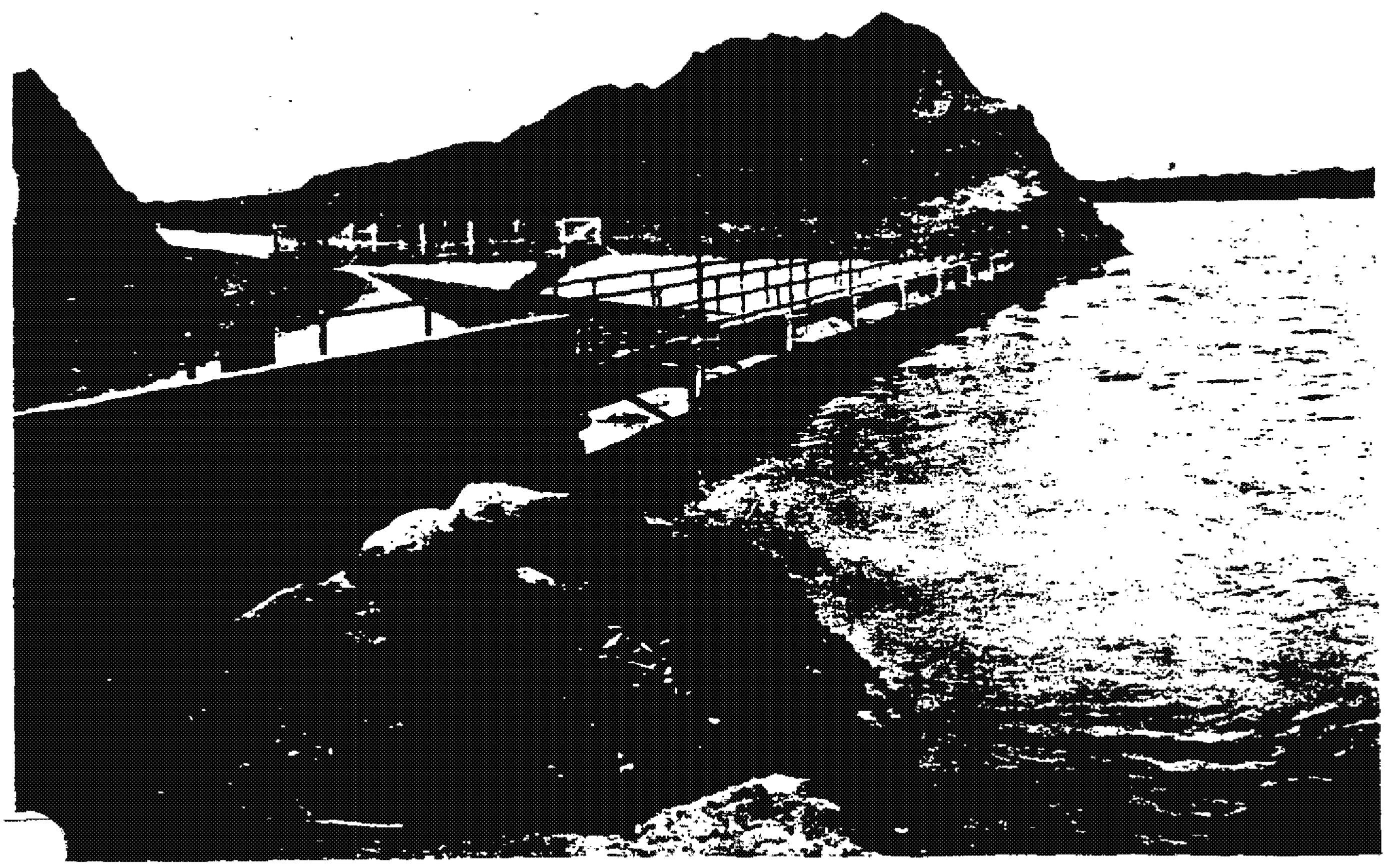

FIGURE 26.—San Juan heading, Middle Rio Grande Conservancy District, New Mexico.

water-consuming acreages within the district as shown by the 1936 survey are given by divisions in table 66.

TABLE 66.—*Irrigated and other water-consuming acreages in Middle Rio Grande Conservancy District, 1936*

Irrigation division	Acreage irrigated	Other water-consuming acreage	Total
Cochiti	5,208	14,231	19,439
Albuquerque	22,819	35,308	58,127
Belen	23,895	53,149	77,044
Socorro	7,237	25,835	33,072
Total	59,159	128,523	187,682

In the original plan of the Middle Rio Grande Conservancy District, the southern third of Socorro Valley, which is included in the Bosque del Apache and Pedro Armendaris No. 33 grants, was to be a part of the district and to be drained by the district. In the final plan as carried out, however, this area, which extends for about 16 miles from the present southern boundary of the district to San Marcial, was not included. As set forth in the original plan, the area within the limits of this proposed improvement amounted to 14,479 acres, exclusive of river bed, roads, ditches, and rights-of-way, and was classified as 1,112 acres irrigated and 13,367 acres nonirrigated. Of the latter, 11,968 acres were listed as salt grass and bosque. This area in the lower Socorro Valley in naturally divided by the river meanders into four units, two on each side of the river. Those on the north comprise land in the Bosque del Apache grant known as the Elmendorf tract. Those on the south comprise the San Marcial unit on the west side of the river and the Val Verde-La Mesa unit on the east side. The irrigated land of the above mentioned classification in the District's original plan was in the Val Verde-La Mesa unit and was served by what was stated to have been the only irrigation ditch of the whole lower Socorro Valley.

The lower area not included in the Middle Rio Grande Conservancy District has never been drained and the water table over much of it is close to the surface. There is, therefore, a large consumption of water by native vegetation. The 1936 survey showed an area of 16,475 acres upon which water is thus consumed due to natural conditions and 919 acres which were irrigated.

Surveys of the unit in the Bosque del Apache grant were made during the summer of 1936 by the United States Biological Survey to determine the feasibility of developing a migratory water-fowl preserve on the lands. The report of this survey proposes that the Biological Survey acquire the entire Bosque del Apache grant of 53,000 acres and convert it into a Federal refuge, developing about 14,000 acres lying in the river valley for the waterfowl preserve. Portions of the higher bottom lands would be drained to furnish water for about 2,400 acres of controlled ponds while ag-cultural crops including food-producing grasses w be grown on about 6,000 acres of the drained lan The latter would be irrigated by indirect diversion from Rio Grande through the canal system of the middle Rio Grande Conservancy District under a water filing acquired with the Grant purchase.

Table 67 lists the Indian Pueblos in the Middle Section and gives their source of water supply.

TABLE 67.—*Indian pueblos in the middle section*

Pueblo	Source of water	Remarks
Acoma	Rio San Jose	In Rio Puerco Basin.
Cochiti	Rio Grande	In Middle Rio Grande Conservancy District.
Isleta	Rio Grande	In Middle Rio Grande Conservancy District.
Jemez	Jemez Creek	
Laguna	Rio San Jose	In Rio Puerco Basin.
Nambe	Nambe Creek	
Picuris	Rio Pueblo	In Embudo Creek Basin.
Sandia	Rio Grande	In Middle Rio Grande Conservancy District.
San Felipe	Rio Grande	In Middle Rio Grande Conservancy District.
San Ildefonso	Pojoaque Creek	Water from Rio Grande also.
San Juan	Rio Grande	Water from Rio Chama also.
Santa Clara	Rio Grande	Water from Santa Clara Creek also.
Santo Domingo	Rio Grande	In Middle Rio Grande Conservancy District.
Santa Ana	Rio Grande	Pueblo is on Jemez Creek, but irrigated lands are along the Rio Grande in Middle Rio Grande Conservancy District.
Taos	Rio Lucero and Rio Pueblo de Taos.	
Tesuque	Tesuque Creek	
Zia	Jemez Creek	

The Elephant Butte-Fort Quitman Section

The 1936 survey showed the irrigated and other water-consuming areas in the Elephant Butte-Fort Quitman section to be as indicated in table 68.

TABLE 68.—*Irrigated and other water-consuming areas, Elephant Butte-Fort Quitman section, 1936*

Subdivision	Acreage irrigated	Other water-consuming acreage	Total
Tributary valleys	1,608	8,353	9,961
Palomas Valley [1]	830	9,553	10,383
Rincon Valley	15,206	12,708	27,914
Mesilla Valley	82,923	27,495	110,418
El Paso Valley [2]	70,002	24,431	94,433
Total	170,569	82,540	253,109

[1] Includes area between Elephant Butte Dam and Hot Springs.
[2] Does not include any of Mexican lands.

There is little irrigation on tributary streams in this section since, as previously noted, most of the tributaries are arroyos in which water flows only at times of sudden and irregular storms. In the region from San Marcial to the upper end of Rincon Valley there are a few tributaries on the west which have small valley areas along upper reaches at some distance from Elephant Butte Reservoir and Rio Grande below. In these upper reaches there is some flow from spri and occasional storm run-off and this is practically used for irrigation in the small valleys. Areas thus irrigated on these tributaries, as shown by the 1936 rvey, are given in table 69. The tributaries are listed downstream order from San Marcial.

Below Elephant Butte Dam, but above and not included in the Rio Grande Project of the Bureau of Reclamation, is the Palomas Valley, with a gross valley floor area of about 10,000 acres. Only a small part of this area is irrigated. As shown by the 1936 survey, it amounted to 830 acres.

TABLE 69.—*Irrigation on Rio Grande tributaries, San Marcial to Rincon Valley, 1936*

Tributary	Acreage irrigated	Remarks
Rio Canada Alamosa	693	Largely in the vicinity of the town of Monticello.
Cuchillo Negro Creek	245	Largely under Cuchillo community ditch near settlement of Cuchillo.
Las Palomas Creek	409	Largely under Las Palomas community ditch above settlement of Las Palomas.
Las Animas River	227	
Percha Creek	34	Between Kingston and Hillsboro and below the latter.
Total	1,608	

The Rio Grande Project includes the agricultural lands in Rincon and Mesilla Valleys and 40 miles of El Paso Valley below El Paso on the Texas side of the river. The planned irrigated acreage of the project, as indicated in reports of the Bureau of Reclamation, is 155,000 acres. Of this, 88,000 acres are in New Mexico and 67,000 acres in Texas; these are the acreages included respectively in the Elephant Butte Irrigation District and the El Paso County Water Improvement District, the two organizations which represent the water users under the Rio Grande Project. Segregated in accordance with the valleys, Rincon includes 16,000 acres, Mesilla 82,000 acres, and El Paso 57,000 acres of the total. As the figures indicate, 10,000 acres of the Mesilla Valley area are in Texas. All old community ditches were taken over by the Project, reconstructed, enlarged, or extended, and incorporated as parts of the present system of more than 630 miles of main canals and laterals through which the waters released from Elephant Butte Reservoir are distributed. There are diversion dams and permanent diversion works at six points along the river. These are Percha Dam at the head of Rincon Valley, diverting to the Arrey canal; Leasburg Dam at the head of Mesilla Valley, diverting to the Leasburg canal; Mesilla Dam southwest of Las Cruces, diverting to the east side and west side canals; the International Diversion Dam

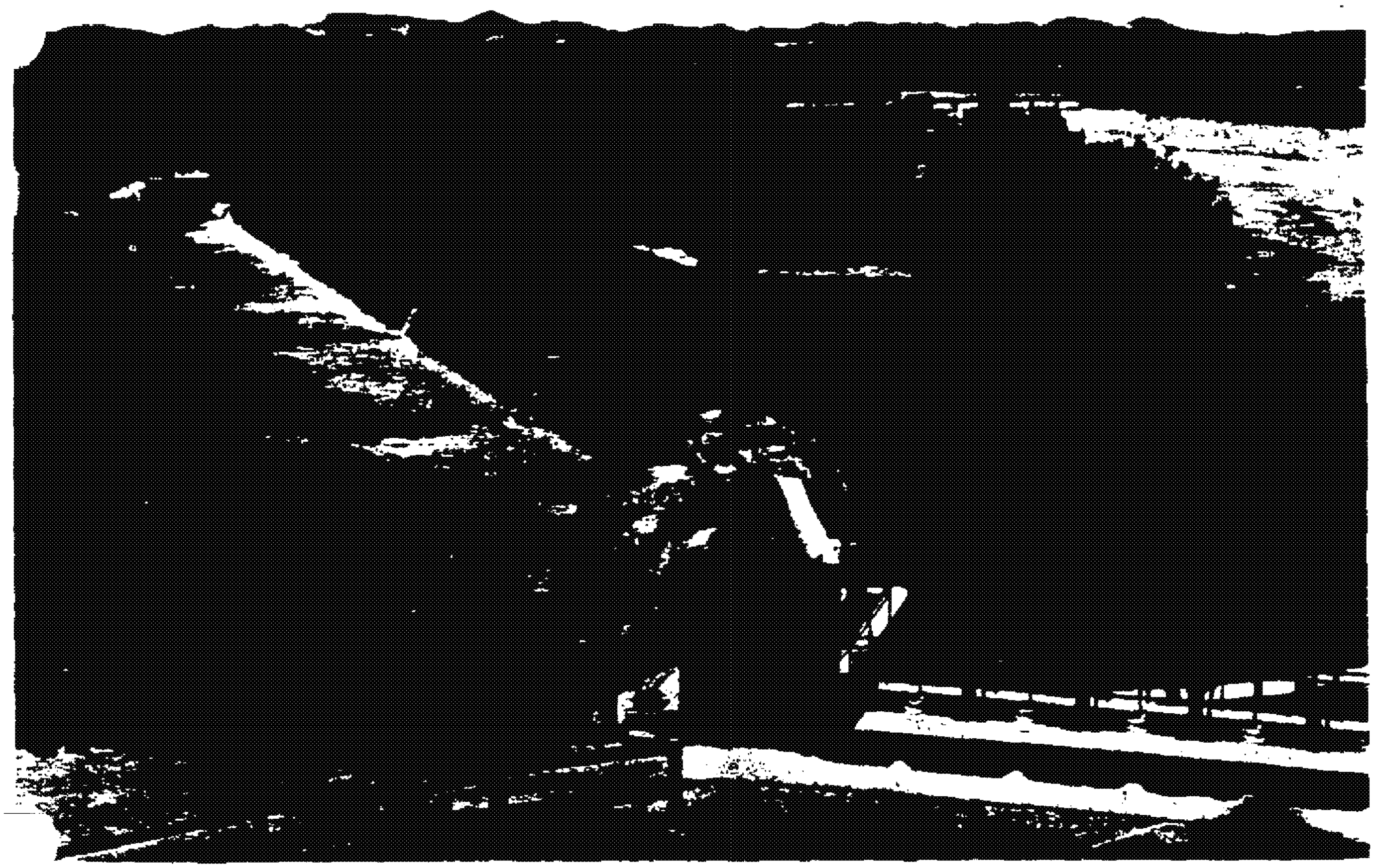

FIGURE 37.—Leasburg Diversion Dam, Rio Grande Project. Head of Mesilla Valley, N. Mex.

FIGURE 28.—Small farm areas, northwest of Las Cruces, N. Mex. Rio Grande Project.

opposite El Paso, diverting to the Mexican Acequia Madre on the west side and to the Franklin canal on the east side; Riverside Heading about 15 miles below El Paso, diverting to the Riverside canal and Franklin feeder; and Tornillo Heading near the town of Fabens, diverting to the Tornillo canal. The drainage system of the Project is completed except for revisions and reconstruction occasioned by the river rectification program of the International Boundary Commission, and it comprises more than 450 miles of deep open drains.

The International Diversion Dam is owned by Mexico and was built to divert water into the Mexican canal. It is at this dam that delivery must be made to Mexico of 60,000 acre-feet annually under the terms of the treaty of 1906. The Bureau of Reclamation is responsible for this delivery, which must be accomplished largely through releases from Elephant Butte Reservoir, more than 125 miles upstream. The channel of the Rio Grande is thus used to carry water both for delivery to Mexico and for canals serving the Rio Grande Project. Below the Mexican Dam the river channel carries water to the Rio Grande Project canals heading below El Paso. In spite of its dual obligation to deliver water to Mexico and to the Rio Grande Project canals, the United States neither owns nor controls this carrying channel from Elephant Butte to the Mexican Dam. Since quantities of water considerably in excess of 60,000 acre-feet must pass the Mexican Dam to supply Project canals below El Paso, and since the United States has no control over Mexican diversion to the Acequia Madre at the west end of the dam, which lies in Mexican territory, it has never been possible to deliver exactly 60,000 acre-feet to Mexico or to determine accurately the extent of the Mexican diversion. As a result of this situation, it is indicated that the diversions by Mexico have exceeded the treaty specifications by substantial amounts. Moreover, there are other Mexican ditches heading on the river below Juarez and having no rights under the treaty, into which water is diverted if and when possible. An estimate of Mexican diversions in the period 1930–36, derived by elimination in a study taking into account all available data of stream flow, diversion return flow, and arroyo inflow, is given in the section of this report on water uses and requirements.

Since the construction of Elephant Butte Dam, the river channel from it to El Paso has progressively decreased in capacity due to the elimination of large floods and their scouring action, and to the growth of vegetation in former flood channels. As a result, relatively small floods, originating below Elephant Butte Dam chiefly in the western arroyos above Caballo Narrows, coming into the restricted river channel, constitute a distinct menace to the valley lands and to the irrigation structures of the Rio Grande Project. The river channel is, and always has been, unstable and shifting. Below El Paso the International Boundary Commission has been engaged for some time upon a program of river rectification and control in accordance with a convention between the United States and Mexico concluded February 1, 1933; much of the construction work between El Paso and Fort Quitman is complete.

To bring about the control and stabilization of the river channel from Caballo Narrows to El Paso, to obtain flood control storage sufficient to operate and maintain this channel when constructed as well as the present rectified channel below El Paso, and to accomplish control of the delivery of water to Mexico and of diversion by Mexico under the treaty, three projects were proposed by the American section of the International Boundary Commission, namely, Caballo Reservoir, river canalization from Caballo Dam to El Paso, and the American diversion dam and canal.

When Elephant Butte Dam was constructed, gates and six penstock openings were built into it in anticipation of power development. The character of the releases from the reservoir for irrigation preclude development of firm power, but a reservoir below the dam of sufficient capacity to accomplish re-regulation would make it possible. It was therefore proposed by the

FIGURE 29.—Mexican (International) Dam on Rio Grande, near El Paso.

Bureau of Reclamation that Caballo Reservoir be given a capacity which would provide both for flood control and for re-regulation such that firm power could be developed at Elephant Butte Dam. An allocation of funds for Caballo Dam was made by the Federal Emergency Administration of Public Works, and in May 1936 work was begun under the direction of the Bureau of Reclamation. As planned, this dam will provide a reservoir of 350,000 acre-feet capacity, of which 100,000 acre-feet will be reserved for flood control. The dam is about 25 miles below Elephant Butte Dam and 2 miles above Percha Diversion Dam. The lands to be flooded are in the Palomas Valley.

The Caballo-El Paso canalization project will provide a rectified normal flow channel with levees set back to provide capacity for the maximum anticipated flood.

Under the American Dam project a diversion dam is being built on Rio Grande just above the Mexican boundary and entirely within the territorial limits of the United States. From this dam, on the Texas side, a 2-mile canal will be built to connect with the present Franklin canal. In this way diversion of water to Rio Grande Project lands of El Paso Valley and delivery to Mexico under the treaty will be controlled.

The acreages within the boundaries of the Rio Grande Project as shown by the 1936 survey are given in table 70.

TABLE 70.—*Acreage irrigated on the Rio Grande project, 1936*

Subdivision:		*Acreage irrigated*
Rincon Valley		15, 206
Mesilla Valley:		
In New Mexico	72, 258	
In Texas	10, 665	
Total		[illegible]
El Paso Valley		56, 423
Total		154, 552

Reference to table 92 in the following section of this report, which gives the irrigated acreage of Rio Grande Project, 1930 to 1936, inclusive, as reported by the Bureau of Reclamation, shows a figure for 1936 about 12 per cent lower than the figure for that year as

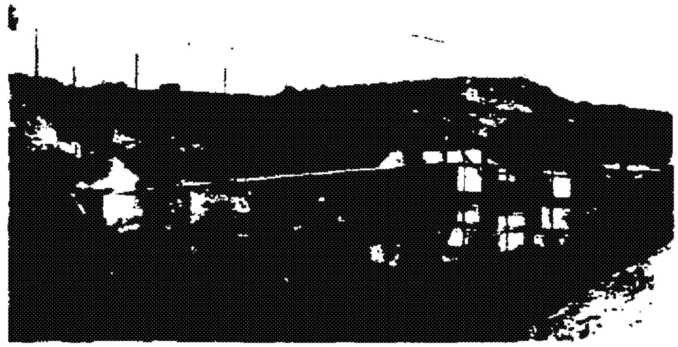

FIGURE 31.—Hudspeth Canal heading and Tornillo wasteway at end of Tornillo Canal. Rio Grande Project.

obtained by the Bureau of Agricultural Engineering and shown in table 70, although the difference between figures for the total acreage of the Project as found by the 1936 surveys of the two bureaus is only about 1 percent. The difference in the irrigated acreage figures is largely due to handicaps under which the Bureau of Agricultural Engineering worked in the early part of the 1936 season, and to greater precision in the Bureau of Reclamation surveys not feasible or necessary in the case of the Bureau of Agricultural Engineering survey. It was required that the latter be planned to cover the entire Upper Rio Grande Basin with a degree of accuracy as needed for the purpose of the Rio Grande joint investigation, and the latter was not such as to require the precision of instrumental surveys. A detailed comparison of the Project acreages as obtained by the two surveys is given in Part III of this report.

The Hudspeth County Conservation and Reclamation district, below and southeast of the Rio Grande Project, is served by an irrigation and drainage system as shown on the map, plate 22. The Hudspeth main canal heads at the lower end of the Tornillo canal of the Rio Grande Project about 12 miles southeast of Fabens and diverts the residual flow of the latter canal. At Alamo Heading on Rio Grande, about 8 miles

RE 30.—Franklin Canal at settling basin and sluiceway, near El Paso. Rio Grande Project.

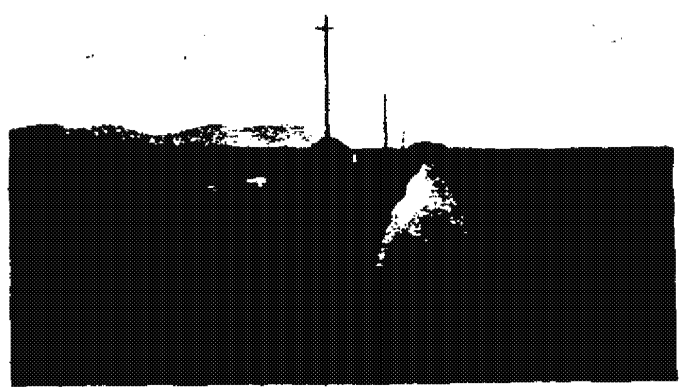

FIGURE 32.—Main canal in lower Hudspeth district, Texas.

below the end of the Tornillo canal, river flow, consisting chiefly of drainage and return water, is diverted by gravity to the Hudspeth feeder canal which joins the Hudspeth canal a short distance northwest of Fort Hancock. The diversion by the Hudspeth district of the drainage and waste flow from the Rio Grande Project is made under a Warren Act contract. This contract extends only to the return water as it occurs in the normal operation of the Rio Grande Project and puts no obligation upon the latter for delivery of any specific amounts of water. The acreage irrigated from Rio Grande in 1936 in Hudspeth County was 13,579, and this was only about 300 acres more than the irrigated acreage in the Hudspeth district.

On the Texas side of the river between Guayuco Arroyo, which is the terminus of the Hudspeth district canal system, and the canyon below Fort Quitman there is some irrigation by individual landowners, who divert from the river by short gravity ditches or by pumping plants. The total acreage shown to be thus irrigated in 1936 was 526 acres. This included about 200 acres in the Hudspeth district below Guayuco Arroyo.

No data are available on the El Paso Valley acreage irrigated from Rio Grande on the Mexican or Juarez Valley side. Estimates in various reports and in the annual histories of the Rio Grande Project have varied from 25,000 to 40,000 acres.

PART I
SECTION 4.—WATER USES AND REQUIREMENTS

For Irrigation

In the Upper Rio Grande Basin the use of water for irrigation constitutes practically its entire use. Although there is, of course, use by cities and villages throughout the basin, the amount so consumed represents a very small part of the total use in the basin. Use of water for power development is confined to a few small units and is not consumptive. It is the use of water for irrigation and the disposition of it for that purpose which give rise to the problems of the basin with which this investigation is chiefly concerned.

Irrigated and Other Water-Consuming Areas, 1936

It has been mentioned in the preceding section of this report that the Bureau of Agricultural Engineering carried through as one of its assignments on the Rio Grande joint investigation, a complete survey and mapping of the 1936 vegetative cover of the basin. This was done in order to determine by vegetative classification the acreage irrigated in the basin as well as the acreage of all other areas consuming water in appreciable quantities and located within constructed irrigation systems or minor additions and extensions already planned. In the detailed report of the survey given in Part III of this report the data obtained are assembled in three tables, A, B, and C. Table A presents the figures for the part of the Rio Grande Basin in Colorado, table B for the part in New Mexico from the Colorado line to San Marcial, and table C for the part in New Mexico and Texas from San Marcial to Fort Quitman. Table 71 of this section is a summary of the data for the entire Upper Rio Grande Basin. It shows that 2,092,817 acres were mapped. Of this total 988,826 acres were given water artificially, including 923,594 irrigated, 46,319 temporarily out of cropping, and 18,913 in cities, towns, and villages. An area of 1,017,466 acres used water but was not irrigated, including 948,171 of native vegetation, and 69,295 of water and river bed surfaces. Finally, 86,525 acres were in bare lands, roads, rights-of-way, etc.

TABLE 71.—*Irrigated and other water-consuming areas in Upper Rio Grande Basin, 1936*

Major unit	Total area mapped	Agricultural and other lands artificially given water				Other water-using areas, nonirrigated			
		Irrigated in 1936	Temporarily out of cropping	Cities, towns, and villages	Total irrigated, "out" and towns	Native vegetation	Water and river bed surfaces	Total nonirrigated	Bare land, roads, rights-of-way, etc.
Total, Upper Rio Grande Basin	2,092,817	923,594	46,319	18,913	988,826	948,171	69,295	1,017,466	86,525
Colorado (total)	1,446,652	600,243	18,979	6,029	625,251	737,199	13,762	750,961	70,440
Closed basin area	733,425	277,922	8,875	1,034	287,831	404,014	4,010	408,024	37,570
Live area	713,227	322,321	10,104	4,995	337,420	333,185	9,752	342,937	32,870
Southwest area	482,531	270,350	7,228	4,103	281,681	176,191	6,549	182,740	18,110
Southeast area	230,696	51,971	2,876	892	55,739	156,994	3,203	160,197	14,760
New Mexico (total)	537,894	242,684	21,681	12,097	276,462	193,116	53,591	246,707	14,725
Colorado State line to Buckman	127,729	75,173	4,534	3,110	82,817	31,622	10,956	42,578	2,334
Areas on main stem of Rio Grande	12,878	5,891	374	233	6,498	3,651	2,336	5,987	393
West side tributaries (to and including Rio Chama)	49,011	29,154	1,207	564	30,925	11,645	5,973	17,618	468
East side tributaries	65,840	40,128	2,953	2,313	45,394	16,326	2,647	18,973	1,473
Buckman to south boundary Middle Rio Grande Conservancy District	221,786	76,690	8,323	7,141	92,154	96,507	25,532	122,039	7,593
Areas on main stem of river (Middle Rio Grande Conservancy District)	187,682	59,159	2,980	6,165	68,304	90,401	21,895	112,296	7,082
West Side tributaries (all below Rio Chama)	34,104	17,531	5,343	976	23,850	6,106	3,637	9,743	511
Bosque del Apache grant	12,583					10,164	1,970	12,134	449
Bosque del Apache grant to San Marcial	4,811	919	330		1,249	2,617	907	3,524	38
San Marcial to Elephant Butte Dam	26,147					22,071	3,384	25,455	692
Elephant Butte Dam to Texas State line	144,838	89,902	8,494	1,846	100,242	30,135	10,842	40,977	3,619
Palomas Valley	10,383	830	501	304	1,635	7,435	1,190	8,625	123
Elephant Butte Irrigation District	124,494	87,464	7,362	1,404	96,230	18,604	6,251	24,855	3,409
West Side tributaries	9,961	1,608	631	138	2,377	4,096	3,401	7,497	87
Texas (total)	108,271	80,667	5,659	787	87,113	17,856	1,942	19,798	1,360
El Paso County Water Improvement District No. 1	86,676	67,088	3,842	787	71,717	11,957	1,861	13,818	1,141
Hudspeth County	21,595	13,579	1,817		15,396	5,899	81	5,980	219

Diversions by Major Canal Systems, 1936

Gross diversions from Rio Grande in 1936 by major canal systems in the upper basin were measured by the Geological Survey in the San Luis and Middle sections and by the Bureau of Reclamation in the Elephant Butte-Fort Quitman section, as part of the Rio Grande joint investigation. In its report the Bureau of Agricultural Engineering has summarized these diversion data and combined them with the corresponding 1936 acreages served by the canals, to derive the figures for gross diversions per unit of area. The summarization is shown in table 72.

The very wide difference in the figures for diversions per acre irrigated as between canals of the San Luis, Middle, and Elephant Butte-Fort Quitman sections is, of course, mainly due to the wide variation in the amounts of water wasted from the canals below the points of measurement. Data on these wastes in 1936 are incomplete and a full comparison of net diversions is not possible. The gross diversion data are of interest, but they afford little indication of the actual consumption of water and the requirements for it.

Consumptive Use of Water

One of the more important elements to be determined in any study of the use of water for irrigation is the "consumptive use" or the volume of water that is actually consumed within a given area and lost to the basin. Under the Rio Grande joint investigation the study and determination of the consumptive use of water in the upper basin and the consumptive requirements of its major units were assigned to the Bureau Agricultural Engineering. The investigation of bureau included a complete review of previous studies by various investigators, and field work in 1936 of two types: (1) Consumptive use-of-water studies on large representative areas, and (2) evapo-transpiration measurements by means of tank and soil-moisture experiments. The results are reported in detail in Part III, and salient features of the report are briefly reviewed in the following paragraphs.

Definitions.—The following definitions of consumptive use were used by the Bureau of Agricultural Engineering in its study:

Consumptive use (Evapo-transpiration): The sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time.

Valley consumptive use: The sum of the volumes of water absorbed by and transpired from crops and native vegetation and lands upon which they grow, and evaporated from bare land and water surfaces in the valley; all amounts measured in acre-feet per 12-month year on the respective areas within the exterior boundaries of the valley.

The valley consumptive use (K) is equal to the amount of water that flows into the valley during 12-month year (I) plus the yearly precipitation on the valley floor or project area (P) plus the water in ground storage at the beginning of the year (G_s) minus the

TABLE 72.—*Gross diversions by major canal systems in upper Rio Grande Basin, 1936*

Major unit	Area mapped in 1936, acres	Area served in 1936, acres				1936 canal diversions, acre-feet			
		Irrigated	Temporarily out of cropping	Towns, etc.	Total	Total	Per acre irrigated	Per acre given water	Per acre of mapped area
(1)	(2)	(3)	(4)	(6)	(6)	(7)	(8)	(9)	(10)
COLORADO									
San Luis Valley:[1]									
Rio Grande Canal	142,196	111,844	3,861	11	115,516	182,600	1.63	1.58	1.28
Farmers' Union canal	94,280	46,267	2,775	397	49,439	45,710	.99	.92	.48
Prairie Ditch	29,471	12,043	976	125	13,144	10,900	.91	.83	.37
San Luis Valley canal	40,524	8,234	1,159	14	9,407	21,790	2.64	2.31	.54
Monte Vista canal	33,512	24,382	371	19	24,772	37,520	1.54	1.51	1.12
Empire canal	64,341	20,794	925	12	21,731	57,370	2.76	2.64	.89
NEW MEXICO									
Middle Rio Grande Conservancy District	187,682	59,159	2,980	6,165	68,304	619,969	10.48	9.08	3.30
Cochiti division	19,439	5,208	169	401	5,778	75,058	14.41	12.99	3.86
Albuquerque division[2]	56,127	22,819	913	4,241	27,973	284,892	10.29	8.40	4.04
Belen division	77,044	23,895	1.165	530	25,590	241,993	10.13	9.46	3.14
Socorro division[3]	33,072	7,237	733	993	8,963	68,046	9.40	7.59	2.06
NEW MEXICO AND TEXAS									
Rio Grande project	211,170	154,552	11,204	2,191	167,947	968,218	6.26	5.77	4.59
Rincon Valley	27,914	15,208	2,129	110	17,445	78,410	5.16	4.49	2.81
Mesilla Valley	110,418	82,923	5,569	1,528	90,018	417,058	5.03	4.63	3.78
El Paso Valley[4]	72,838	56,423	3,506	558	60,487	472,750	8.38	7.82	6.49
Hudspeth County Conservation and Reclamation District No. 1	21,595	13,579	1,817	....	15,396	77,154	5.68	5.01	3.57

[1] Areas here shown for San Luis Valley are those served by the principal canals diverting from the main stem of Rio Grande.
[2] Including Albuquerque.
[3] Including Socorro.
[4] Excluding El Paso.

amount of water in ground storage at the end of the vear (G_e) minus the yearly outflow (R): all amounts easured in acre-feet. The consumptive use of water er acre of irrigated land is equal to (K) divided by irrigated area (A_i); and consumptive use per acre of the entire valley floor is equal to (K) divided by the entire valley area. The unit is expressed in acre-feet per acre.

Stream-flow depletion: The amount of water which annually flows into a valley, or upon a particular land area (I), minus the amount which flows out of the valley or off from the particular land area (R) is designated "stream-flow depletion" (I−R). It is usually less than the consumptive use and is distinguished from consumptive use in the Rio Grande studies.

Past investigations.—The results of previous studies by various investigators are summarized in table 73. It will be noted that there is marked variability in the stream-flow depletion estimates for the same or approximately the same areas. This is not unusual. Precise estimates have been and are difficult, because there are many variable factors influencing consumptive use and stream-flow depletion. Some variability in the estimates may be attributed to dissimilar conditions under which the determinations were made and to lack of specific definitions.

Bureau of Agricultural Engineering investigations.—The results of the consumptive use and stream-flow depletion determinations of the Bureau of Agricultural Engineering by inflow-outflow and other methods applied to representative areas or tracts in the upper basin are summarized in table 74. The location and nature of the many evapo-transpiration stations which were established and maintained are shown in table 75. There is no attempt here to summarize the results

TABLE 73.—*Consumptive use of water in Upper Rio Grande Basin as derived from previous studies of various investigators*

Date	Investigator	Area included	Consumptive use in acre-feet per irrigated acre per year	Stream-flow depletion per irrigated acre per year	Remarks
1930	R. J. Tipton	Southwest area—San Luis Valley		2.18	Average, 1921–29.
1930	do	Conejos area—San Luis Valley		2.58	Do.
1930	do	Southwest area minus Conejos, San Luis Valley		1.93	Do.
1930	do	North area—San Luis Valley		2.06	Do.
1933	do	Closed basin irrigated from Rio Grande		1.2	
'933	do	Closed basin irrigated from other streams		1.5	
'3	R. J. Tipton and F. C. Hart	Bowen-Carmel—San Luis Valley	2.30	1.42	Average, 1930, 1931, and 1932.
1	H. W. Yeo and R. F. Black	Water District 20, San Luis Valley		2.01	Average, 1915–28.
31	Yeo and Black	Water District 22, San Luis Valley		2.67	Average, 1921–28.
1931	do	Entire San Luis Valley	3.17	2.10	Average, 1918–27.
1936	C. R. Hedke and Bureau of Agricultural Engineering.	do		2.52	Average, 1900–23.
1928	R. I. Meeker and L. T. Burgess	Mesilla Valley		3.5	Average, 1923–27.
1928	Meeker and Burgess	Elephant Butte to El Paso		3.15	Average, 1920–27.
1928	do	El Paso to Fort Quitman		2.8	Average, 1923–27.
1928	E. P. Osgood	Elephant Butte to Fabens		1.0	Average, 1919–27.
			Total stream-flow depletion in 1,000 acre-feet units		
1919	Harold Conkling and E. B. Debler	Middle Valley	508		Average, 1895–1918
1925	C. R. Hedke	do	565		1925.
1927	Debler-Elder	do	510		Average, 1895–1926.
1927	do	do	535		By comparison to Mesilla Valley.
1929	R. G. Hosea	do	481		Comparison to Mesilla Valley.
1932	E. B. Debler	do	480		Do.
1932	do	do	498		By integration—present.
1928	E. P. Osgood	Elephant Butte to Fabens	657		1927.
1924	E. B. Debler and A. W. Walker	Rio Grande project	787		1923 and previous records.
1928	R. G. Hosea	do	783		Average, 1923–27.

TABLE 74.—*Consumptive use of water by representative areas in Upper Rio Grande Basin as derived by Bureau of Agricultural Engineering*

Area or tract	Total acreage	Irrigated acreage	Period covered	Consumptive use [1] in acre-feet per— Irrigated acre	Consumptive use [1] in acre-feet per— Acre of total	Stream-flow depletion in acre-feet per irrigated acre per year	Remarks
Southwest—San Luis Valley	400,000	219,900	1925–35, inclusive	3.02	1.66	1.92	11-year averages.
Do	400,000	224,000	1936	3.28	1.83	1.91	
Central Southwest—San Luis Valley	114,000	61,000	1936	3.34	1.80	1.55	
Bowen-Carmel, San Luis Valley	20,000	14,000	1936	2.75	1.86	1.27	
Isleta-Belen, Middle Valley	17,500	9,000	April–December 1936	4.46	2.28	3.39	Inflow-outflow method.
Do	21,074		1936		2.73		Integration method.
Mesilla Valley	109,000	65,814	1919–35	4.52	2.73	3.30	17-year averages.
Do	110,418	82,925	1936	3.66	2.75	2.67	
Middle Valley				4.10			Estimate using Hedke heat units method.

[1] Includes consumption of precipitation.

TABLE 75.—*Evapo-transpiration and soil-moisture sampling stations established and maintained by Bureau of Agricultural Engineering in Upper Rio Grande Basin in 1936*

Station	Location	Description of installation
Wright	Closed basin, San Luis Valley	2 wheat tanks and 2 potato tanks.
West	Southwest area, San Luis Valley	1 wheat tank; 1 potato tank; U. S. Weather Bureau class A evaporation pan; rain gage; anemometer.
Parma	6 miles east of Monte Vista, San Luis Valley	1 tule tank; 2 meadow grass tanks; U. S. Weather Bureau class A evaporation pan; rain gage; anemometer.
San Luis Lakes	Sump of closed basin, San Luis Valley	U. S. Weather Bureau class A evaporation pan; rain gage; anemometer.
J. L. Phillips farm	5 miles south of Albuquerque, Middle Valley	Soil-moisture sampling plots in orchard, alfalfa field, and vineyard.
Albuquerque, Belen, and Socorro divisions	Middle Valley	Soil-moisture sampling in native-vegetation areas near geological survey observation wells.
Los Poblanos ranch	5 miles north of Albuquerque, Middle Valley	2 alfalfa tanks; rain gage.
Isleta	Adjacent to river at Isleta, Middle Valley	1 cattail tank; 1 sedge tank; 1 salt grass tank; 1 willow tank; U. S. Weather Bureau class A evaporation pan; rain gage; anemometer.
El Vado Dam	El Vado Dam on Chama River, Middle Section	U. S. Weather Bureau class A evaporation pan; rain gage; anemometer; thermometers. Cooperation U. S. Weather Bureau and Middle Rio Grande conservancy district.
Socorro	Middle Rio Grande conservancy district yard at Socorro, Middle Valley.	U. S. Weather Bureau class A evaporation pan; rain gage.
State College	Near Las Cruces, N. Mex	Soil-moisture sampling plots; cotton at agronomy farm, field EC and field 9W; alfalfa at horticultural farm.
Do	do	2 cotton tanks; 2 alfalfa tanks.
Mesilla Dam	5 miles southwest of State College, N. Mex	2 cattail tanks; 1 salt grass tank; U. S. Weather Bureau class A evaporation pan; rain gage.

TABLE 76.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, San Luis Valley, Colo.*

Location	Irrigated lands			Native vegetation			Miscellaneous			
	Alfalfa, clover	Native hay, pasture	Miscellaneous crops	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
Closed basin area:										
Saguache County	2.5	1.5	1.5	1.0	1.3	3.8	1.5	1.5	3.5	0.7
Rio Grande County	2.5	2.0	1.5	1.5	2.0	3.8	1.5	1.5	3.5	.7
Alamosa County	2.5	2.0	1.5	1.5	1.8	3.8	1.5	1.5	3.5	.7
Southwest area:										
South Fork, Schraders, Pinos Creeks, and areas above	2.0	1.5	1.5	.8	.8	3.5	1.5	1.5	3.3	.7
Monte Vista canal, Empire canal, and small canals	2.5	2.0	1.5	1.5	1.5	3.8	1.5	1.5	3.5	
Alamosa Creek, La Jara Creek, and Terrace Irrigation District	2.3	1.8	1.5	1.5	1.5	3.8	1.5	1.5	3.5	
Conejos River and tributaries, San Antonio River, and Los Pinos River	2.0	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	
Rio Grande canal, San Luis canal, and small canals (south closed area)	2.5	2.0	1.5	1.5	2.0	3.8	----------	1.5	3.5	.7
Southeast area:										
Trinchera Creek and tributaries	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	.7
Blanca, Ute, and Sangre de Cristo Creeks	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	.7
Culebra Creek and Costilla Creek	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	.7

TABLE 77.—*Estimate of consumptive water requirements in the San Luis Valley, Colo. (including precipitation), based on 1936 acreages*

Location	Irrigated lands			Native vegetation			Miscellaneous [1]			Total area mapped		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
Closed basin area:												
Saguache County	171,182	272,426	1.59	223,678	271,932	1.22	35,978	34,297	0.95	430,838	578,655	1.34
Rio Grande County	56,792	101,212	1.78	4,227	8,668	2.05	4,008	6,048	1.51	65,027	115,928	1.78
Alamosa County	49,948	101,992	2.04	176,109	300,214	1.70	11,503	14,852	1.29	237,560	417,058	1.76
Entire area	277,922	475,630	1.71	404,014	580,814	1.44	51,489	55,197	1.07	733,425	1,111,641	1.52
Southwest area:												
South Fork, Schraders, Pinos Creeks, and areas above	20,438	31,616	1.55	3,429	8,610	2.51	2,823	5,310	1.88	26,690	45,536	1.71
Monte Vista canal, Empire canal, and small canals	84,851	165,362	1.95	77,809	132,693	1.71	9,404	12,678	1.35	172,064	310,733	1.81
Alamosa Creek, La Jara Creek, and Terrace Irrigation District	49,018	88,409	1.80	43,339	71,113	1.64	8,063	10,823	1.34	100,420	170,345	1.70
Conejos River and tributaries, San Antonio River, and Los Pinos River	82,389	132,871	1.61	25,614	45,105	1.76	12,471	17,546	1.41	120,474	195,522	1.62
Rio Grande canal, San Luis canal, and small canals (south closed area)	33,654	64,575	1.92	26,000	48,817	1.88	3,229	5,966	1.85	62,883	119,358	1.90
Entire area	270,350	482,833	1.79	176,191	306,338	1.74	35,990	52,323	1.45	482,531	841,494	1.74
Southeast area:												
Trinchera Creek and tributaries	16,847	27,185	1.61	73,173	77,936	1.07	5,955	7,436	1.25	95,975	112,557	1.17
Blanca, Ute, and Sangre de Cristo Creeks	2,669	4,390	1.64	6,286	11,412	1.82	619	1,063	1.72	9,574	16,865	1.76
Culebra Creek and Costilla Creek	32,455	52,909	1.63	77,535	79,674	1.03	15,157	18,697	1.23	125,147	151,280	1.21
Entire area	51,971	84,484	1.63	156,994	169,022	1.08	21,731	27,196	1.25	230,696	280,702	1.22
Total	600,243	1,042,947	1.74	737,199	1,056,174	1.43	109,210	134,716	1.23	1,446,652	2,233,836	

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces: pooled water, river, and canal surfaces and exposed beds; bare land, roads, rights-of-way, .

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obtained at these stations; reference is made to Part III for a description of the work and a complete statement of the results.

The Bureau of Agricultural Engineering on the basis of its own work and that of others proposed estimates of the present consumptive requirements for water in the various sub-basins of the Upper Rio Grande Basin as shown in tables 76 to 81, inclusive. These embody the consumptive use determinations as derived by the so-called integration method; that is, based on all available experience and judgment, unit values of consumption (acre-feet per acre) are assigned to the various classes of vegetative and other cover, taking into account the location of the latter within the basin with respect to altitude and latitude. These units are then multiplied by the corresponding class acreages to derive the total consumptive use in acre-feet. Since the unit figures represent consumption which is to be supplied from any and all sources of water, the total figures derived include precipitation and ground-water contributions as well as stream-flow depletion.

TABLE 78.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, Colorado-New Mexico State line to San Marcial, N. Mex.*

Location	Irrigated lands			Native vegetation			Miscellaneous			
	Alfalfa	Native hay, pasture	Miscellaneous	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
State line to Rinconada [1]										
Rinconada to Embudo	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Embudo to Santa Fe County line	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Santa Fe County line to Buckman	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Middle Rio Grande Conservancy District:										
Cochiti division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Albuquerque division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Belen division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Socorro division	4.0	2.5	2.0	2.5	3.0	5.2	2.0	2.0	4.5	1.0
Bosque del Apache grant	4.0	2.5	2.0	2.5	3.5	5.8	2.0	2.0	5.0	1.0
Bosque del Apache to San Marcial	4.0	2.5	2.0	2.5	3.5	5.8	2.0	2.0	5.0	1.0

[1] Canyon section.

TABLE 79.—*Estimate of consumptive water requirements, main stem of Rio Grande, Colorado-New Mexico State line to San Marcial, N. Mex. (including precipitation), based on 1936 acreages*

Location	Irrigated lands			Native vegetation			Miscellaneous [1]			Total area mapped		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
State line to Rinconada [2]												
Rinconada to Embudo	191	349	1.83	31	78	2.50	156	540	3.46	378	967	2.56
Embudo to Santa Fe County line	4,894	10,037	2.05	2,243	6,615	2.95	2,212	6,608	2.99	9,349	23,260	2.49
Santa Fe County line to Buckman	806	1,823	2.26	1,377	5,030	3.65	968	3,102	3.20	3,151	9,955	3.16
Middle Rio Grande Conservancy District:												
Cochiti division	5,208	12,549	2.41	11,232	40,756	3.63	2,999	8,611	2.87	19,439	61,916	3.19
Albuquerque division	22,819	61,608	2.70	23,495	81,322	3.46	11,813	35,902	3.04	58,127	178,832	3.08
Belen division	23,895	65,188	2.73	40,794	123,322	3.02	12,355	36,421	2.95	77,044	224,931	2.92
Socorro division	7,237	18,124	2.50	14,820	58,899	3.96	10,955	40,156	3.67	33,072	117,179	3.54
Bosque del Apache grant				10,164	56,364	5.55	2,419	10,299	4.26	12,583	66,663	5.30
Bosque del Apache to San Marcial	919	2,539	2.76	2,617	14,137	5.40	1,275	5,233	4.10	4,811	21,909	4.55
Total	65,969	172,217	2.61	106,833	386,523	3.62	45,153	146,872	3.25	217,954	705,612	3.24

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces—pooled water, river and canal surfaces and exposed beds; bare land, roads, rights-of-way etc.
[2] Canyon section.

TABLE 80.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, San Marcial, N. Mex., to Fort Quitman, Tex.*[1]

Location	Irrigated lands				Native vegetation			Miscellaneous			
	Cotton	Alfalfa	Native hay, pasture	Miscellaneous crops	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
San Marcial to Elephant Butte Dam					2.5	3.2	5.8			5.5	0.8
Palomas Valley (Elephant Butte Dam to Apache Canyon)		4.0	2.5	2.0	2.5	3.2	5.0	2.0	2.0	4.5	.8
Rincon Valley (in Sierra and Dona Ana Counties)	2.5	4.0	2.5	2.0	2.5	3.0	4.8	2.0	2.0	4.5	.7
Mesilla Valley in New Mexico and Texas	2.5	4.0	2.5	2.0	2.5	2.8	4.8	2.0	2.0	4.5	.7
El Paso division, Rio Grande project	2.5	4.2	2.5	2.0	2.5	3.0	4.8	2.0	2.0	4.5	.7
Hudspeth County Conservation and Reclamation District No. 1	2.5	4.2		2.0	2.5	3.2	5.0		2.5	4.5	.7

[1] Results of Bureau of Plant Industry salinity studies were not available when these estimates were made.

TABLE 81.—*Estimate of consumptive water requirements, main stem of Rio Grande, San Marcial, N. Mex., to Fort Quitman, Tex. (including precipitation), based on 1936 acreages*

Location	Irrigated lands			Native vegetation			Miscellaneous [1]			Total area mapped		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
San Marcial to Elephant Butte Dam				22,071	114,796	5.20	[2] 20,750	110,873	5.34	[2] 42,821	225,669	5.27
Palomas Valley (Elephant Butte Dam to Apache Canyon)	830	2,011	2.42	7,435	25,868	3.48	2,118	7,063	3.34	10,383	34,942	3.37
Rincon Valley (in Sierra and Dona Ana Counties)	15,206	40,346	2.65	7,310	27,955	3.82	5,398	16,817	3.12	27,914	85,118	3.05
Mesilla Valley in New Mexico and Texas	82,923	227,365	2.74	13,198	43,199	3.27	14,297	34,735	2.43	110,418	305,299	2.76
El Paso division, Rio Grande project	56,423	163,105	2.89	10,053	32,654	3.25	[3] 6,362	14,927	2.35	[3] 72,838	210,686	2.89
Hudspeth County Conservation and Reclamation District No. 1	13,579	35,631	2.62	5,899	22,567	3.83	2,117	5,061	2.39	21,595	63,259	2.93
Total area	168,961	468,458	2.83	65,966	267,039	4.05	[2,3] 51,042	189,476	3.71	[2,3] 285,969	924,973	3.23

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces—pooled water, river, and canal surfaces and exposed beds; bare land, roads, rights-of-way, etc.
[2] Includes water surface area of Elephant Butte Reservoir (16,674 acres) as averaged for June 1936.
[3] Exclusive of city of El Paso (6,210 acres).

NOTE.—Results of Bureau of Plant Industry salinity studies were not available when estimates were made.

Basin Totals of Supply and Use

The data for total water production in the Upper Rio Grande Basin as derived in a previous section, and the consumptive use data of tables 76 to 81 combined with the acreage data of tables A, B, and C of Part III, afford a comparison of figures for total supply and consumption and an approximation of basin surpluses or deficiencies. Such a comparison is shown in table 82. For each of the three major sections of the upper basin, San Luis, Middle, and Elephant Butte-Fort Quitman, and for the whole upper basin, there are shown (1) the total irrigated and other water-consuming acreage (native vegetation, etc.) as found by the 1936 survey, (2) the consumptive use of water as measured by stream-flow depletion, and (3) the derived weighted average unit stream-flow depletion. The consumption is then compared to the water supply as measured by the natural run-off to the sections and to the entire basin, for a normal, maximum, and minimum run-off year. Since there is no return to Rio Grande from the closed basin (except for that in the Rio Grande drain) any surplus to Rio Grande in the San Luis section must be derived as the run-off to the southwest and southeast areas less the consumption (stream-flow depletion) in those areas and the consumption in the closed basin served from Rio Grande. The acreage shown in the table for San Luis section is therefore that for the southwest and southeast areas plus that in the closed basin served from Rio Grande, and the consumption shown is that corresponding to this acreage. The acreage figures of table 82 are taken from tables A, B, and C of Part III and the consumption figures partly from tables 76 to 81 and partly by further derivations combining the data of the consumptive use and acreage tables where the former do not give the complete data; for example, the consumption by the closed basin area served from Rio Grande and the consumption by the tributary areas in the Middle and Elephant Butte-Fort Quitman sections. Estimates of acreage and consumption in Mexico were also included in an endeavor to make the comparisons complete for the upper basin. The data of tables 76 to 81 represent total consumption, including precipitation. In deriving the stream-flow depletion figures of table 82, therefore, correction was made for precipitation by subtracting from the unit consumption figures, 0.6 for San Luis Valley and 0.7 for the main river valleys and 1.0 for the tributary valleys of the Middle and Elephant Butte-Fort Quitman sections.

TABLE 82.—*Comparison of water supply and stream-flow depletion by irrigation, Upper Rio Grande Basin*

Item No.	Item	San Luis section	Middle section	Elephant Butte-Fort Quitman section	Upper Rio Grande Basin
1	Irrigated and water consuming acreage, 1936	[1] 1,047,000	367,000	[2] 336,000	1,750,000
2	Consumptive use (stream flow depletion) acre-feet	[3] 1,047,000	768,000	[4] 885,000	2,700,000
3	Unit stream flow depletion-acre-feet per acre	1.00	2.09	2.63	1.54
	NORMAL OR MEAN YEAR				
4	Water supply—total natural run-off, acre-feet	[5] 1,379,000	1,333,000	165,000	2,877,000
5	Surplus or deficiency, item 4 − item 2, acre-feet	332,000	565,000	−720,000	177,000
	MAXIMUM YEAR (1897)				
6	Water supply—total natural run-off, acre-feet	[5] 1,589,000	2,080,000	614,000	4,263,000
7	Surplus or deficiency, item 7 − item 2, acre-feet	542,000	1,312,000	−271,000	1,583,000
	MINIMUM YEAR (1902)				
8	Water supply—total natural run-off, acre-feet	[5] 507,000	452,000	112,000	1,071,000
9	Surplus or deficiency, item 9 − item 2, acre-feet	−540,000	−316,000	−773,000	−1,629,000

[1] Excludes closed basin area except that irrigated from Rio Grande.
[2] Includes an estimate of 40,000 acres in Mexico.
[3] Excludes closed basin consumption except by area served from Rio Grande.
[4] Includes estimate of 130,000 acre-feet in Mexico.
[5] Excludes water production of closed basin.

For San Luis and Middle sections, table 82 shows surpluses in the maximum and normal years and deficiencies in the minimum year. Elephant Butte-Fort Quitman section shows deficiencies in all years. For the entire upper basin, a surplus of 177,000 acre-feet is shown for the normal or mean year. Considering the nature of the derivation of this figure and the many factors involved, it is in fair agreement with the 13-year mean outflow of Rio Grande at Fort Quitman, 1924–36, which is 211,000 acre-feet. In the maximum year there is a basin surplus of over a million and a half acre-feet, and in the minimum year an equivalent or slightly greater deficiency.

In the data of table 83, the water supply and stream-flow depletion figures are used to show a comparison of the water "beneficially" consumed and that consumed "otherwise." For the purposes of this comparison beneficial consumption is taken to be that by the irrigated acreage only. Of the water consumed otherwise there may be certain uses such as reservoir evaporation, for example, which are not necessarily nonbeneficial but which would not be classed as directly beneficial. However, besides many unavoidable consumptive losses, the "otherwise" uses include many which are avoidable. These may be consumption by native vegetation which could be prevented advantageously by drainage, transmission losses which could be educed economically by canal improvements, excess use associated with the practice of careless irrigation methods, or operation wastes.

TABLE 83.—*Comparison of directly beneficial and other consumptive uses of water in irrigation, Upper Rio Grande Basin*

[Unit, 1,000 acre-feet except as noted]

Basin unit	Total annual inflow of run-off, 46-year mean	Total acreage irrigated, 1936, 1,000-acre units	Stream-flow depletion by irrigated acreage, 1936; directly beneficial consumptive use		Total annual outflow of run-off, 46-year mean	Beneficial use plus outflow (5)+(6)	Other consumptive uses (2)−(7)
			Unit, acre-feet per acre	Total			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
San Luis section	1,567	600	1.14	684	[1] 448	1,132	435
Middle section	[2] 1,781	[3] 153	1.50	230	[4] 1,031	1,261	520
Elephant Butte-Fort Quitman section	[5] 1,196	[6] 201	2.30	462	[7] 211	673	523
Upper Rio Grande Basin	....	954	1.44	1,376	....	....	1,478

[1] Mean annual outflow at Lobatos with present development San Luis Valley.
[2] Lobatos outflow 448,000 plus Middle section production 1,333,000 acre-feet.
[3] 66,000 acres on main stem of Rio Grande and 87,000 acres in tributary valleys.
[4] Mean annual outflow at San Marcial with present development San Luis Valley.
[5] San Marcial outflow 1,031,000 plus Elephant Butte-Fort Quitman section production 165,000 acre-feet.
[6] Includes estimate of 30,000 acres in Mexico.
[7] Mean outflow at Fort Quitman 1924 to 1936, inclusive.

In explanation of table 83, it is shown for San Luis section, for example, that the total irrigated acreage in 1936 was 600,000 acres, which consumed (depleted the stream flow) an estimated 684,000 acre-feet. This is the directly beneficial consumption in the section. These data are taken from table 77 with a correction to the unit consumption for irrigated lands, as given therein, of 0.6 acre-foot per acre for precipitation, in order to derive stream-flow depletion. With present development in San Luis Valley it is estimated that the mean outflow at Lobatos, 1890–1935, would have been 448,000 acre-feet (table 18). The total of directly beneficial consumption and outflow is therefore 1,132,000 acre-feet, and this subtracted from the mean total inflow to the valley of 1,567,000 acre-feet leaves 435,000 acre-feet consumed annually on areas other than the irrigated acreage. A portion of this large loss can be recovered by drainage. Similarly, the "other consumptive uses" derived for the Middle and Elephant Butte-Fort Quitman sections are, respectively, 520,000 and 523,000 acre-feet, making the basin total for this consumption or loss, 1,478,000 acre-feet. This is a little more than the total basin consumption by the irrigated acreage, shown as 1,376,000 acre-feet. In other words, of the total stream-flow depletion in the basin, about half is beneficially consumed by the irrigated acreage and the other half is represented by losses, some of which are avoidable.

Diversion Requirements of Major Units

Beyond knowledge of the consumptive use of water in the Upper Rio Grande Basin, it is essential to any adjustments which may be proposed for an equitable division of the water between the three sections of the basin that the requirements of the major units of those sections in terms of the necessary diversion demand upon the stream flow be known. In San Luis Valley this means the demand upon Rio Grande at or above Del Norte to satisfy the requirements of the area served by Rio Grande and the demand upon Conejos River to satisfy the area served by that stream. The demands upon other streams of San Luis Valley are not of concern in the present consideration since other than by occasional flood flows these streams contribute practically no water to the flow of Rio Grande leaving the valley. In the Middle section the essential requirement is the demand upon Rio Grande at Otowi Bridge to serve the Middle Rio Grande Conservancy District, and in the Elephant Butte-Fort Quitman section it is the demand upon Elephant Butte Reservoir to serve the Rio Grande Project and fulfill the treaty obligation to Mexico.

The San Luis section.—Rio Grande Area.—For the area served from Rio Grande in San Luis Valley, the diversion demand was derived from the acreage and consumptive use figures of tables A of Part III and 76, and the return flow data as given under the caption of "return water" in the previous section of this report on water supply. From table A the irrigated acreage in 1936 was 306,000 acres. Due to the current subnormal water supply, this may have been below average although there are no comparable data for previous years to provide a comparison. To make some allowance for this possibility as well as to include certain of the other water-consuming areas which are served unavoidably, the area of 306,000 acres was increased by 15 percent to a round figure of 350,000 as the acreage irrigated from Rio Grande on which the diversion demand was based. From the data of tables A and 76, the average unit consumptive use of the crops included in the area of 306,000 acres irrigated from Rio Grande in 1936 was 1.9 acre-feet per acre. Subtracting a precipitation allowance of 0.6 foot from this figure and applying the resulting unit stream-flow depletion to 350,000 acres gives 455,000 acre-feet as the total stream-flow depletion. To get the diversion demand there must be added to this figure the total of indivertible waste and return flow. In the portion of this report dealing with return flow it is shown that the return, including waste, in 1936 from Rio Grande diversions, exclusive of those to the closed basin, amounted to 36 percent of those diversions. From this and the other return-flow data given, it was concluded that a return of 30 percent might be conservatively selected in deriving the diversion demand. Application of this percentage gave a demand of 650,000 acre-feet. This was then taken as the yearly requirement for diversion from Rio Grande for the irrigation of 350,000 acres. By way of comparison, the mean of the annual diversions from Rio Grande below the Del Norte gage in the period 1930–36, inclusive, was 501,000 acre-feet. The maximum diversion in this period was that in 1932, amounting to 729,000 acre-feet.

Use of the estimated demand of 650,000 acre-feet in subsequent reservoir operation studies required that its monthly distribution be established as well as the total of return flow to Rio Grande to be anticipated, and its monthly distribution. In the succeeding section of this report on storage development, mention is made of an ideal monthly distribution for Rio Grande diversions in San Luis Valley developed by R. J. Tipton, consultant to the Colorado State Engineer. This was derived from an extensive compilation of the diversions of San Luis Valley canals having old priorities and from the distribution in other comparable regions having adequate storage control. This ideal distribution was taken as the basis for monthly distribution of the diversion demand as developed in this report, both for the area served from Rio Grande and that under the Conejos River. The monthly distribution of the 650,000 acre-feet demand is shown in table 84.

From the data of table 36 and tables 40 to 42 in the section of this report on return water, the total return to the river both above and below Alamosa from R[illegible] Grande diversions is indicated to have been 1[illegible] percent of the total Rio Grande diversions in 1934, 16.1 percent in 1935, and 19.6 percent in 1936. Assuming that the data of these last 3 years may be taken as a fair index (beginning with 1934 there appears to have been an increase in return water) of the return, a figure of 16 percent was adopted to represent the proportion of total Rio Grande divisions returned to the river. The monthly distribution of return flow has been erratic in the past, depending on monthly diversions, which, in turn, have been dependent on practically unregulated stream flow. With storage regulation and distribution of diversions more nearly in accordance with the ideal monthly demand the monthly distribution of return flow would without doubt show a corresponding uniformity. To derive such a distribution, the computed returns, by months, during the years 1934 to 1936 were compared to the corresponding monthly diversions and the relations so obtained used as the basis for estimate of the return flow and its distribution under the ideal diversion distribution. The resulting distribution is shown in table 84. For a comparison, the actual distribution as indicated by the mean of the return data for 1934, 1935, and 1936 is shown in table 38 of the previous section on retur[n] water.

TABLE 84.—*Monthly distribution of estimated diversion demand and resulting return flow, Rio Grande and Conejos areas, San Luis Valley*

[Unit, 1,000 acre-feet except as noted]

Month	Area served by Rio Grande diversions: Diversion demand on Del Norte		Area served by Rio Grande diversions: Return flow to Rio Grande 16 percent of diversions		Conejos area [1]: Diversion demand on Mogote: Above mouth San Antonio	Conejos area [1]: Diversion demand on Mogote: Below mouth San Antonio	Conejos area [1]: Diversion demand on Mogote: Total	Conejos area [1]: Return flow 35 percent of diversions
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percent		*Percent*					
January	0	0	2	2	0	0	0	2
February	0	0	2	2	0	0	0	2
March	0	0	2	2	0	0	0	2
April	5	33	3	3	2	10	12	2
May	17	110	8	8	5	34	39	6
June	27	175	19	20	8	54	62	15
July	26	169	19	20	8	52	60	15
August	18	117	17	18	5	36	41	14
September	5	33	12	13	2	10	12	10
October	2	13	8	8	0	4	4	6
November	0	0	5	5	0	0	0	4
December	0	0	3	3	0	0	0	2
Total	100	650	100	104	30	200	230	80

[1] Area under Conejos and San Antonio at mouth. Area which would be served by Conejos storage only.

Column (2) ideal diversion distribution after R. J. Tipton.
Columns (6), (7), and (8) based on percentage distribution of column (2).
Column (9) based on percentage distribution of column (4).

Conejos Area.—The diversion demand derived for the Conejos area is that upon the Conejos River at Mogote to serve the area now irrigated from the Conejos and the inflow from San Antonio River. This is the area which would be benefited by proposed storage on the Conejos. The actual stream-flow depletion by this area is given by subtracting the outflow as measured at the mouth of Conejos River from the inflow as measured on Conejos River at the Mogote gage and on San Antonio River at its mouth. The period for which records of all three stations are available is from 1923 to 1936. In this period the mean annual stream flow depletion was 154,500 acre-feet. Extending the records by estimates to include the period 1911–35 (the period used subsequently in reservoir operation studies), the mean annual stream-flow depletion derived for this period is 157,000 acre-feet.

The irrigated and other water-consuming area under the Conejos as mapped in 1936 and shown in table A of Part III was 115,705 acres. Breaking this down to the classifications indicated, and applying the Bureau of Agricultural Engineering estimates of unit consumptive use as given in table 76 less 0.6 foot for precipitation, gives a total stream-flow depletion for this area of 117,000 acre-feet. This is substantially lower than the mean annual depletion as given by the stream-flow records. In selecting the depletion figure to be used in deriving the diversion demand for this area, it was considered inadvisable to depart materially from the mean of actual depletions in recent years. A round figure of 150,000 acre-feet was therefore adopted. In the section of this report on return water, table 39 shows a return in 1936 for the Conejos area amounting to 44 percent of the diversions. This high percentage is ascribed to the present conditions of wild flooding which prevail in the Conejos area during the short period of spring run-off when heavy overdiversions are made in an endeavor to offset to some degree the effects of the extreme lack of conformity between the irrigation demand and the unregulated supply. With a supply regulated by storage, overdiversion should be eliminated to great extent with a corresponding reduction in the return water percentage. In view of these considerations, a figure of 35 percent was adopted as representing the proportion of the diversions which would be returned as indivertible waste and drainage. Using this percentage, the diversion demand on the Conejos River for the Conejos area becomes 230,000 acre-feet. It is necessary to divide this demand into that for the area above, and that for the area below, the junction of the San Antonio with the Conejos, in order that the amount of usable and indivertible inflow of the San Antonio may be determined. The 1936 survey shows that 88 percent of the area mapped lies below the junction. Using this as a basis of division, the Conejos River diversion demand is 30,000 acre-feet above and 200,000 acre-feet below the junction.

For monthly distribution of the demand the same ideal distribution was used as in the case of diversions from Rio Grande. Likewise, the same monthly distribution was assigned to the return flow as in the case of return from Rio Grande diversions. The distributions of the demand and return flow are shown in table 84.

The Middle section.—The demand on Rio Grande at Otowi Bridge for the area from that point to San Marcial, including the area of the Middle Rio Grande Conservancy District, was derived by selection of a value for the stream-flow depletion between Otowi Bridge and San Marcial based on consideration of four separate estimates of that depletion.

Stream Flow Depletion, 1890–1935.—In the section of this report on water supply, in connection with the correction of recorded Rio Grande run-off for present development, estimates were derived for mean annual stream-flow depletion and tributary inflow, 1890–1935, Otowi Bridge to San Marcial, of 586,000 and 359,000 acre-feet, respectively. Comment was made that because of the uncertainty with respect to tributary inflow, nothing better than rough approximations of these quantities is possible and that the figures derived should be considered accordingly.

Stream-flow Depletion Based on Water Production Estimates.—In the estimates of water production, Appendix B of this report, table 199 gives the estimated annual water production 1890 to 1935 of the southern unit of the Middle section. This is the unit of the Rio Grande drainage area from Otowi Bridge to San Marcial. The production figures represent the natural run-off of tributary streams above irrigation depletions. The latter can be estimated from the data on irrigated areas and consumptive use as given in table B, Part III, and table 78, respectively. If the depletions so derived are then deducted from the water production figures an approximation of the Rio Grande tributary inflow, Otowi Bridge to San Marcial, may be obtained which is entirely independent of any other derivations of this tributary inflow as given in this report. The sum of the tributary inflow and the difference in flow between Otowi Bridge and San Marcial then affords an independent estimate of the Middle Valley depletion. The derivation of such an estimate is indicated in table 85. Table B shows a total water-consuming area in the tributary valleys of 40,000 acres. Unit depletion figures based on the data of table 78 were applied to the acreages of the various classes comprised in the 40,000 acres giving a total depletion of 63,000 acre-feet. This represents an average unit stream-flow depletion of 1.6 acre-feet per acre, or a consumptive use of 2.6 acre-feet per acre (1.0 foot was allowed for precipitation). The

63,000 acre-feet was taken as the depletion for years of normal or greater run-off and reduced for less than normal years, roughly in proportion to the percentage below normal of the southern unit run-off as given by table 199.

TABLE 85.—*Stream-flow depletion, Otowi Bridge to San Marcial, 1890–1935, based on tributary inflow derived from water production estimates*

[Unit, 1,000 acre-feet]

Year (1)	Water production in drainage area above irrigation diversions (2)	Irrigation depletions in tributary valleys (3)	Rio Grande tributary inflow (2)−(3) (4)	Otowi Bridge flow less San Marcial flow (5)	Stream-flow depletion (4)+(5) (6)
1890	610	63	547	422	969
1891	818	63	755	−292	463
1892	600	63	537	331	868
1893	260	53	207	459	666
1894	120	15	105	146	251
1895	440	63	377	37	414
1896	125	16	109	121	230
1897	710	63	647	−320	327
1898	185	40	145	127	272
1899	148	27	121	442	563
1900	102	7	95	240	335
1901	188	40	148	200	348
1902	72	4	68	223	291
1903	602	63	539	397	936
1904	168	34	134	18	152
1905	620	63	557	−373	184
1906	630	63	567	353	920
1907	855	63	792	594	1,386
1908	270	54	216	247	463
1909	560	63	497	655	1,152
1910	295	57	238	416	654
1911	625	63	562	308	870
1912	618	63	555	409	964
1913	171	34	137	246	383
1914	447	63	384	317	701
1915	759	63	696	293	989
1916	672	63	609	377	986
1917	200	42	158	382	540
1918	156	30	126	363	489
1919	640	63	577	87	664
1920	376	62	314	136	450
1921	314	58	256	118	374
1922	100	6	94	303	397
1923	189	40	149	241	390
1924	309	57	252	313	565
1925	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1926	[illegible]	[illegible]	451	268	719
1927	592	63	529	282	811
1928	167	33	134	302	436
1929	407	63	344	87	257
1930	235	49	186	194	380
1931	113	13	100	139	239
1932	760	63	697	328	1,025
1933	207	44	163	65	228
1934	187	40	147	136	283
1935	406	63	343	71	414
46-year mean	385	48	337	225	562

Column (2) from table 199 in Appendix B.
Column (3) estimated from data of table B, Part III, and table 78.

The mean annual values for Middle Valley depletion and tributary inflow given by this estimate are 562,000 and 337,000 acre-feet, respectively.

Stream-Flow Depletion in 1936.—Subsequent to the studies which gave the figures of the preceding paragraphs the 1936 records of Middle Valley stream flow, diversions, and drainage, as obtained under the Rio Grande joint investigation, became available, and an analysis of these data was made in an endeavor to determine the stream-flow depletion and tributary inflow in 1936. The measurements gave a record of all surface flow in river, canals, and drains past seven cross sections of the valley—Otowi Bridge, Cochiti, San Felipe, Isleta, Bernardo, San Acacia, and San Marcial. It was thought that with these records and those of the diversions and drain flow in each of the six river sections, the stream-flow depletion and tributary inflow might be isolated for each section and finally summed up to give the valley totals. This was found to be impractical, however, because of lack of sufficient data on wastes. There are a great many wasteways in the conservancy district below the points where the diversions to the canals are measured and it was only possible to measure a small portion of these wastes in 1936. Hence, data on net diversions, an essential item, were not available. Lacking the data for this determination, attention was directed to utilization of the available data to furnish an estimate of minimum tributary inflow, from which the minimum stream-flow depletion might be derived. The daily records of total inflow and outflow for the six river sections from Otowi Bridge to San Marcial were compared, making due allowance for time lag between cross sections, to give the gains in each section. Only days when gains were indicated were tabulated. From the indicated gain between upper and lower limits of a section, the outflow of interior drains, considered as having no source in tributary inflow, was subtracted (a correction which would probably be strictly applicable only to winter months when there are no diversions), and to the gain was added the estimated evaporation from the river surface in the section. Manifestly, if there is a gain in a section it represents the excess of tributary inflow over that portion which supplies the total consumption in the section. Hence the gains in the section as above derived less drain flow and plus only that part of the consumption in the section represented by the evaporation from the river surface must of necessity account for the very minimum of tributary inflow. Consideration was given to the available records of flow of Jemez Creek at its mouth, but not to those of Rio Puerco at Rio Puerco, as the latter station is about 25 miles above the mouth and there are undoubtedly substantial losses below the station. If the tributary inflow as derived for the San Felipe-Isleta section was smaller than the flow of Jemez Creek, the recorded flow of the latter was taken as the total tributary inflow. This is conservative as there were, in all probability, other concurrent sources of tributary inflow to the section. The deductions of daily tributary inflow were summed up by months for each section as shown in table 86. Complete records for the year were not available for each section, so that, as indicated, combinations of longer sections were necessary for some months to complete the estimates. As shown by this table the total of the estimated minimum tributary inflow to the Middle Valley in 1936 is 362,000 acre-feet. The monthly totals of table 86

TABLE 86.—*Estimated minimum tributary inflow, Middle Rio Grande Valley, Otowi Bridge to San Marcial, 1936*

[Unit, 1,000 acre-feet]

River section	January	February	March	April	May	June	July	August	September	October	November	December	Year
Otowi Bridge to Cochiti	2.0	8.0	6.6	8.7	8.4	0.6	1.8	0.9	0.8	0.5	1.6	1.3	40.9
Cochiti to San Felipe	4.3	2.5	7.5	30.1	17.5	9.0	8.6	7.4	2.6	3.6	1.5	.8	96.4
San Felipe to Isleta						[1] 0	8.0	3.3	25.4	6.5	8.2	6.7	58.1
Isleta to Bernardo						[1] .2	0	0	0	0	0	0	.2
Bernardo to San Acacia						[1] 2.2	5.1	26.3	20.0	8.2	3.3	4.6	69.7
San Acacia to San Marcial				[2] 20.1	3.1	0	0	1.5	1.6	0	0	0	26.3
San Felipe to San Acacia				[2] 20.1	25.0	[3] 0							46.0
San Felipe to San Marcial	5.6	.9	0	[4] 17.5									24.0
Total	11.9	11.4	14.1	96.5	54.0	12.9	23.2	39.4	51.4	18.8	14.6	13.4	301.6

[1] June 14-30. [2] Apr. 18-30. [3] June 1-13. [4] Apr. 1-17.

applied to the monthly differences between Otowi Bridge and San Marcial gave monthly figures for minimum stream-flow depletion as shown in table 87. These total 566,000 acre-feet for the year as the estimated minimum stream-flow depletion in the Middle Valley in 1936.

TABLE 87.—*Estimated minimum stream flow depletion, Middle Rio Grande Valley, Otowi Bridge to San Marcial, 1936*

[Unit, 1,000 acre-feet]

Month	Otowi Bridge inflow less San Marcial outflow	Estimated minimum tributary inflow	Corresponding minimum stream flow depletion
January	−17.4	11.9	−5.5
February	−6.8	11.4	4.6
March	−.9	14.1	13.2
April	45.8	96.5	142.3
May	22.1	54.0	76.1
June	59.4	12.9	72.3
July	38.8	23.2	62.0
August	38.2	39.4	77.6
September	1.7	51.4	53.1
October	12.6	18.8	31.4
November	14.4	14.6	29.0
December	−3.2	13.4	10.2
Year	204.7	301.6	566.3

Stream-flow Depletion by Integration Method.—As shown in table 79, the Bureau of Agricultural Engineering has applied unit values for consumption, determined on the basis of all available data, to the mapped areas to derive the total consumptive water requirement on the main stem of Rio Grande from the Colorado State line to San Marcial. Deducting from the total the consumption shown for the area above Otowi Bridge (Buckman) gives a consumption of 675,000 acre-feet from Otowi Bridge to San Marcial. (This does not include the canyon section from Otowi Bridge to Cochiti, which was not mapped.) Allowing 0.7 foot for precipitation on the total area of 205,000 acres gives a deduction of 144,000 acre-feet to make the estimated stream-flow depletion, Otowi Bridge to San Marcial, 531,000 acre-feet.

Diversion Demand on Rio Grande.—Four estimates of stream-flow depletion, Otowi Bridge to San Marcial, have been described: (1) 586,000 acre-feet based on a study of available data for the period 1890–1935, (2) 562,000 acre-feet based on tributary inflow derived from water-production estimates, (3) 566,000 acre-feet as a minimum based on 1936 data, and (4) 531,000 acre-feet based on unit-consumption values derived from experience and judgment applied to the mapped acreage. Estimates by previous investigators are shown by table 73 to have been substantially lower, in most cases, than any of these four. Since, in any case the deficiency in basic data has been such that approximations only were possible, a depletion figure of 550,000 acre-feet was more or less arbitrarily fixed upon as the basis in this report for deriving the required diversion demand upon the Rio Grande of the Middle Valley area.

As indicated by table 71, the irrigated area in the Middle Rio Grande Conservancy District in 1936 was 59,000 acres. The Burkholder report (table 5, p. 3) shows that the net irrigable area included in the district as set forth in the approved plan, is 123,267 acres. Assuming that under full development the maximum acreage irrigated in any one year would be 80 percent of this, or, in round numbers, 100,000 acres, the question of whether an allowance should be made for greater stream-flow depletion when the 100,000 acres are irrigated is to be considered.

Reference to the figures for the conservancy district in table B, Part III, shows that there were in the district in 1936, 43,968 acres in grass and 19,639 acres in brush. If the irrigated lands are not expanded to include bosque areas (which show a higher rate of water consumption than grass or brush lands) it appears that the grass and brush lands must be those which will later be brought under cultivation and irrigated in making up the 100,000 acres. By applying the unit consumptive use figures given in table 78 for grass and brush in the conservancy district to their respective acreages as given above, a total consumption of 169,000 acre-feet is obtained. This divided by the total acreage of grass and brush lands gives an average unit consumptive use for them of 2.66 acre-feet per acre. A similar computation for the irrigated lands in the district, using the data of table 79, gives 2.66 acre-feet per acre, or precisely the same average unit consumptive use for these lands as for the grass and brush lands.

From the above considerations it appears that no increase over present consumption or stream-flow depletion is to be anticipated with the future increase in the irrigated acreage of the Middle Rio Grande Conservancy District. No allowance was made, therefore, for a future average annual stream-flow depletion, Otowi Bridge to San Marcial, greater than 550,000 acre-feet.

Of the 550,000 acre-feet depletion, the consumption figures of table 79 for the area between the Middle Rio Grande Conservancy District and San Marcial indicate that stream-flow depletion of about 80,000 acre-feet occurs in this area. Since this is depletion caused principally by swamp, bosque, and pooled water surfaces, it need not be supplied on an irrigation schedule and can be assumed to draw upon indivertible drainage return, wastes, and tributary inflow.

To derive the diversion demand, indivertible return and wastes were added to the depletion figure and the dependable contribution of divertible tributary inflow subtracted from it. Indivertible return was taken as the flow of interior drains from the Socorro division throughout the year and from the other divisions of the conservancy district in the months November to February, inclusive. From table 43, this totaled 70,000 acre-feet in 1936. Indivertible wastes were taken as those from the Socorro division only. Sluicing wastes, considered to be required only during 3 months of low river flow, were estimated from 1936 data at 20,000 acre-feet. Operation wastes were estimated at about a third of the gross diversions to Socorro division in 1936, or 20,000 acre-feet. Although two studies previously described give values for the total mean annual tributary inflow to Middle Valley of about 360,000 acre-feet, only a portion of this inflow is, of course, to be relied upon as a dependable and divertible source of supply. As conservatively representing that portion, the inflow from Otowi Bridge to San Felipe plus half only of Jemez Creek inflow (because of its confluence with Rio Grande below important diversion points and occasional indivertible peaks) was adopted. From the data of table 86 and that of Jemez Creek discharge, this portion of the valley's total tributary inflow in 1936 amounted to about 150,000 acre-feet, or slightly over 40 percent of the total. In order to allow for the divertible tributary inflow in determining the diversion demand in past years, monthly percentages based on the ratio of the Otowi Bridge-San Felipe-Half Jemez inflow to the total, as given by 1936 data, were computed and applied to the monthly estimates of total inflow in past years given by table 23. The percentages so used, reduced slightly from the computed values and rounded, are shown in table 88. In the operation studies described in a subsequent section, it was found that the mean, 1911–35, of usable tributary inflow derived by application of the percentages as above described was 110,000 acre-feet, or 31 percent of the mean, for the same period of the total tributary inflow. In deriving the monthly distribution of the diversion demand, that on the irrigation schedule was based on 1936 diversions of the conservancy district and the original distribution figures as proposed in the Burkholder report of that district. The demand for the area of native vegetation and water surfaces below the district was distributed in accordance with net monthly evaporation from Elephant Butte Reservoir. Monthly distribution of return flow was based on 1936

TABLE 88.—*Middle Valley diversion demand on Rio Grande, Otowi Bridge to San Marcial*

[Totals and monthly distribution of quantities in the derivation of net demand. Unit, 1,000 acre-feet except as noted]

Month	Scheduled demand on Otowi Bridge flow					Demand and supply below conservancy district				
	Middle Rio Grande Conservancy District diversions		Sluicing wastes Socorro division	Total demand	Deduction for tributary inflow (percent of total tributary inflow)	Demand	Supply			Net return or deficiency
	Percent	Quantity					Operation waste	Sluicing waste	Drain return	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
January	0	0	----	0	----	2	----	----	12	10
February	0	0	----	0	----	4	----	----	10	6
March	3	17	----	17	90	7	1	----	3	−3
April	15	84	----	84	50	9	3	----	3	−3
May	18	101	----	101	50	12	3	----	3	−6
June	19	106	----	106	50	12	4	----	3	−5
July	19	106	7	113	30	9	4	7	3	5
August	16	90	7	97	15	7	3	7	3	6
September	8	45	6	51	10	6	2	6	3	5
October	2	11	----	11	20	6	----	----	3	−3
November	0	----	----	0	----	4	----	----	12	8
December	0	----	----	0	----	2	----	----	12	10
Year	100	560	20	580	----	80	20	20	70	30

Column 3 includes depletion, 470,000; indivertible drainage, 70,000; and operation waste, 20,000 acre-feet.
Column 6. Percentages of total monthly tributary inflow considered as dependable and divertible.
Column 7. Demand for area between conservancy district and San Marcial. Distributed as for evaporation.
Column 8. Same distribution as for column 3.
Column 11. (8)+(9)+(10)−(7). Negatives can be supplied from river surplus or indivertible tributary inflow, not necessarily during current month, but during season.

records for interior drains. The monthly distributions d totals of the quantities thus determined as those to , used to give the net diversion demand on Rio Grande for the Middle Valley are shown in table 88.

The Elephant Butte-Fort Quitman Section.—Derivation of the demand upon Rio Grande at San Marcial, or upon Elephant Butte Reservoir, for the area of the Elephant Butte-Fort Quitman section was based on the actual diversions and use of water in the section from 1930 to 1936, inclusive, as shown by a detailed study of river flow, net diversions, drainage, river-bed losses, and arroyo inflow in four river sections from Elephant Butte Dam to Fort Quitman. Certain modifications of the requirements indicated by the data of this period were made to allow for salinity control, the economy to be effected upon completion of the American diversion dam, and the irrigated acreage for complete development of Rio Grande Project. The diversion demand was also derived independently, by use of the consumptive requirement data of the Bureau of Agricultural Engineering.

Net Diversions and Stream-flow Depletion, 1930–36.—In a study to derive monthly stream-flow depletion as well as to account as nearly as possible for all losses and gains in the Elephant Butte-Fort Quitman section in the period 1930 to 1936, the section was vided into four divisions—Elephant Butte-Leasburg, asburg-El Paso, El Paso-Tornillo, and Tornillo-Fort Quitman. Records were available as follows: River flow at upper and lower limits of divisions, full period; canal diversions, wastes, and drain flow for each of the three upper divisions, and to the lower boundary of Rio Grande Project in the lowest division, full period; diversions to Hudspeth district, main canal, full period, and Alamo feeder, 1931–36; Hudspeth drainage and waste, 1936 only. No records were available of Mexican diversions, waste, or drainage. Estimates of arroyo inflow were used as derived in Appendix B of this report. In the El Paso-Tornillo division it was estimated as one-third, and in the Tornillo-Fort Quitman division as two-thirds of the total inflow from El Paso to Fort Quitman. In the two upper divisions the differences between river inflow and outflow, after correction for intervening arroyo inflow, diversions, wastes to river, and drainage return, were attributed to river-bed loss or gain. In the El Paso-Tornillo division, river-bed losses were assumed as half the 7-year mean of river-bed losses in the Leasburg-El Paso division. This, then, gave Mexican diversions in this division as the residual after correcting the inflow-outflow differences for arroyo inflow, net diversions, drainage return, and river-bed losses. Completion of the analysis for the Tornillo-Fort Quitman division required that the Hudspeth drainage and wastes 1930 to 1935 be estimated on the basis of the 1936 data. An assumption of relatively high river-bed losses at approximately one-fourth of the Rio Grande flow below the Rio Grande Project gave Mexican diversions in this division as residuals of the analysis which are probably conservative.

In addition to the analyses above described, an accompanying study was made to determine the disposition of Elephant Butte Reservoir releases by estimating the respective amounts of unused (first use water from the reservoir as distinguished from returned drainage originally from the reservoir) reservoir releases, arroyo inflow and drainage return included in the net diversions and river losses, and in the river flow passing the lower station of each division. This necessitated certain assumptions with respect to the effective

TABLE 89.—*Estimated net Rio Grande Diversions by Mexico, Juarez to Fort Quitman, 1930–36* [1]

[Unit, acre-feet]

Month	1930	1931	1932	1933	1934	1935	1936	Mean	Specified by Mexican treaty
JUAREZ TO TORNILLO BRIDGE [2]									
January	2,100	4,500	4,600	4,700	4,600	1,500	2,000	3,500	0
February	600	3,500	1,500	7,100	3,200	2,700	2,800	3,100	1,090
March	2,000	7,000	9,500	12,500	3,400	6,100	4,600	6,500	5,460
April	8,200	6,800	13,800	11,900	11,800	16,700	11,200	11,500	12,000
May	12,500	7,500	16,200	13,500	17,200	18,400	20,100	15,000	12,000
June	13,500	13,600	20,600	16,700	20,100	21,900	16,200	17,500	12,000
July	17,900	17,900	22,500	18,900	21,800	27,100	18,200	20,700	8,180
August	14,800	15,500	24,900	24,800	28,400	40,000	20,900	24,300	4,370
September	12,300	11,900	19,400	12,300	8,500	9,500	6,300	11,400	3,270
October	8,200	11,800	3,500	10,200	6,900	5,000	4,200	7,000	1,090
November	6,200	6,400	9,600	10,600	5,300	1,400	1,700	5,900	540
December	4,600	5,500	7,400	8,900	4,500	1,000	100	4,500	0
Year	102,900	111,900	153,500	152,100	135,600	151,300	108,300	130,900	60,000
TORNILLO BRIDGE TO FORT QUITMAN									
Year	41,000	50,000	66,000	45,000	57,000	28,000	35,000	46,000	----------

[1] Estimates derived as residuals after accounting for all other losses and gains in river section. In accordance with probable accuracy and extent of necessary assumptions, estimates for upper section are considered reasonably good; those for lower section only fair.
[2] Includes Guadalupe Canal waste to Mexico.

TABLE 90.—*Estimated percentages of reservoir water, arroyo inflow, and drainage in net diversions and disposal of reservoir releases, Elephant Butte-Fort Quitman section, 1930–36*

Division or item	Mean disposal of reservoir water 1930-36 (percentage distribution)	Mean percentage content, 1930-36, in net diversions, of—			
		Unused reservoir releases [1]	Arroyo inflow	Drain flow and seepage	Total
Rincon	8.5	97.5	2.2	[2] 0.3	100.0
Mesilla	46.4	89.8	2.8	7.4	100.0
El Paso	18.4	58.4			
Upper El Paso (Franklin canal)		61.5	3.4	35.1	100.0
Lower El Paso (Tornillo canal)		38.2	4.1	57.7	100.0
Rio Grande Project	73.3	79.8	3.0	17.2	100.0
Hudspeth	2.2	33.9	6.1	60.0	100.0
Juarez (Mexico)	11.4	49.5	5.4	45.1	100.0
Upper Juarez		58.3	3.1	38.6	100.0
Lower Juarez		24.4	11.8	63.8	100.0
Riverbed losses	9.2				
Passing Fort Quitman	3.9	17.2	14.8	68.0	100.0
Total	100.0				

[1] Distinguished from returned drainage originally from the reservoir.
[2] Invisible accretion to river.

Estimates based on detail study of all available data, 1930-36, on river flow, reservoir releases, diversions, wastes, drain flow, and arroyo inflow.

TABLE 91.—*Average net diversions and stream-flow depletion in divisions of Elephant Butte-Fort Quitman section, 1930 to 1936, inclusive*

[Unit 1,000 acre-feet]

Division	Net diversions	Drainage return	Stream-flow depletion [1]
Rincon	67.0	35.0	32.0
Mesilla	397.8	192.9	204.9
El Paso	[2] 242.1	127.7	114.4
Rio Grande Project	706.9	355.6	[1] 351.3
Hudspeth [3]	49.5	17.0	32.5
Upper Juarez [4]	131		
Lower Juarez [5]	46		

[1] Note that from nature of derivation (net diversions less drainage) these stream-flow depletion figures do not include river bed losses.
[2] Upper El Paso division 210,700 and lower division (Tornillo canal) 31,400 acre-feet.
[3] Records of waste and drainage only available for 1936, other years estimated.
[4] Mexican diversions between El Paso and Tornillo, estimated by elimination.
[5] Mexican diversions between Tornillo and Fort Quitman, estimated by elimination.

amounts of arroyo inflow and drainage return in each division and these were made to conform as closely as possible with actual physical limitations and know operation practices.

Summaries of the data derived by these studies are given in tables 89 to 92. Table 89 shows the estimated net diversions by Mexico and indicates a mean annual diversion, 1930 to 1936, between Juarez and Tornillo Bridge, of 71,000 acre-feet in excess of the treaty allotment. In addition, Mexican diversions between Tornillo Bridge and Fort Quitman are roughly estimated at close to 50,000 acre-feet, making a total diversion of about three times the treaty allotment. There are probably no diversions in January as table 89 would indicate. However, since the diversions were derived as residual quantities, the mean amount shown for January of 3,500 acre-feet, or less than 3 percent of the mean annual diversion, is well within the limit of error to be anticipated under this method of analysis.

Table 90 shows the estimated percentages of unused reservoir water, arroyo inflow, and drain flow in the net diversions to the various divisions and in the flow passing Fort Quitman; also the mean percentage of total reservoir releases distributed to each division. It is indicated that the water to lower El Paso division (Tornillo Canal) is only 38 percent unused reservoir water, while that to upper El Paso division (Franklin Canal) is 62 percent. Of the total reservoir releas the Rio Grande Project is shown as receiving 7. percent.

Tables 91 and 92 give the data on net diversions and stream-flow depletion. For the Rio Grande Project the mean annual depletion, 1930–36, is indicated to have been 351,000 acre-feet, or 2.58 acre-feet per acre irrigated. It is to be noted that from the

TABLE 92.—*Stream-flow depletion and acreage irrigated, Rio Grande Project, by divisions, 1930–36*

Item	1930	1931	1932	1933	1934	1935	1936	Mean
RINCON DIVISION								
Stream-flow depletion, acre-feet	32,500	27,300	34,700	28,400	41,800	24,500	34,500	32,000
Acreage irrigated	12,702	13,069	12,463	12,283	12,776	11,834	13,528	12,655
Depletion, acre-feet per acre	2.55	2.09	2.78	2.31	3.27	2.07	2.55	2.53
MESILLA DIVISION								
Stream-flow depletion, acre-feet	240,200	214,200	245,100	210,900	208,500	131,600	183,600	204,900
Acreage irrigated	76,373	76,722	76,709	77,061	68,605	62,175	74,813	73,708
Depletion, acre-feet per acre	3.15	2.79	3.20	2.74	3.04	2.12	2.45	2.80
EL PASO DIVISION								
Stream-flow depletion, acre-feet	135,600	105,800	106,600	106,200	132,500	89,300	124,500	114,400
Acreage irrigated	55,532	54,499	48,277	49,862	47,711	46,066	50,460	50,344
Depletion, acre-feet per acre	2.44	1.94	2.21	2.13	2.78	1.94	2.47	2.27
RIO GRANDE PROJECT								
Stream-flow depletion, acre-feet	408,400	347,300	386,400	345,500	382,800	245,400	342,600	351,[illegible]
Acreage irrigated	144,607	144,290	137,449	139,206	129,092	120,075	138,901	136[illegible]
Depletion, acre-feet per acre	2.82	2.41	2.81	2.48	2.97	2.04	2.47	[illegible]

Acreage data as furnished by Bureau of Reclamation.
NOTE.—Stream-flow depletion derived from net diversions less drainage and does not include river-bed losses.

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nature of the derivation of this stream-flow depletion (net diversions less drain flow) it does not include river-bed losses. Mean unit depletion figures shown for the three Project divisions are: Rincon, 2.53; Mesilla, 2.80; and El Paso, 2.27 acre-feet per irrigated acre.

Diversion Demand.—The demand upon Elephant Butte Reservoir to be assured for the Elephant Butte-Fort Quitman section was considered to be that required by Rio Grande Project and fulfillment of the Mexican treaty obligation under the conditions which will prevail upon completion of the American diversion dam and extension to it of Franklin Canal, a project now under construction. By this development the 60,000 acre-feet required to be delivered to the Mexican Canal will be released to the river below the new dam so that it may be diverted as at present by the international dam. All other river water (except local flood waters) will be diverted to Franklin Canal by the American dam and carried to a point below the international dam where the water for Riverside, Hansen, and Tornillo Canal headings will be spilled back to the river. Under this arrangement the Mexican diversion at the international dam will be definitely limited to 60,000 acre-feet, and, assuming that the estimates of diversions by Mexico in the past as given in table 89 are reasonably correct, this means an average annual saving of about 70,000 acre-feet. In the section from Juarez to Tornillo Bridge there is another Mexican canal, San Augustine, which heads above the Hansen and Tornillo headings and which will, therefore, still be in a position to divert from the river. It is a small canal, however, compared to the Acequia Madre at the international dam. The present opportunity for diversions by other Mexican canals at lower river points will not be changed, but any diversions below Tornillo heading are from wastes and return waters. As the new arrangement makes no change in the delivery of water to Tornillo heading via the river channel into which drainage is discharged above the heading, no change in the quality of the water diverted at this heading is to be anticipated.

Assuming continued use of arroyo inflow and drainage return as in the 7-year period, 1930–36, the net diversion of reservoir water to be assured the Rio Grande project, taking the mean of 7 years of past diversions as a criterion, is given by the data of tables 90 and 91 as follows:

Mean net diversions of unused reservoir water, 1930–36

	Acre-feet
Rincon division	65, 300
Mesilla division	357, 400
El Paso division	141, 400
Rio Grande Project	564, 100

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This was the net diversion for an average irrigated area on the project in the 7 years of 136,000 acres. The range in acreage irrigated in that 7-year period, as shown by table 92, was from a minimum of 120,000 in 1935 to a maximum of 145,000 in 1930. The figure for 1936 of 139,000 is close to the 7-year mean. Data obtained from the Bureau of Reclamation show a variation from year to year in the figure given for net irrigable area of the Project. The variation is small and is largely due to progress below El Paso in the river channel rectification program of the International Boundary Commission and consequent changes in sovereignty of lands exchanged between Mexico and the United States to maintain the international boundary in the center of the rectified channel. Taking a round figure of 175,000 acres, which is close to the average of the figures reported for the 11-year period 1926–36, the maximum irrigated acreage of 1930 was 83 percent and the minimum of 1935, 69 percent, of the net irrigable acreage. Experience has demonstrated that the acreage irrigated in any one year on a fully developed irrigation project rarely exceeds 90 percent of the irrigable area and generally ranges from less than 80 up to 90 percent. For the Rio Grande project it was considered that the maximum irrigated area of 145,000 acres could be taken as representing the irrigated acreage under full development. A comparison of annual reservoir releases 1930 to 1936 with the irrigated acreage of the project in the same years would seem to indicate that increase or decrease in the amounts of water released has had little or no relation to the changes from year to year in the irrigated acreage. Apparently the releases have been strongly influenced by other factors, such as arroyo inflow, precipitation, nature of crops, and impending water shortage. However, in order to assure an adequate diversion demand for an irrigated acreage of 145,000, the previous figure of 564,000 acre-feet for net diversion of unused reservoir water was increased by the ratio of 145,000 to 136,000, giving 600,000 acre-feet. This neglects the fact that any increase in the irrigated acreage over the mean of the past few years would, as shown by the 1936 survey and report of the Bureau of Agricultural Engineering, probably constitute a substitution of present water-consuming areas of native vegetation and hence involve no material increase in consumption.

An addition of 65,000 acre-feet to the net diversion requirement to allow for operation and other wastes indivertible by the project was derived as shown in table 93.

River-bed losses above Tornillo Heading of unused reservoir releases, another addition required, were derived for each division as the residual quantities after the reservoir water in net diversions was subtracted from the differences between the amounts of reservoir water passing at upper and lower river stations of the division. The mean losses, 1930–36, so derived were 30,200 acre-feet in Rincon division, 26,800 in Mesilla division, and 6,500 in El Paso division down to Tornillo Heading, making a total of 63,500 acre-feet.

Using the figure of 61.5 percent shown in table 90 for the percentage of unused reservoir releases in the river water at El Paso, the release of reservoir water required to supply the treaty allotment of 60,000 acre-feet to Mexico becomes 37,000 acre-feet. The remainder is made up from drainage return and arroyo inflow.

The items making up the required diversion demand on Elephant Butte Reservoir, as developed in the discussion to this point, are:

	Acre-feet
Net diversions for Rio Grande project irrigated acreage of 145,000	600,000
Rio Grande project wastes	65,000
River-bed losses above Tornillo Heading	64,000
Fulfillment of Mexican treaty obligation	37,000
Total	766,000

TABLE 93.—*Derivation of operation and other wastes indivertible by Rio Grande Project*

Item	Project wastes		
	Total acre-feet	Percentage of unused reservoir water included [1]	Reservoir water (acre-feet)
Flow in river passing Tornillo Heading in 1936 [2]	117,400	27.[illegible]	32,200
Waste to Mexico from Guadalupe canal (mean 1930–36)	1,400	61.5	900
Wastes below project, comprising wasteways discharging below Tornillo Bridge, Tornillo canal waste, and Hudspeth diversion (mean 1930–36)	84,100	38.2	32,100
Total	202,900		65,200

[1] See table 90.

[2] Reference to the records of discharge of Rio Grande at Tornillo Bridge indicates the flow past Tornillo Heading in 1934, 1935, and 1936 was greatly reduced below that in previous years. (The result, presumably, of initiation of more economical operation practices.) The 1936 flow was therefore considered as probably more representative of future conditions than the 7-year mean.

[3] Less than percentage for Tornillo canal because of indivertible arroyo inflow included in river flow passing Tornillo.

Additional Requirement for Salinity Control—As presented in a previous section of this report, investigation of the quality of water in the Upper Rio Grande Basin has shown increased concentrations of salt in the irrigation and drainage water in the downstream direction such that, whereas the average concentration of the irrigation water at El Paso at the head of Franklin canal, as shown by electrical conductance, is 127; the concentration at the head of Tornillo canal in the lower El Paso Valley is 212. The marked increase between these two points is of course due to the heavy depletion of Rio Grande flow in the vicinity of El Paso and the influx of drainage to the river just above Tornillo Heading. The percentages of unused reservoir releases in the river at the head of Franklin and Tornillo canals, as shown by table 90, are respectively 62 and 38, and it is to be noted that the ratio of these percentages is almost exactly equal to the inverse ratio of the average conductances of the water at the two points.

The water users of the lower El Paso Valley have complained of damage to crops and have attributed it to high salt concentrations in the irrigation water, particularly in such a year as 1935, when, following the dry year of 1934 and resultant low level in Elephant Butte Reservoir, diversions and waste were definitely reduced in fear of an impending shortage. Table 94 gives the net diversions and acreage irrigated in upper El Paso Valley under Franklin and Riverside canals and in the lower valley under Tornillo canal for the years 1934, 1935, and 1936. Data on the irrigated acreage under Tornillo canal for earlier years were not available. This table shows the reduction made in 1935 in the diversion per acre in both upper and lower sections of the valley. It shows also that there has apparently been no greater unit application of water made under Tornillo canal for the purpose of minimizing the effects of higher salt concentrations than in upper El Paso Valley.

TABLE 94.—*Comparison of net diversions per irrigated acre under upper and lower El Paso Valley canals of Rio Grande Project, 1934–36*

Item	1934	1935	1936	Mean
UPPER EL PASO VALLEY—FRANKLIN AND RIVERSIDE CANALS				
Acreage irrigated	40,819	39,875	42,776	41,157
Net diversions—total acre-feet	226,800	174,700	202,000	201,200
Acre-feet per irrigated acre	5.55	4.38	4.73	4.89
LOWER EL PASO VALLEY—TORNILLO CANAL				
Acreage irrigated	6,892	6,191	7,684	6,922
Net diversions—total acre-feet	38,500	24,100	35,400	32,700
Acre-feet per irrigated acre	5.59	3.89	4.61	4.72

In accordance with the data and discussion of quality of water in a previous section of this report, high salt concentrations in the irrigation water must be offset by greater applications of water to the land, if the concentration of the soil solution in the root zone of the plants is to be maintained low enough so that the plants will not suffer. With respect to such control it was stated that the indefiniteness under present knowledge of the quantitative factors involved lead in this report to more or less arbitrary assumptions as to the amount of additional water needed to be applied to maintain a satisfactory salt balance. Furthermore, after due consideration of the available information regarding adverse salinity conditions in the valley below El Paso, it was determined to assume the need for such additional water only in the area of the Rio Grande Project that lies under Tornillo canal.

It is indicated that the average salt concentration of the water available for diversion at the Franklin and Riverside headings is within the range of permissible amounts. At the Tornillo Heading, however, concentrations are claimed to be high enough to show injurious effects on vegetation. Hence, although, as indicated by table 94, no increase in the Tornillo diversions per acre over those of Franklin and Riverside has been made, it appears that some increase should be made.

With respect to the magnitude of the increase to be made, it seemed best to arbitrarily assume an amount which could be considered reasonable, pending the collecting of data over a number of years to determine definitely its adequacy. The increase in diversions thus assumed for the Tornillo canal was 60 percent.

From table 91 the mean net diversion, 1930–36, by Tornillo canal was 31,400 acre-feet. An increase of 60 percent amounts to 18,800 acre-feet, making a total diversion of 50,200 acre-feet, which is 3.2 times the estimated average stream-flow depletion in the Tornillo unit. This is to be compared with an average net diversion, 1930–36, to the entire El Paso division of 2.1 times the stream-flow depletion therein, as indicated by table 91.

In considering this allowance for salinity control, cognizance should be taken of the liberal allowance which was made for wastes, as shown in table 93, in deriving the Rio Grande Project diversion demand.

Of the 18,800 acre-feet increase indicated for Tornillo canal, 38 percent, as taken from table 90, or 7,100 acre-feet, would be unused reservoir release. Taking, then, 7,000 acre-feet as a rounded figure for salinity control, its addition to the previous total derived for the annual demand upon Elephant Butte Reservoir gives 773,000 acre-feet. This is the demand adopted in this report for subsequent reservoir operation studies. The annual demand on Rio Grande at San Marcial was derived by adding the estimated mean annual amounts of evaporation and seepage from Elephant Butte Reservoir. From data and analyses given in the section of this report on water supply, mean annual seepage losses were estimated at 60,000 acre-feet and evaporation at 120,000 acre-feet. The latter represents the mean for the period 1915–35. A summarization of the items included in the total of the required demand on San Marcial is given in table 95.

Depletion and Diversion Demand by Integration Method.—Using the Bureau of Agricultural Engineering data on acreages and estimated consumptive requirements as given in table 81, and reducing unit values for consumption by 0.7 foot to correct for precipitation, the stream-flow depletion requirement for the Rio Grande Project area is derived as follows:

Classification	Acreage	Stream-flow depletion	
		Unit, acre-feet per acre	Total acre-feet
Irrigated area	154,552	2.1	325,000
Native vegetation	30,561	2.7	82,500
Miscellaneous	26,057	1.9	49,500
Total	211,170		457,000

TABLE 95.—*Required annual diversion demand upon Rio Grande at San Marcial for Rio Grande project and Mexican treaty obligation*

Item	Annual demand in acre-feet on—	
	Elephant Butte Reservoir	San Marcial
Net diversions for Rio Grande project irrigated acreage of 145,000	600,000	
Rio Grande project wastes	65,000	
Riverbed losses above Tornillo Heading	64,000	
Salinity control in area under Tornillo canal	7,000	
Fulfillment of Mexican Treaty obligation	37,000	
Total reservoir releases		773,000
Reservoir evaporation	120,000	
Reservoir seepage	60,000	
Total reservoir losses		180,000
Total demand on San Marcial		953,000

This total includes all losses in the area. To compare it with the Project figure of 351,000 acre-feet previously derived by subtracting drain return from net diversions, it must be reduced by the losses, such as those from the river bed, not included in the 351,000 acre-feet. The mean annual river-bed losses above Tornillo Heading as derived by the detail study of 1930–36 data was 90,000 acre-feet. Subtracting this from 457,000 gives 367,000 acre-feet for the Project stream-flow depletion by the integration method, as against the 351,000 acre-feet.

The necessary allowances for drain flow, wastes, arroyo inflow, and salinity control to derive the required diversion demand on Elephant Butte Reservoir, based on the total Project stream-flow depletion of 457,000 acre-feet, are indicated in the following summary:

		Acre-feet
Total required stream-flow depletion, Rio Grande Project, by integration method		457,000
Flow in river passing Tornillo Heading in 1936 [1]	117,400	
Total of arroyo inflow above Tornillo Heading, mean 1930–36	53,200	
Net river waste below project		64,200
Indivertible wastes and drain flow below project, comprising drain flow and waste discharging below Tornillo Bridge, waste to Mexico from Guadalupe Canal, Tornillo Canal waste, and Hudspeth diversion, mean 1930–36		136,000

[1] 1936 flow considered as probably more representative of future conditions than the 7-year mean because of marked reduction in flow beginning with 1934.

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	Acre-feet
Salinity control in area under Tornillo Canal [1]	19,000
Fulfillment of Mexican Treaty obligation	60,000
Total required demand on Elephant Butte Reservoir	736,000

[1] Increase in diversion requirement of Tornillo Canal.

This demand on the reservoir of 736,000 acre-feet lacks 37,000 acre-feet of agreement with the corresponding demand of 773,000 acre-feet as derived in the previous analysis. If in the 773,000 acre-feet derivation, no increase had been made in the mean net diversion figure of 564,000 acre-feet in accordance with the ratio of 145,000 acres, as the irrigated acreage of complete development, to 136,000 acres, the 7-year mean of irrigated acreage, the resulting summation for the demand on the reservoir would have been 737,000 acre-feet; a demand practically identical with that derived by the integration method using the Bureau of Agricultural Engineering estimates of unit consumption. Notwithstanding the implication of the foregoing, and in view of the fact that between 144,000 and 145,000 acres were actually irrigated in 1929, 1930, and 1931, and more than 142,000 in 1926 and 1928, it was considered that the required demand on the reservoir of 773,000 acre-feet should be used as a conservative estimate.

Monthly Distribution of Demand on Reservoir.—The monthly distribution of the adopted demand on the reservoir was taken to correspond with the mean monthly distribution of total net diversions to Rio Grande Project in the period 1930 to 1936. Although this does not conform exactly to the distribution specified by the Mexican Treaty for delivery of the 60,000 acre-feet to Mexico, the latter represents a relatively small portion of the total demand on the reservoir so that any modification of the distribution as derived for the Project, to correct for it, was considered unnecessary. The adopted distribution is shown in table 96. The peculiar drop in May after the heavier draft of April is characteristic of diversions in the F Grande Project and occurs in most years in all th divisions.

TABLE 96.—*Monthly distribution of required annual demand on Elephant Butte Reservoir*

Month	Monthly distribution of demand	
	In percent	In acre-feet
January	0	0
February	3	23,000
March	8	62,000
April	15	116,000
May	13	100,000
June	15	116,000
July	17	131,000
August	16	124,000
September	9	70,000
October	2	15,000
November	1	8,000
December	1	8,000
Year	100	773,000

Distribution based on mean monthly distribution of total net diversions to Rio Grande project in the period 1930 to 1936.

Uses and Requirements Other Than Those for Irrigation

The total use of water in the Upper Rio Grande Basin for purposes other than irrigation is but a small fraction of the irrigation use. Such other use is represented by domestic consumption in cities, towns, and villages as the principal, and power generation as a very minor, use. Construction which will increase the power use is now under way. As another classification, plans have been made by the Biological Survey for use of water for a large migratory waterfowl refuge on the Bosque del Apache Grant north of San Marcial.

Use by Cities, Towns, and Villages

As a general average it has been observed that the water requirement of cities and towns corresponds closely to the irrigation requirement of agricultural lands of equivalent area. Hence, in mapping and tabulating the irrigated and water-consuming areas of the Upper Rio Grande Basin, the Bureau of Agricultural Engineering included the area of cities, towns, and villages in special classification as shown in table 71, and in deriving the consumptive requirements of the various units of the basin, as shown in tables 76 to 81, a unit consumption corresponding to agricultural use was selected and applied to the areas of this classification to give their total consumption. Except for surface supplies in a few instances in some of the tributary areas, the city, town, and village water supplies are practically all obtained by pumping from ground water which, in turn, has its source in stream flow and in precipitation on the floor of the valleys. From a basin-wide standpoint, therefore, this use constitutes a stream-flow depletion. By including the areas of cities, towns, and villages in the total areas for which consumptive requirements are estimated, the demands upon stream flow derived therefrom for the major units of the basin, as developed in preceding paragraphs of this section of the report, have included an allowance for city, town, and village use. Hence no special consideration of this use or allowance for it is here required.

Table 97 gives the area of the cities, towns, and villages and corresponding stream-flow depletion as derived from the Bureau of Agricultural Engineering data. Albuquerque is included in the figures for the Middle section, but El Paso is excluded from those for the Elephant Butte-Fort Quitman section. Exclusiv of El Paso's use, this shows a total annual stream-flo

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depletion by the cities, towns, and villages in the entire Upper Rio Grande Basin of 21,000 acre-feet.

While the supply for cities and towns is here treated as a consumptive use, it is to be observed that the sewage, whether raw, treated, or spread by broad irrigation, becomes return water as effectively as the return from irrigation. The aggregate amount probably varies between 60 and 75 percent of the city supply and is, therefore, relatively greater than return from irrigation.

In San Luis Valley the water supply of practically all towns and villages which overly the artesian basin is derived from artesian wells. The survey of artesian wells in the valley made by the Geological Survey in 1936 indicated a total of 1,380 artesian wells in Alamosa, Center, La Jara, Monte Vista, and Sanford, with a total annual discharge of about 8,700 acre-feet.

TABLE 97.—*Estimated water consumption by cities, towns, and villages in the Upper Rio Grande Basin*

Basin unit	Area of cities, towns, and villages (acres)	Annual stream-flow depletion	
		Unit, acre-feet per acre	Total acre-feet
(1)	(2)	(3)	(4)
San Luis section:			
Closed basin	1,034	0.9	930
Southwest area	4,103	.9	3,700
Southeast area	892	.9	800
Total	6,029		5,430
Middle section:			
Main stem Rio Grande from Colorado line to San Marcial	[1] 6,398	1.3	8,320
West side tributary areas	1,540	1.0	1,540
East side tributary areas	2,313	1.0	2,310
Total	10,251		12,170
Elephant Butte-Fort Quitman section:			
San Marcial to Texas State line	1,846	1.3	2,400
El Paso to Fort Quitman in Texas	787	1.3	1,020
Total [2]	2,633		3,420
Total Upper Rio Grande Basin [2]	18,913		21,000

[1] Includes Albuquerque.
[2] City of El Paso, 6,210 acres, is not included. The city and private industries are supplied from deep wells. Production of municipal wells in 1936 was 8,800 acre-feet. A 1936 survey of private and other than city wells made by the city water works indicated an annual production by these wells of about 5,600 acre-feet.

Column (2). From data of Bureau of Agricultural Engineering, table 71.
Column (3). From data of Bureau of Agricultural Engineering, tables 76, 78, and 80, corrected for precipitation.

The water supply for Albuquerque, a city of about 34,000 population, is obtained by deep-well pumping. The present annual draft on the wells is about 3,000 acre-feet, which represents an average daily consumption of 2.7 million gallons. The maximum daily consumption in summer months is about 6 million gallons. These figures correspond to an average consumption per capita per day of 80 gallons and a maximum of about 175 gallons. The city has filed an application with the Federal Emergency Administration of Public Works for a project which would substitute a mountain supply from Jemez Creek watershed for the present pumped supply. As outlined in the report on the Jemez project prepared by the consulting engineers engaged by the city, the project would comprise two reservoirs on the headwaters of Jemez Creek, the Valle Grande and the San Antonio, with capacities of 12,000 and 15,000 acre-feet, respectively, and a 52-mile pipe line to the city diverting from Jemez Creek near Jemez Springs, about 15 miles below the reservoirs. The project is designed to deliver 6,000 acre-feet of water per year as the requirement of the city when the population will have doubled (estimated to occur in 1965) without any impairment of the natural stream-flow supply as now used for the irrigation of Indian and other lands below Jemez Springs. As to the net effect on the water supply in the Rio Grande, of substituting the Jemez project for the present pumping system, the opinion is expressed by the project's consultants that the present use is undoubtedly a draft, direct or indirect, on Rio Grande; that therefore construction of the Jemez project amounts only to a change in point of diversion; and that since there would be practically no transmission losses with the pipe line, the change would result in a substantial saving of losses by evaporation and seepage which occur under present conditions, in lower Jemez Creek and the Rio Grande, for an equivalent delivery of water to Albuquerque through stream channels.

The water supply for El Paso, with a population of about 110,000, is obtained from 10 wells ranging in depth from 650 to 850 feet. It is indicated that the source of the ground water upon which these wells draw is the precipitation on an extensive area to the east of El Paso. According to data furnished by the superintendent of the city waterworks, the production of the municipal wells in 1936 was 8,800 acre-feet. The average annual production, 1932 to 1936, inclusive, was 8,380 acre-feet. In 1936 the average daily draft during June, the maximum month, was 11.7 million gallons, and during December, the minimum month, 5.5 million gallons. In addition to the municipal wells there are many wells owned and operated by private industries and others. A 1936 survey by the city waterworks indicated an annual production by these wells of about 5,600 acre-feet with a maximum daily draft during summer months of 7.5 million gallons and a minimum in winter months of 3.5 million gallons. With respect to the future of the water supply for El Paso, the following is quoted from a letter of January 12, 1937, from the superintendent of the city waterworks to the engineer in charge of the Rio Grande joint investigation:

> We are contemplating the drilling and construction of three additional wells within the very near future, said construction to be contingent upon the recommendations and advice which will be contained in a report of a survey of the underground water

resources of El Paso and vicinity which was made during 1935 and 1936 by the United States Geological Survey.

The records which this department has maintained over a period of years indicate that the static level of our ground-water supply is slowly receding. This, of course, can mean but one thing; that is, that the pumpage in this area exceeds the recharge.

Should the static level continue to drop during the next 10 or 20 years as it has during the last 15 years, we believe that we shall find it necessary to seek another source of supply. Of course, there is but one other source of supply available and that is the Rio Grande. However, we do not think that it will be necessary for us to use water from that source for several years, if at all.

Use for Power Purposes

The present hydroelectric plants of 100 horsepower or more in the upper Rio Grande Basin are listed in table 98. As indicated, the total of installed horsepower is only 390. At the present time Caballo Dam is under construction on Rio Grande, 25 miles below Elephant Butte Dam. As planned, the reservoir formed by this dam will have a capacity of 350,000 acre-feet to serve the dual purposes of flood control—for which 100,000 acre-feet of capacity is reserved—and re-regulation for irrigation such that firm power can be developed at Elephant Butte Dam. When Elephant Butte Dam was constructed, gates and six penstock openings were built into it in anticipation of future power development. Without re-regulation below the dam, water must be released from the reservoir in accordance with the irrigation demand and releases of this character will not permit development of firm continuous power. With Caballo Reservoir under construction, the Bureau of Reclamation has given tentative consideration to an installation at Elephant Butte Dam of 25,000 kilowatts. Operation studies of the Bureau indicate a possible development of 95 million kilowatt-hours annually with ~~no~~ loss to the water supply of the Rio Grande project or waste. The tured Elephant Butte spills and arroyo inflow to Ca Reservoir are estimated to offset any losses due to increased evaporation at Elephant Butte and Caballo Reservoirs and to minor spills from Caballo Reservoir in the winter.

TABLE 98.—*Hydroelectric plants of 100 horsepower or more in Upper Rio Grande Basin*

State	Stream	Operator	Use for power	Installed horsepower
New Mexico	Rio Grande (Elephant Butte Dam).	Bureau of Reclamation.	Operation of dam and camp.	150
Do	Santa Fe Creek	New Mexico Power Co.	Standby for city of Santa Fe.	100
Do	Rio Colorado	Molybdenum Corporation of America.	Milling	140
Total				390

As noted in subsequent sections of this report, the Bureau of Reclamation is investigating the possibilities of power development in connection with the proposed Wagon Wheel Gap Reservoir on Rio Grande in Colorado and with the San Juan-Chama transmountain diversion. With irrigation the primary and paramount use for water in the Upper Rio Grande Basin, and w shortages in the available water supplies to meet c pletely the demands for that use, the rule rather th the exception, the development of water power on these projects, or on any others proposed must, as in the case of the Caballo project, be so coordinated with irrigation requirements that the primary position of the latter is fully maintained.

PART I

SECTION 5.—STORAGE DEVELOPMENT

Present Development

Practically all storage development to date in the Upper Rio Grande Basin, by reservoirs of 1,000 acre-feet capacity or more, has been for irrigation purposes. Tables 99 and 100 list those reservoirs in the Rio Grande Basin of Colorado and New Mexico, respectively, of 1,000 acre-feet capacity or more, which are constructed and in operation. All of them are operated solely for irrigation. At Elephant Butte Dam there is a small 150-kilowatt power unit which is operated incidentally to serve the storage works, camp and adjacent recreational area.

Although the need for storage to regulate the water supply of the upper Rio Grande and Conejos basins for irrigation in San Luis Valley was indicated in the early nineties, construction on any large scale was prevented by the embargo as previously explained. This was effective until 1925, and since 1929 storage development of magnitude has been limited by the terms of the Rio Grande Compact. As indicated by table 99, the major storage development for San Luis Valley lands that could be accomplished notwithstanding the embargo, took place in the period from about 1908 to 1914. Of the present total storage capacity of 309,134 acre-feet in the Rio Grande Basin of Colorado, it is to be noted that 136,868 acre-feet capacity is in the southeast area. Here the stream flow is now fully, or almost fully, regulated and utilized. The same is more or less true with respect to Alamosa and La Jara Creeks, controlled by Terrace and La Jara Reservoirs, respectively, in the southwest area. There is no storage on the Conejos River and tributaries and that in the upper Rio Grande drainage above the valley has a combined capacity of 130,804 acre-feet.

The first major storage development in the Rio Grande Basin of New Mexico was the Elephant Butte Reservoir, completed in 1916 with a capacity of 2,638,900 acre-feet. As previously stated, this was built by the Bureau of Reclamation to insure fulfillment of the delivery of water to Mexico in accordance with the treaty of 1906 and to furnish a water supply for the Rio Grande Project. The original capacity has been diminished by the deposition of silt. Data on the accumulation of silt and the resulting reduction in capacity as given in table 101 are taken from Technical Bulletin No. 524, Department of Agriculture, July 1936,

TABLE 100.—*Reservoirs constructed and operated in the Rio Grande Basin of New Mexico, of 1,000 acre-feet capacity or more*

Reservoir	Local drainage	Year completed	Capacity in acre-feet	Remarks
Elephant Butte	Rio Grande	1916	[1] 2,273,700	Rio Grande project, Bureau of Reclamation.
Childers	Smith Lake	1917	1,000	
Costilla	Costilla	1920	20,750	Owned by Costilla Estates Development Co.
Bluewater	Bluewater	1927	57,500	Owned by Bluewater-Toltec Irrigation District.
Santa Cruz	Santa Cruz	1929	4,600	Owned by Santa Cruz Irrigation District.
El Vado	Chama	1935	198,000	Owned by Middle Rio Grande Conservancy District.
Carson	Aguaje de la Petaca.	1936	7,430	Owned by Carson Irrigation District.
Total capacity			2,562,980	

[1] By silt survey of 1935.

TABLE 99.—*Reservoirs constructed and operated in the Rio Grande Basin of Colorado, of 1,000 acre-feet capacity or more*

Reservoir	Local drainage	Unit of San Luis section	Year completed	Capacity in acre-feet	Remarks
[illegible] Lake	San Antonio	Southwest area	1883	9,710	
[illegible]	House Canyon	do	1908	1,200	
Eastdale no. 1	Culebra-Costilla	Southeast area	1910	3,468	
Eastdale no. 2	do	do	1910	3,041	
La Jara	La Jara	Southwest area	1910	14,052	
Sanchez	Culebra	Southeast area	1911	101,000	
[illegible]	Alamosa	Southwest area	1912	17,700	Owned by Terrace Irrigation District.
[illegible] Park	South Fork, Rio Grande	do	1912	4,400	Owned by Mosca Irrigation District.
[illegible] Lakes	Headwaters, Rio Grande	do	1912	2,575	
[illegible] Canyon	Road Canyon	do	1912	2,800	
[illegible] Grande	Rio Grande	do	1913	51,113	Owned by San Luis Valley Irrigation District.
[illegible] Maria	Clear	do	1913	42,000	Owned by water users under Rio Grande and Monte Vista Canals.
Mountain Home	Trinchera	Southeast area	1913	20,147	Owned by Trinchera Irrigation District.
[illegible]	do	do	1914	6,212	Do.
[illegible]	Clear	Southwest area	1925	26,716	Owned by Del Norte Irrigation District.
Total capacity, southwest area				172,266	
Total capacity, southeast area				136,868	
Total capacity				309,134	

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FIGURE 33.—Rio Grande Reservoir on Rio Grande in Colorado.

"Silting of Reservoirs." This shows the capacity to have been 2,273,700 acre-feet in April 1935, a reduction from original capacity of 365,200 acre-feet or an average capacity loss in 20 years of 18,000 acre-feet per year.

In the period since its completion, Elephant Butte Reservoir has accomplished the complete regulation of the flow of Rio Grande at San Marcial. Only twice in the period, first in 1920, and again in 1924, has the water level reached the elevation of the bottom of the spillway gates. In 1924 there was some release of water in excess of project demands which might otherwise have been spilled. From table 24, which gives the storage content on the first of each month, 1915 to 1935, it is to be noted that the lowest content since the reservoir filled was reached on May 1, 1935, and that it was then 436,000 acre-feet.

TABLE 101.—*Silt accumulation and capacity changes, Elephant Butte Reservoir*

Date of survey	Period covered	Time in years	Reservoir capacity in acre-feet	Silt deposit in acre-feet	Average silt deposition per year in acre-feet
1903-08	Original survey		2,638,860		
1916	January 1915 to December 1916	1.91	2,584,865	53,995	28,270
1920	December 1916 to August 1920	3.67	2,498,850	86,015	23,437
1925	August 1920 to August 1925	5.00	2,407,125	91,725	18,345
1935	August 1925 to April 1935	9.67	2,273,674	133,451	13,801
	January 1915 to April 1935	20.25		365,186	18,034

The other reservoirs listed in table 100 are on tributary streams and with the exception of El Vado provide more or less complete regulation of flow. As shown by table 174 of Appendix A, the estimated mean annual run-off of Rio Chama above El Vado Reservoir is 329,500 acre-feet. The extent to which this flow may be regulated by El Vado Reservoir is indicated in a subsequent section of this report in which an operation study of the reservoir is made as an incident to an analysis of the effect on Middle and Elephant Butte-Fort Quitman sections of present irrigation development in San Luis Valley and given diversion demands in the two sections (Condition No. 2). It is found that in the 25-year period, 1911–35, the reservoir would have spilled in every year except 1931 and 1934, and that the average annual spill for the period would have been 206,000 acre-feet.

At the present time, a dam is under construction on Rio Grande about 25 miles below Elephant Butte Dam. This will form the Caballo Reservoir of 350,000 acre-feet capacity. As planned by the American Section of the International Boundary Commission and the Bureau of Reclamation, the latter of which is supervising the construction of the dam, the purpose of this reservoir is to provide (1) flood control for the arroyos between Elephant Butte and Caballo, (2) control and stabilization of the river channel as now rectified below El Paso and as planned to be rectified from Caballo to El Paso, and (3) re-regulation such that firm power may be developed at Elephant Butte Dam. Ot the total capacity, 100,000 acre-feet is to be reserved for flood control.

Proposed Development

Colorado Projects

As stated by representatives of Colorado, the major problem concerned with water utilization in San Luis Valley is provision of sufficient storage capacity to so regulate stream flow that diversions may conform to and parallel the irrigation demand of the lands that are now irrigated. This applies chiefly to the upper Rio Grande and the lands served by diversions above Alamosa and to the Conejos River and tributaries and the lands irrigated thereunder. For reasons previously explained, this major problem is not concerned with storage in the southeast area, in the closed basin, or on other streams of the southwest area. Except for the regulation provided by the 131,000 acre-feet of storage capacity on Rio Grande, the lands under Rio Grande and Conejos River and tributaries are dependent on

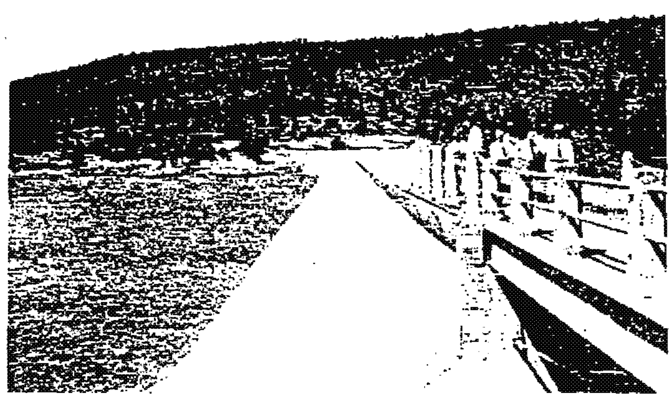

FIGURE 34.—El Vado Dam on Rio Chama, New Mexico.

the run of the stream. As a result, seasonal water shortages occur nearly every year and there are frequent occurrences of severe annual shortages. The lack of conformity between the monthly distribution of supply and diversions and the ideal irrigation demand is indicated by table 102 and figure 36. The monthly distribution of these quantities is given for Rio Grande above Alamosa for 1935, a year of 97 percent normal run-off, and for 1936 when the run-off was 67 percent normal. In the distribution of diversions a segregation was made for the Farmers' Union canal of the San Luis Valley Irrigation District. This district owns and operates the Rio Grande reservoir and has, more nearly than other systems, sufficient storage to regulate supply to irrigation demands. The distribution shown for ideal irrigation demand is that developed and used by R. J. Tipton, consultant to the Colorado State Engineer, in a manuscript report of March 1930. It was derived from an extensive compilation of the diversions by Farmers' Union canal and other canals having old priorities and from the distribution of demand in other comparable regions having adequate storage control. As indicated by figure 36, there is a wide divergence between the water supply and the demand in July and August, and even in June in a year of low run-off like 1936. In the case of the Farmers' Union canal diversions, there is a better approach to the ideal demand in these months, but there was still a heavy overdiversion in June of 1935 and throughout the spring of 1936. In the Conejos area the lack of conformity is more pronounced. With no storage whatever and the spring run-off generally culminating earlier than on Rio Grande, there is a very large overdiversion in the spring months and a shortage in the summer months. Early in the history of irrigation in San Luis Valley the necessity of utilizing the run-off of the streams to greatest possible advantage, combined with favorable soil conditions in the western portion of the valley, lead to adoption of the subirrigation method which has prevailed ever since. By this method the spring overdiversions are largely used to bring up and maintain the ground water close to the plant roots. As far as it may be so effective, this constitutes a substitution of water storage underground for surface reservoir storage. It results, however, in an excessive consumption of water, particularly in the central and eastern portions of the closed basin, where the high water table feeds the transpiration of a large area of native vegetation.

In order to assure a seasonal distribution of water supply in accordance with irrigation demand as well as to provide carry-over storage to reduce annual shortages, the water users of San Luis Valley under the Rio Grande and Conejos River have for many years proposed certain major storage developments on these streams. As a part of the Rio Grande joint investigation, the Bureau of Reclamation undertook an investigation of these storage projects, and a progress report thereon was submitted in March 1937. Investigations of certain of the projects were continuing at this writing, June 1937. Final data and results are incorporated in Part V of this report. The following paragraphs summarize the results of this investigation as presented in the March 1937 progress report. In a subsequent section of this report on the availability and use of water under given conditions, analyses are made of the effect on San Luis, Middle, and Elephant Butte-Fort Quitman sections of the prospective operation of these reservoirs under various combinations of storage and irrigation draft.

Wagon Wheel Gap Reservoir.—The site of this reservoir is on the main stem of Rio Grande 32 miles above

TABLE 102.—*Comparison of monthly distribution of water supply, diversions, and ideal irrigation demand, Rio Grande and Conejos River*

Month	Rio Grande above Alamaso								Conejos River and Tributaries			
	1935—Run-off 97 percent normal				1936—Run-off 67 percent normal				1936—Run-off 90 percent normal			
	Rio Grande near Del Norte	All diversions less Farmers' Union canal	Diversion Farmers' Union canal	Ideal irrigation demand	Rio Grande near Del Norte	All diversions less Farmers' Union canal	Diversion Farmers' Union canal	Ideal irrigation demand	Conejos River and tributaries	Diversions	Consumption	Ideal irrigation demand
	Monthly quantities in percent of seasonal											
January	1.2				2.0				0.9			
February	1.3	0.6	1.5		2.1	0.2			1.1			
March	2.2	2.1	.3		2.9	3.0			1.7	2.5	1.1	
April	5.4	5.7	3.8	5	14.2	15.1	13.6	5	25.2	15.4	23.8	5
May	12.0	11.4	6.6	17	30.0	30.6	35.1	17	35.4	37.2	31.2	17
June	38.5	34.8	41.3	27	18.9	18.7	35.1	27	12.2	23.0	19.9	27
July	18.7	22.0	25.0	26	8.4	8.1	16.2	26	3.3	6.6	5.9	26
August	10.6	11.3	19.9	18	8.0	10.7		18	4.9	6.2	7.4	18
September	4.1	5.9	1.6	5	5.7	8.0		5	3.4	3.3	4.9	5
October	2.9	4.0		2	3.2	4.8		2	3.5	3.8	3.8	2
November	1.0	2.2			2.6	.8			3.3	2.0	2.0	
December	1.2				2.0				1.5			

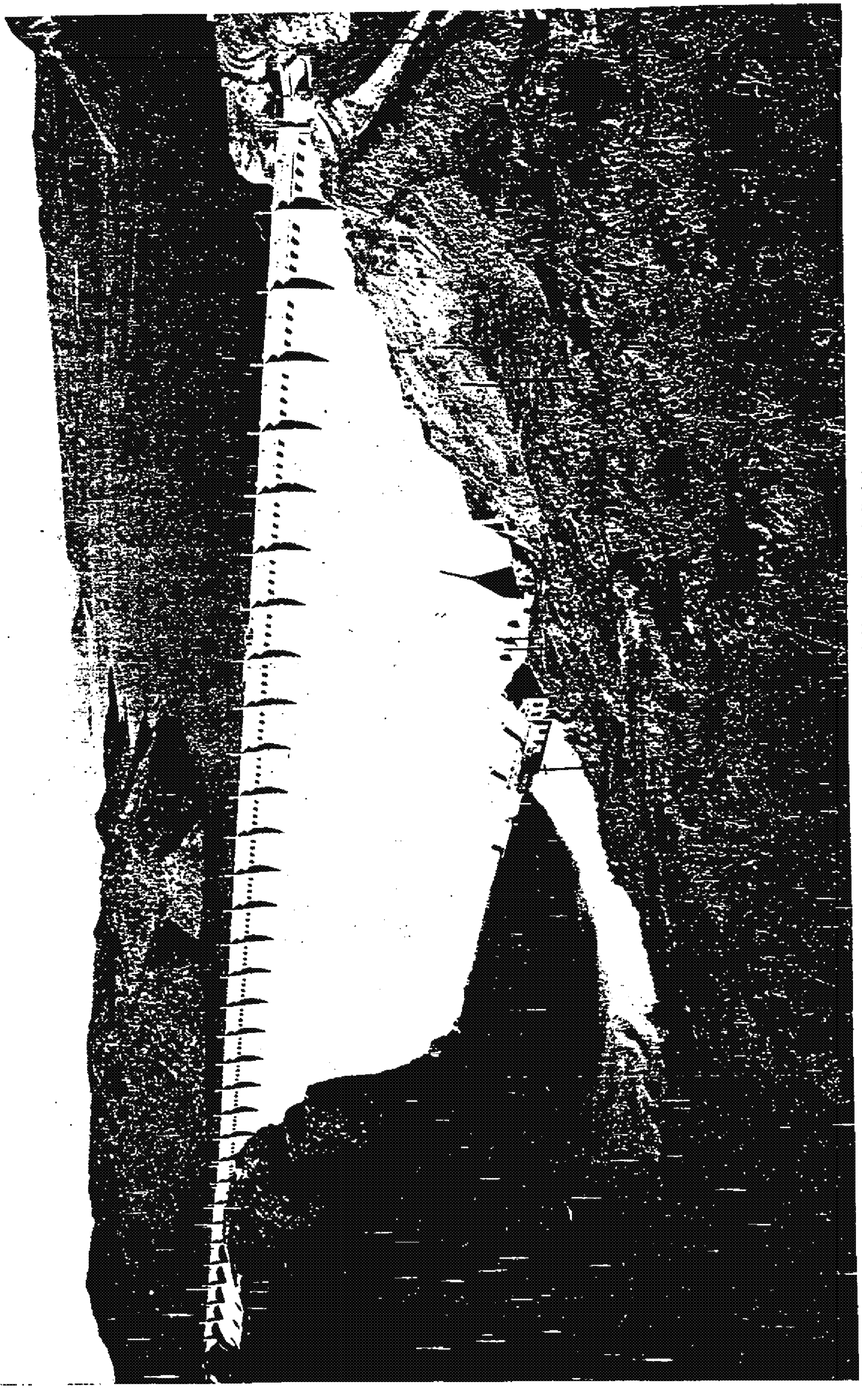

FIGURE 35.—Elephant Butte Reservoir, N. Mex. Rio Grande Project.

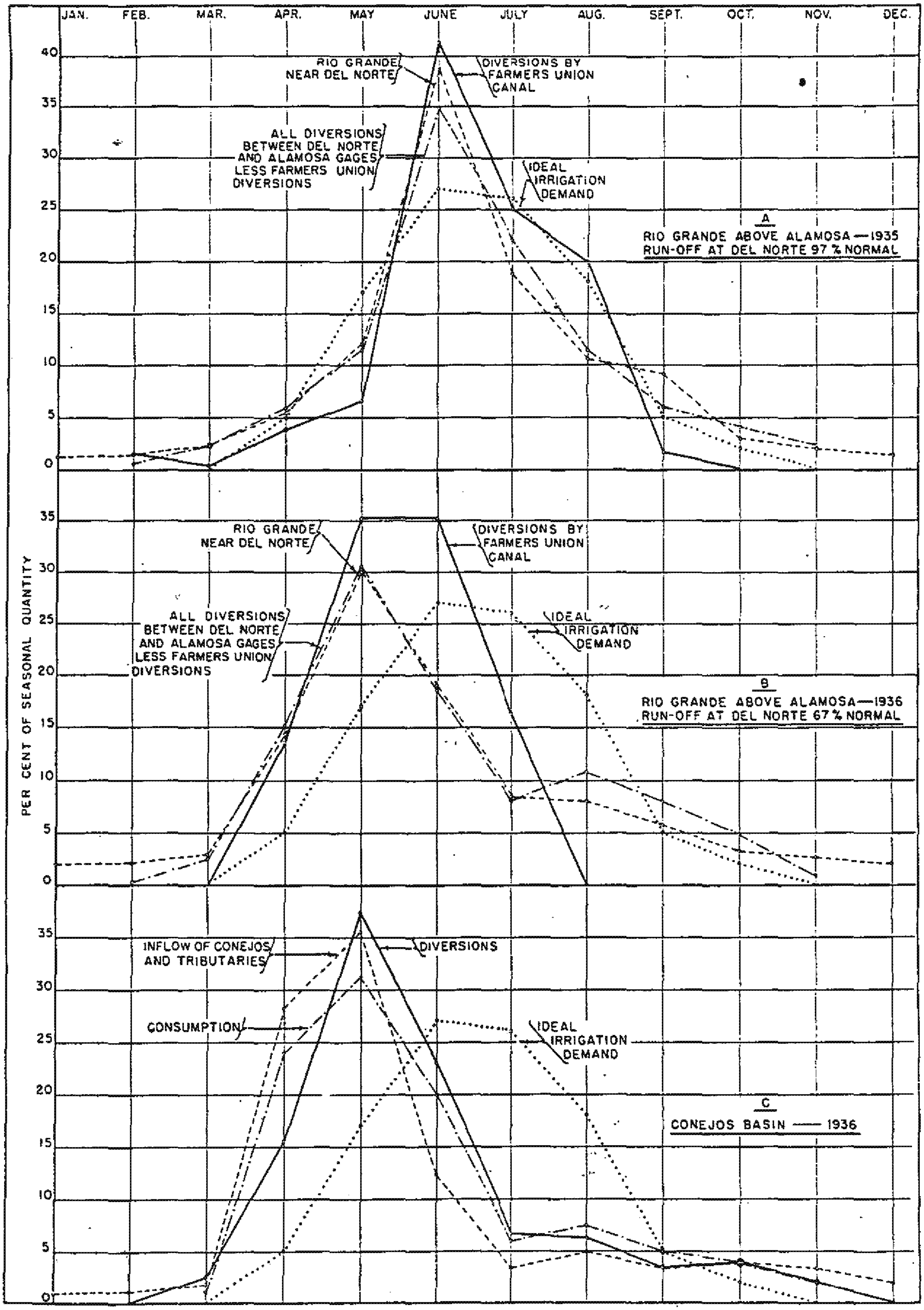

FIGURE 36.—Comparison of monthly distribution of water supply, diversions, and ideal irrigation demand Rio Grande and Conejos River, San Luis Valley, Colo.

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FIGURE 37.—Wagon Wheel Gap Dam site, on Rio Grande, Colo. Looking upstream.

Del Norte, Colo. The dam site is about 9 miles southeast of Creede and the Creede branch of the Denver & Rio Grande Western Railroad runs directly through it. The investigation as reported was limited to a survey of the dam site, geological exploration and drilling, and a preliminary plan and estimate for a reservoir with a capacity of 1,000,000 acre-feet. The normal water surface elevation for this capacity is 8,773, and the reservoir area at this elevation is 8,500 acres. Land in the reservoir area is largely, if not wholly, privately owned. The geological investigation of the reservoir gives no indication of unsatisfactory conditions. Normal seep and spring occurrences indicate a water table tributary to the river and the volcanic rock and compact Creede sedimentaries filling the older Rio Grande Channel and mantling the basin indicate that little, if any, reservoir seepage could occur. At the dam site the walls of the canyon are sheer. The rock forming the foundation and abutments is andesite or latite, massive, hard, and competent. In the center of the canyon drilling has shown an 80-foot depth above bed rock of boulders, cobbles, gravel, and sand in a loose, porous deposit which it would be necessary to remove. The site is well adapted to a concrete-arch type of dam. Studies and estimates were made for a concrete gravity dam as well as for other sections of arch dams. Ample deposits of sand and gravel of good quality are located both upstream and downstream from the damsite. The dam for which the estimate is reported is of the constant angle arch type, 1,200 feet long at the crest with a maximum height of 430 feet above the foundation. A straight uncontrolled overflow type of spillway 140 feet long at crest elevation of 8,773 would be located in a saddle approximately 560 feet from the right abutment. With the water at its maximum elevation of 8,780, or 7 feet over the crest, the spillway capacity is 10,000 second-feet. Discharge is to a natural channel leading to the river approximately 1,500 feet downstream from the dam.

In the plans for the dam provision is made for a future power installation by placing two 19-foot diameter tunnels with plugs through the dam for a later installation of two 13-foot diameter penstocks. The estimated cost of the dam, exclusive of cost of power plant, rights-of-way, highway and railroad reconstruction, and property damage, is $9,417,255 or $9.40 per acre-foot of storage. The Wason gage on Rio Grande is within the reservoir site, and as shown by Table 127 of Appendix A the estimated mean annual run-off, 1890–1935, at Wason is 450,600 acre-feet. The drainage area above Wason is 700 square miles. Above the dam site it is 751 square miles, or 107 percent of that above Wason. The mean annual run-off at the dam site was taken as 105 percent of that at Wason, or 473,000 acre-feet.

Summary of data, Wagon Wheel Gap Reservoir

[Concrete arch, constant angle type, dam]

Storage capacity .... acre-feet..	1, 000, 000
Spillway capacity .... second-feet..	10, 000
Regulated outlet capacity at 67-foot head.... do....	5, 000
Elevation top of dam	8, 780
Normal reservoir water-surface elevation	8, 773
Maximum reservoir water-surface elevation	8, 780
River level	8, 440
Maximum height of dam above bedrock ...... feet..	430
Total estimated cost of dam [1]	$9, 417, 255
Estimated mean annual run-off to reservoir, 1890–1935 .... acre-feet..	473, 000
Drainage area .... square miles..	751

[1] Exclusive of right-of-way, power plant, and reconstruction of railroad and highway.

Vega Sylvestre Reservoir.—The Vega Sylvestre Reservoir is generally considered as an alternative for the Wagon Wheel Gap Reservoir. The site is on the main stem of Rio Grande about 17 miles above Wagon Wheel Gap. There are several important tributaries between the two sites, so that the mean annual run-off, 1890–1935, of the 528 square miles above Vega Sylvestre, estimated at 344,000 acre-feet, is substantially less than that at Wagon Wheel Gap. Estimates and designs as reported are for a capacity of 240,000 acre-feet. This is the capacity that San Luis Valley interests had tentatively selected as best suited to valley needs. Much of the reservoir site is a mountain meadow used for pasture and wild hay. Colorado State Highway No. 149 from Creede to Lake City passes through portions of it and reconstruction of approximately 7 miles of this highway would be required. Geological investigations of the reservoir show that the indicated underlying Creede siltstones are heavily mantled with river and glacial terrace gravels. These detrital materials are unconsolidated and extremely porous, so that ground storage of some magnitude may be expected. However, there is no reason to suspect an unsatisfactory reservoir basin. Normal spring and seep occurrences indicate a water table tributary to the river, with remote chance for an inclined or perched condition. Geologically, the dam site must be classified as a poor one as it requires excessive corrective designs and measures to overcome what are inherently dangerous characteristics. In the river bed, porous gravels would be encountered for at least 100 feet beneath the river and they may continue to 150 or 200 feet. For the left abutment there is andesite rock, uniformly hard but somewhat fractured, but on the right abutment rock is so deep that it would not be reached by the dam. Support and impervious properties must rely upon the character of the overlying glacial moraine.

While much more prospecting, testing, and analyzing must be done before the limitations of safe and economical design can be determined, estimates have been

FIGURE 33.—One of the lower dam sites on Conejos River, above San Luis Valley, Colo.

made for two tentative plans of development. The dam-site selection is controlled by the relative values for foundation purposes of the materials in the river bed and right abutment. Plan A presents a scheme to secure a deep cut-off in the stable river gravels and avoid so far as possible dependence on the reworked morainic material. A blanket is carried upstream to increase percolation distances. The dam, of rolled earth-fill and rock-fill type, is located in the wide portion of the river bottom where the overlying beds of re-sorted glacial and recent river gravels have been largely eroded. The upper portion of the upstream face has a 3:1 slope and the lower portion a long blanket with variable slopes. The downstream slope varies from 2½:1 in the upper portion to variable slopes approximating 12:1 in the lower portion. A long low dike is required at a low section in the reservoir west of the dam. The spillway, designed for 15,000-second-foot capacity, is located on the left abutment in the andesite rock. Test pits have shown a sufficient supply of suitable materials for construction of the earth embankment at a distance of approximately three-fourths mile below the dam site on the right bank. The estimated cost under plan A, including right-of-way and highway relocation, is $4,825,879, or $20.10 per acre-foot of storage.

Summary of data, Vega Sylvestre Reservoir, plan A

[Rolled earth-fill and rock-fill dam]

Storage capacity.....................acre-feet..	240,000
Spillway capacity.....................second-feet..	15,000
Regulated outlet capacity at 45′ head......do....	5,000
Elevation top of dam..........................	8,970
Maximum reservoir water-surface elevation.......	8,962
Height of dam above stream bed...........feet..	125
Total estimated cost, dam and reservoir..........	$4,825,879
Estimated mean annual run-off to reservoir 1890–1935.........................acre-feet..	344,000
Drainage area...................square miles..	528

Plan B presumes that the reworked morainic material is more satisfactory than assumed in plan A and takes advantage of a better profile obtained by swinging the axis of the dam southwesterly and directly across the narrowest portion of the valley. A much deeper cut-off trench is required and extensive blanketing at the upstream toe of the dam. The estimated cost under plan B is $4,524,581, slightly lower than that under plan A, chiefly because of the smaller volume in the embankment.

Conejos Reservoirs.—The original program for investigations on the Conejos River provided only for a survey and exploration of dam site no. 1, about 8 miles above the Mogote gage. This site had been selected several years ago and the reservoir surveyed, but no prospecting had been done. Survey of the dam site, drilling, and test-pit work were carried on simultaneously. It was soon discovered that geological conditions were such that the feasibility of the site was questionable, because of the excessive depth of sand and gravel overburden which extends across the river and under the mammoth landslide comprising the right abutment. Designs and estimates for this site have not been completed, pending a thorough exploration of the right abutment. The main highway from Alamosa over Cumbres Summit into New Mexico passes by the left end of the dam site and crosses the reservoir site about 3 miles above the dam site, and a new secondary road is now being constructed from the river crossing on the main highway to the upper end of the reservoir site. Construction of the reservoir would therefore require relocation of 5 miles of primary highway and 7 miles of secondary highway. Several resort camps and summer homes are within the reservoir area. The reservoir capacity curve derived from the 1925 survey by R. J. Tipton indicates a capacity of 100,000 acre-feet at an elevation approximately 131 feet above the river bed at the dam site. The estimated mean annual run-off, 1890–1935, of the 282 square miles above the Mogote gaging station is 255,600 acre-feet.

Upon discovery of the unfavorable conditions at dam site no. 1, search for other sites was begun and continued until a reconnaissance of the entire river from Mogote to altitudes of more than 10,000 feet had been completed. This resulted in the selection of eight other possible sites. These are described and the extent of the investigations at each of them is detailed in the Bureau of Reclamation report, Part V. Designs and estimates were completed only for the upper Conejos site, designated as No. 6. This is located on the Conejos River about a mile above Platoro in Conejos County, Colo. It is 42.5 miles via gravelled highway from Platoro to the nearest railroad shipping point, Monte Vista. The reservoir is entirely on

Government land within a national forest. The data are:

Summary of data, upper Conejos Reservoir No. 6

[Compacted embankment type dam]

Storage capacity............acre-feet..	32, 000
Spillway capacity............second-feet..	6, 000
Regulated outlet capacity............do....	500
Elevation top of dam............	10, 010
Maximum reservoir water-surface elevation............	10, 005
Maximum height of dam............feet..	115
Length of dam............do....	540
Length of auxiliary dike............do....	400
Height of auxiliary dike............do....	38
Reservoir area at spillway level............acres..	710
Total estimated cost, dam and reservoir............	$608, 404
Cost per acre-foot of storage............	$19. 01
Estimated mean annual run-off to reservoir, 1912-35 [1] acre-feet..	48, 700

[1] Estimated by precipitation-altitude method.

One of the other sites investigated, the Mogote, is an offstream site about 3½ miles north of the Conejos River, just at the edge of San Luis Valley. A feeder canal from the river to the reservoir offers no difficulties, but the reservoir basin is possibly 150 feet above the water table and may not be sufficiently tight. Previous surveys have indicated that a capacity of 30,000 acre-feet can be secured at this site with a dam about 90 feet high and 800 feet long. Explorations are now in progress and until these are completed and estimates are made no conclusions can be drawn as to the feasibility of this reservoir.

New Mexico Projects

Except for terminal storage for the San Juan-Chama transmountain diversion project, the only storage project included for investigation under the funds allocated for use in New Mexico was the State Line Reservoir.

State Line Reservoir.—This reservoir on Rio Grande, approximately at the Colorado-New Mexico State line, and the Closed Basin Drain are recommended in the present Rio Grande Compact signed in 1929 in the following language:

> * * * That for the economic development and conservation of the waters of the Rio Grande Basin and for the fullest realization of the purposes recited in the preamble to this compact, it is of primary importance that the area in Colorado known as the closed basin be drained, and the water thus recovered be added to the flow of the river, and that a reservoir be constructed in Colorado upon the river, at or near the site generally described as the State Line Reservoir site. The installation of the drain will materially augment the flow of the river, and the construction of the reservoir will so regulate the flow as to remove forever the principal causes of the difficulties between the States signatory hereto.

At the time the compact was signed it was considered that regulation of the flow of Rio Grande below all

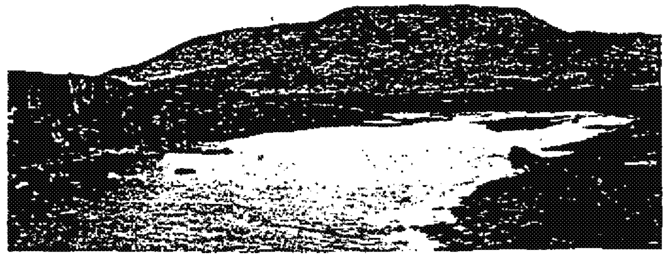

FIGURE 39.—Rio Grande near Colorado-New Mexico State line. Looking downstream from "Stateline" Bridge. (Lobatos gaging station.)

Colorado diversions by means of a reservoir at the State line would provide an assurance of flow to New Mexico such as to largely remove one of the principal causes of interstate controversy.

Surveys and explorations at this site were begun late in 1936, but had not been completed at the writing of Part I of this report. They were continuing under a further program of investigation by the Bureau of Reclamation in 1937 the final report of which is given in Part V.

Two sites for the dam have been proposed. The Middle Rio Grande site (Middle Rio Grande Conservancy District), about 1½ miles above the State line, has been surveyed and drilled by the Middle Rio Grande Conservancy District. A dam there, built to elevation 7,570, would have a maximum height of 150 feet and store 750,000 acre-feet. At elevation 7,510 with a maximum height of 90 feet, the capacity would be only about 250,000 acre-feet. The higher elevation would submerge part of the city of Alamosa (elevation 7,550), numerous outlets of drainage ditches in the San Luis Valley, and preclude the drainage of the sump area of the closed basin. An elevation of 7,510 appears to be about the highest level to which water can be stored without undue interference with existing developments. The lack of capacity at such an elevation above the Middle Rio Grande site and an effort to secure more favorable geologic conditions, led to a search for another site farther downstream.

The Costilla River site selected lies just below the mouth of Costilla River, which enters the Rio Grande Canyon from the east about 3 miles below the State line. It is in a box canyon of basaltic rock with almost vertical sides, the top width of the canyon at 7,520 being only about 500 feet. The river surface is at elevation 7,375, or 45 feet lower than at the Middle Rio Grande site. Costilla River lies in a narrow box canyon for almost a mile before it joins Rio Grande, but above this canyon there is a large basin which would increase the storage capacity materially over that available at the Middle Rio Grande site. Drillings at the Costilla River site have disclosed a water table at approximately elevation 7,375, or 50 feet below the river bed. This implies a rather pervious bed beneath the entire reservoir.

Investigations were in progress at a new site, the Ute Mountain dam site, about 7.5 miles below the Costilla River dam site and about 10.5 miles south of the State line. Springs in the canyon walls here indicate a water table tributary to the river and in conformity with the ground water gradient projected from the Middle Rio Grande and Costilla sites, already drilled. Although a materially higher dam would be required at the Ute Mountain site than at the other sites for a given capacity, the Ute Mountain site holds greater possibilities and provides more storage capacity under the limiting elevation.

Smaller projects.—Although not included for investigation by the Bureau of Reclamation as a part of the Rio Grande joint investigation, there have been a number of smaller storage projects proposed for construction on Rio Grande tributaries in New Mexico. Table 103 gives a list and description of such projects as proposed in applications to the Federal Works Progress Administration or to the Federal Emergency Administration of Public Works. Under the President's Executive Order of September 23, 1935, approval of these projects has been withheld, pending clearance by the National Resources Committee, which, in turn, awaits completion of the Rio Grande joint investigation and report.

Flood Control by Reservoirs

In spite of the damage that may result from them, floods have an economic value in the Upper Rio Grande Basin in flushing the river channel and carrying away the sand and silts that inevitably accumulate during a preceding series of low-water years.

Since the operation of Elephant Butte Reservoir began, the only floods in the Elephant Butte-Fort Quitman section have been the flash floods from tributaries. The reduction of peak discharges in the main river has had the effect of flattening the river slope between the diversion dams, and from tributary arroyos has come considerable debris that tends to choke the channel. The combined effect of these two factors is that a comparatively moderate tributary flood may be more serious now than a much larger one was before Elephant Butte Dam was constructed.

In the Middle Valley, the silting of the channel during a series of low water years such as obtained from 1933 to 1936, inclusive, made the moderate freshet of 1937 loom larger than it otherwise deserved.

The maximum recorded flood of the lower portion of the Middle Valley occurred September 22–26, 1929, due to continued rains. At San Marcial the flood peak of September 24 has been estimated at 47,000 second-feet. The town of San Marcial was virtually destroyed. Most of the water came from Rio Puerco, Rio Salado, and other tributaries. The maximum 24-hour discharge of Rio Grande at Otowi Bridge was only 6,540 second-feet on September 23, while Rio Chama contributed a maximum of only 2,480 second-feet on the same date.

In San Luis Valley floods are generally due to rains coinciding with the spring melting of snows, although the maximum recorded discharge was from fall rains. The three highest 24-hour discharges recorded on Rio Grande at Del Norte are:

	Second-feet
June 5, 1905	10, 000
October 6, 1911	14, 000
June 30, 1927	12, 600

The highest recorded general flood on Rio Grande occurred during the spring of 1905. That was a generation ago and in that period of time such catastrophies are easily forgotten. During the flood the following maximum 24-hour discharges were recorded:

	Second-feet
June 5 at Del Norte	10, 000
June 8 at Lobatos	13, 100
June 9 at Otowi Bridge	17, 400
June 12 at San Marcial	18, 500
June 14 at El Paso	23, 600

If Wagon Wheel Gap Reservoir of 1,000,000 acre-feet capacity had been in operation during this flood the

TABLE 103.—*Projects involving storage in the Rio Grande Basin of New Mexico as proposed in P. W. A. or W. P. A. applications*

Application to	Tributary	County	Reservoir capacity in acre-feet	Dam		Acreage to be irrigated	Estimated cost
				Type	Height in feet		
W. P. A.	Tusas Creek	Rio Arriba	1, 735	Earth	92	3,000, now under cultivation	$142, 201
Do	La Lama Creek	Taos	38	do	30	Now under cultivation	22, 900
Do	Rio Grande de los Ranchos	do	3, 385	do	78	2,781, now under cultivation	162, 637
Do	Cabresto Creek	do	1, 675	do	126	3,100, now under cultivation	155, 136
Do	Protero Creek	Rio Arriba	3, 028	Concrete arch	140	3,000, new land	174, 315
P. W. A	Jemez Creek	Sandoval	[1] 27, 000	Earth and rock	40, 50	Municipal supply, city of Albuquerque	[2] 2, 2[illegible]
Do	Rio Pueblo de Taos	Taos	500	Rock fill	90	500, new land (Indian)	140, 000
Total			37, 411				$3, 077, 128

[1] Two reservoirs totaling this capacity.

[2] Total for entire water supply project.

reservoir content at the end of April 1905 would have been 138,000 acre-feet. It could have withheld the entire inflow during the following May and June which totaled 381,000 acre-feet. The peak of this flood at Del Norte could, therefore, have been reduced materially, probably to 3,000 or 4,000 second-feet. (Tributary daily flows are not available to permit of a closer estimate.)

Assuming State Line Reservoir had been in operation with a capacity of 460,000 acre-feet (a tentative figure obtained from a preliminary map of 1937 surveys made subsequent to the March 1937 progress report of the Bureau of Reclamation), it would have contained 240,000 acre-feet at the end of April 1905. The Lobatos run-off for May was 178,000 acre-feet, so that the reservoir would have been full and spilling before the peak of 13,100 second-feet on June 8 occurred. The State Line Reservoir operating alone, therefore, would not have had the effect of reducing the flood peak on the river below. If, however, Wagon Wheel Gap Reservoir had also been in operation, the flood peak at Lobatos could have been substantially reduced, with consequent reduction throughout the Middle Valley.

All reservoirs heretofore proposed in the Upper Rio Grande Basin would be primarily for irrigation purposes and unless additional capacity were provided and the reservoir operated so as to preserve the added space for flood storage, it would be necessary to consider any flood control benefit as incidental to irrigation. However, Elephant Butte Reservoir with a capacity twice the normal Rio Grande inflow has effectively reduced Rio Grande flood peaks below it as far as Fort Quitman. Similarly, Wagon Wheel Gap Reservoir, with a proposed capacity twice the normal inflow, should as effectively reduce general flood peaks in San Luis Valley and confer some benefit in this respect on the Middle Valley as well.

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PART I

SECTION 6.—ADDITIONAL WATER SUPPLIES BY IMPORTATION AND SALVAGE

With practically the entire water supply of the Upper Rio Grande Basin at present consumed above Fort Quitman, there appear to be only two noteworthy sources to which resort may be had for additional water supplies. One is the importation of water from another drainage basin and the other, the salvage of present wastes and losses within the basin. Although storage in upper parts of the basin may be expected to result in a favorable redistribution of water supply with respect to the lands served, no new water is made available to the basin as a whole, except insofar as the redistribution may effect savings in losses and wastes suffered at present because of the lack of a regulated supply, and presumably a realization of savings is the basis upon which storage for upper-valley lands is to be justified with respect to the lower-valley lands of the basin. Under the heading of additional water supplies for the basin, storage must, therefore, in the last analysis, be placed in the classification of salvage of present wastes and losses in excess of the increased consumption by reservoir evaporation.

Importation

The possibility of importation of water from another drainage basin to augment the supplies of the Upper Rio Grande Basin has long been considered by the water users in the three States of the basin. Of the outside drainage basins to be considered, there is only one which appears to afford reasonable opportunities and to which serious consideration has been given. That is the San Juan Basin of the Colorado River drainage. The diversion of water from the Colorado to the Rio Grande Basin is permissible under the Colorado River compact, and it would afford New Mexico an opportunity to utilize, in greater or less measure, its share of the waters of the Colorado Basin under that compact.

As a part of the Rio Grande joint investigation, the Bureau of Reclamation was assigned to an investigation of and report upon the projects which have been proposed for transmountain diversion of San Juan waters to Rio Grande. Four separate projects—one, the San Juan-Chama, proposed by New Mexico, and three, the Animas-Rio Grande, Weminuche Pass, and San Juan-South Fork Rio Grande, proposed by Colorado—were investigated. The following paragraphs briefly summarize the results of these investigations as presented in a March 1937 progress report of the Bureau of Reclamation. Certain features of these projects were the subject of investigations which were continuing at the time Part I was written. Final data and results are incorporated in Part V of this report. In a subsequent section consideration is given to the possible accomplishments of these diversions under various assumed schedules of operation.

San Juan-Chama Transmountain Diversion

As planned, this project begins with the diversion of Turkey Creek, a tributary of San Juan River, into a reservoir of 70,000 acre-feet capacity on the West Fork of the San Juan River about 14 miles north of Pagosa Springs, Colo. From the bottom of this reservoir, a diversion canal of 300 second-feet capacity carries Turkey Creek and West Fork waters to a 70-foot drop into East Fork about 1 mile above its confluence with the West Fork. About 6 miles upstream, a reservoir of 35,000 acre-feet capacity is planned to regulate the flow of the East Fork. A diversion dam a short distance below the canal drop into the East Fork diverts into a canal of 500 second-feet capacity which lies just above the 7,500-foot contour east of the San Juan River. Coal Creek, Mill Creek, Rito Blanco, and the Blanco River are diverted into the main canal by short feeder canals. On the Blanco River, 5½ miles above the canal crossing, a reservoir of 15,000 acre-feet capacity is planned to regulate the flood flows of that river. From the Blanco River to the Little Navajo River the canal capacity is increased to 700 second-feet and the canal is almost entirely in tunnel. At the lower portal of the tunnel on the Little Navajo River the canal is joined by a diversion canal from the Navajo and Little Navajo Rivers and its capacity is again increased to 800 second-feet. After passing a few miles along the northerly side of the Little Navajo River, the main Navajo River is crossed with a siphon almost a mile long under 350 feet maximum head. At the end of the siphon the canal enters a succession of tunnels and siphons along the south side of the Navajo River to a point about 1½ miles east of Edith and almost on the Colorado-New Mexico boundary line. Continuing nearly due south, the canal traverses several deep cross drainage streams, crosses Amargo Creek and the Denver & Rio Grande Western

R. R. (narrow gage) near Monero, N. Mex., and finally enters a 6-mile tunnel through the Continental Divide beneath Hillcrest on the Jicarilla Indian Reservation. From the lower portal of this tunnel at an elevation of 7,400 feet the water flows in a natural stream bed to Boulder Lake. From the latter, releases may be made to a natural stream channel emptying into El Vado Reservoir.

This system comprises four reservoirs (exclusive of Boulder or Stinking Lakes, alternative terminal reservoirs) with a total capacity of 170,000 acre-feet and a canal system totaling 89.43 miles, of which 17.37 miles are in tunnel. The estimated total cost of the entire project is $22,260,000, or $63.60 per acre-foot of diversion. Of the total cost, $14,786,408 is estimated for the canal system, and $7,440,307 for the West Fork, East Fork, Blanco, Navajo, and Boulder Lake Reservoirs.

The total drainage area contributing to this diversion is 506 square miles, with a mean altitude of 9,688 feet, and the estimated mean annual divertible run-off, 1916–36, is 380,900 acre-feet. Allowing for canal and reservoir losses, the mean annual net delivery of regulated water to Rio Chama above El Vado Reservoir is estimated at 350,000 acre-feet. This yield would be decreased by the San Juan-South Fork Rio Grande transmountain diversion project. The system is designed to deliver an almost constant supply to the terminal reservoir from March to December, inclusive.

Existing developments in the San Juan Basin as far down as Shiprock, N. Mex., would not be impaired by this diversion, but if future developments of any extensive San Juan areas are found to be feasible, an additional reservoir either on the San Juan River or a tributary may be found necessary to avoid conflict in water supplies.

Summary of data, San Juan-Chama transmountain diversion

(See Part V, this report, for alternate lower cost diversion finally developed.)

Contributing San Juan drainage area, square miles	506
Estimated mean annual delivery to Rio Chama, 1916–36, acre-feet	350,000
Estimated total cost	$22,260,000
Estimated cost per acre-foot of diversion	$63.60
Elevation of highest diversion (from Turkey Creek)	7,890
Elevation of Continental Divide tunnel outlet	7,400
Maximum water-surface elevation Boulder Lake, terminal reservoir	7,305
Canal system:	
Main canal capacity, second-feet	300 to 800
Earth canals, miles	52.39
Concrete lined canals, do	15.17
Bench flumes, do	.46
Tunnels, do	17.37
Siphons, do	4.04
Total length of conduits, do	89.43
Reservoirs:	
West Fork San Juan:	
Capacity, acre-feet	70,000
Type of dam: Compacted embankment.	
Height of dam, feet	160
East Fork San Juan:	
Capacity, acre-feet	35,000
Type of dam: Compacted embankment.	
Height of dam, feet	150
Blanco:	
Capacity, acre-feet	15,000
Type of dam: Compacted embankment.	
Height of dam, feet	102
Navajo:	
Capacity, acre-feet	50,000
Type of dam: Compacted embankment.	
Height of dam, feet	120
Boulder Lake (terminal reservoir):	
Capacity, acre-feet	290,000
Outlet capacity, second-feet	2,000
Type of dam: Compacted embankment.	
Height of dam, feet	138
Stinking Lake (alternate terminal reservoir):	
Active capacity, acre-feet	500,000
Outlet capacity at low levels, second-feet	1,000
Type of dam: Compacted embankment.	
Height of dam, feet	115

Animas-Rio Grande Transmountain Diversion

This project contemplates a diversion from the upper reaches of the Animas River, a tributary of San Juan River, to the headwaters of Rio Grande in Colorado. Under the plan for which designs and estimates were made the South Fork of Mineral Creek, Mineral Creek, and Cement Creek would be diverted to a reservoir at Howardsville on the main Animas River near Silverton, Colo. From the Howardsville Reservoir a tunnel would carry the water eastward through the Continental Divide to the upper reaches of Rio Grande about 60 feet above and a mile from the high water line of the existing Rio Grande Reservoir. The highest diversion, that from the South Fork of Mineral Creek, is at elevation 9,852 and bottom grade elevations at the west and east portals of the main tunnel to the Rio Grande are, respectively, 9,698 and 9,612.

The entire project comprises 13.66 miles of conduit in the collection system, including 2.56 miles of tunnel, 12.98 miles of main tunnel, 400 second-feet capacity, and the Howardsville Reservoir of 53,000 acre-feet capacity. The estimated total cost is $10,432,496, or $79.00 per acre-foot of diversion.

The drainage area above 9,800 feet elevation contributing to this diversion is 129 square miles. The estimated mean annual divertible run-off, 1916–35, is 144,000 acre-feet. For the period 1924–35 it is 130,700 acre-feet. The run-off which it is estimated could have been diverted 80 percent of the time is 122,000 acre-feet.

In the minimum year of 1934 only 43,000 acre-feet could have been diverted.

A tentative study of discharges of the Animas River at Tacoma and Durango, depleted for possible diversions to Rio Grande for every month from 1911 to date, indicates that no shortages would have occurred at any time in the 24-year period. It appears, therefore, that the proposed diversions may be made without impairing existing rights or obstructing future developments now considered feasible.

Summary of data, Animas-Rio Grande transmountain diversion

Contributing Animas drainage area...square miles..	129
Estimated mean annual divertible run-off, 1924-35 acre-feet..	130, 700
Estimated total cost	$10, 432, 496
Estimated cost per acre-foot of diversion	$80. 00
Elevation of highest diversion (South Fork Mineral Creek)	9, 852
Elevation of Continental Divide Tunnel outlet	9, 612
Collection system:	
Earth canal.....miles..	1. 14
Combination section.....do....	8. 62
Bench flume.....do....	0. 49
Cut and cover section.....do....	0. 85
Tunnel.....do....	2. 56
Total length of collection conduits....do....	13. 66
Animas-Rio Grande tunnel:	
Capacity.....second-feet..	400
Diameter.....feet..	9. 5
Length.....miles..	12. 98
Howardsville Reservoir:	
Capacity.....acre-feet..	53, 000
Type of dam: Earth embankment.	
Height of dam.....feet..	255

Weminuche Pass Transmountain Diversion

This project contemplates a diversion from the headwaters of Pine River, a tributary of San Juan River, to the headwaters of Rio Grande in Colorado. The plan as developed calls for the diversion of two creeks, one on each side of Pine River at elevation 10,500, to the main stream at the head of the pass and then through the divide by means of a long cut. The canal discharges into an unnamed creek which flows into the existing Rio Grande Reservoir about 3 miles below. The estimated total cost is $264,500, or about $13 per acre-foot of diversion.

The drainage area above 10,500 feet elevation contributing to this diversion is 24 square miles and the estimated mean annual divertible run-off, 1924-35, is 20,455 acre-feet. However, this yield is after allowance has been made for no diversions in 1925, 1931, and 1934 because of interference with storage development on the Pine River project near Bayfield, and after prior transmountain diversion rights of 4,000 acre-feet have been deducted.

Summary of data, Weminuche Pass transmountain diversion

Contributing Pine River drainage area square miles..	24
Estimated mean annual divertible run-off, 1924-35 [1].....acre-feet..	20, 455
Estimated total cost	$264, 500
Estimated cost per acre-foot of diversion	$13. 00
Elevation of highest diversion	10, 500
Total length of canal.....miles..	7. 5

[1] No diversion in 1925, 1931, and 1934.

San Juan-South Fork Rio Grande Transmountain Diversion

This project contemplates a diversion from the headwaters of San Juan River, above the diversion of the San Juan-Chama project, to the South Fork of Rio Grande. The South Fork joins Rio Grande about half way between Del Norte and Wagon Wheel Gap. The plan for which designs and estimates were made provides for the diversion of the West Fork of San Juan River to Beaver Creek by a canal 2.6 miles long, of which 2,400 feet are bench flume. From Beaver Creek an 8-foot tunnel, 3.2 miles long and of 425 second-feet capacity, carries the water southeasterly to meet a tunnel of the same size and 1.0 mile long from Wolf Creek. A 9-foot tunnel, 6.7 miles long and of 525 second-feet capacity, then leads from the junction to the South Fork of Rio Grande. It would require 7 miles of difficult road construction to gain access to the West Fork diversion and the Beaver Creek portal. The South Fork portal is within a half mile of the main graveled highway over Wolf Creek summit, which also passes within 200 feet of the Wolf Creek portal. The latter is approximately 15 miles from the Creede branch of the Denver & Rio Grande Railroad. The estimated total cost of the project is $5,290,306, or about $100 per acre-foot of diversion.

The drainage area above an altitude of 9,050 feet contributing to this diversion is 45 square miles, and the estimated mean annual divertible run-off, 1916-36, is 53,000 acre-feet. In the minimum year of 1934 the yield would have been only 23,000 acre-feet. No existing rights on the San Juan below the diversion would be impaired, but the supply available for the San Juan-Chama diversion would be depleted by the amount diverted to the South Fork of Rio Grande.

Summary of data, San Juan-South Fork Rio Grande transmountain diversion

Contributing San Juan drainage area square miles..	45
Estimated mean annual divertible run-off, 1916-36 acre-feet..	53, 000
Estimated total cost	$5, 290, 306
Estimated cost per acre-foot of diversion	$99. 80
Length of feeder canal West Fork to Beaver Creek miles..	2. 6

Summary of data, San Juan-South Fork Rio Grande transmountain diversion—Continued

Tunnel, Beaver Creek to Junction:	
Length .... miles..	3.2
Diameter .... feet..	8.0
Capacity .... second-feet..	425
Tunnel, Wolf Creek to Junction:	
Length .... miles..	1.0
Diameter .... feet..	8.0
Tunnel, Junction to South Fork:	
Length .... miles..	6.7
Diameter .... feet..	9.0
Capacity .... second-feet..	525
Total length of tunnels .... miles..	10.9

Salvage

In table 83 of the previous section on water uses and requirements it is shown that for the entire Upper Rio Grande Basin approximately half only of the stream flow consumed is by the irrigated acreage; that the other half is consumed by losses, avoidable and unavoidable. Consumption on areas other than the irrigated acreage is, in tables 76 to 81, segregated to native vegetation and miscellaneous. The miscellaneous item includes consumption by the area of towns and villages; land temporarily out of cropping; water surfaces, including pooled water, river and canal surfaces, and exposed beds; and bare lands, including roads, rights-of-way, and the like. It is in the item of consumption by native vegetation that the chief opportunity lies for saving water.

Nonbeneficial Consumption by Native Vegetation

The consumption by areas of native vegetation is the result of a high-water table from which the vegetation may readily draw its supply. The high-water table is the result of seepage from streams and canals but chiefly from irrigated lands with inadequate drainage, or without drainage, upon which overdiversions may have been applied in an endeavor to utilize to the fullest extent the peaks of an unregulated water supply. However, without drainage, the normal diversions from a regulated supply have resulted in time in a high-water table and in a waterlogged condition. Lowering the water table by drainage so that the supply of water to native vegetation would be cut off is, therefore, the solution to water recovery in any plan to take advantage of the chief opportunity for salvage.

The acreages and consumption (including precipitation) under the three classifications of irrigated lands, native vegetation, and miscellaneous are given in table 77 for San Luis section and in tables 79 and 81 for the main stem of Rio Grande in Middle and Elephant Butte-Fort Quitman sections. Comparison of the totals of consumption for these three classifications shows that irrigated lands and native vegetation each account for 44 percent of the combined total of the three. Converting the consumption figures for native vegetation to stream-flow depletion by correcting for precipitation gives the data of table 104. This shows four areas of particularly large stream-flow depletion by native vegetation; the closed basin and southwest areas in San Luis Valley, the Middle Rio Grande Conservancy District area, and the Rio Grande area from San Marcial to Percha Heading. Of these, the indicated depletion of 339,000 acre-feet in the closed basin is by far the largest. This should be expected in view of the conditions conducive to evapo-transpiration losses inherent in a closed basin of this character. The distribution of the native vegetation given in table 104 within the various units listed is shown on the large scale maps of vegetative cover, plates 10 to 22. In the closed basin it is mostly confined to the eastern half, which includes the large sump area, and to scattered bordering areas below tributary streams. In the southwest area it is scattered throughout the irrigated area to considerable extent, although there are some larger blocks which are practically all native grass and brush and which are drawing on ground water that has seeped from irrigated lands.

TABLE 104.—*Estimate of stream flow depletion by native vegetation, Upper Rio Grande Basin* [1]

Basin unit	Native vegetation acreage, 1936	Stream-flow depletion	
		Acre-feet	Acre-feet per acre
SAN LUIS SECTION			
Closed basin area	404,014	339,400	0.84
Southwest area	176,191	165,600	.94
Southeast area	156,994	75,400	.43
Total	737,199	580,400	.79
MIDDLE SECTION—MAIN STEM RIO GRANDE			
Colorado State line to Otowi Bridge	3,651	9,200	2.52
Middle Rio Grande Conservancy District	90,401	241,400	2.67
Bosque del Apache Grant and below to San Marcial	12,781	61,500	4.81
Total	106,833	312,100	2.92
ELEPHANT BUTTE-FORT QUITMAN SECTION—MAIN STEM RIO GRANDE			
San Marcial to Percha Heading	29,506	120,100	4.07
Rio Grande project	30,561	82,500	2.70
Hudspeth County Conservation and Reclamation District	5,899	18,500	3.13
Total	65,966	221,100	3.35
Total of sections	910,000	1,113,600	1.22

[1] Derived from Bureau of Agricultural Engineering consumptive use estimates of tables 77, 79, and 81 by subtracting normal precipitation.

In the Middle Rio Grande Conservancy District there are many scattered areas where the drainage system has been only partially effective or wholly ineffective in lowering the ground water, and these areas are supporting native vegetation which is largely grass and bosque. Outside of the district boundaries there are a number of undrained areas in the Middle Valley upon which heavy growths of native vegetation are consuming large quantities of water. The largest of these is that portion of the Bosque del Apache Grant within the Rio Grande flood plain.

Outside of an area of heavy consumption by native vegetation at the upper end of Elephant Butte Reservoir and along the river between Elephant Butte and Percha Dam, such consumption in the Elephant Butte-Fort Quitman section is largely on scattered small areas within the Rio Grande Project and somewhat larger areas along the river in Hudspeth County.

Data are not available to permit even an approximate determination of the total amount of water which might be feasibly and economically recovered from the million acre-feet or more by which the stream flow is annually depleted in supporting the growth of native vegetation in the Upper Rio Grande Basin. It seems unquestionable, however, that some fraction of this loss should be susceptible of economic recovery by proper drainage construction. There is still a great amount of land which is undrained.

Status of Drainage

As listed in table 105 there are 15 drainage systems in the southwest and closed basin areas of San Luis Valley, besides a large number of roadside drains not included in any system. The gross area under these 15 systems is 206,000 acres, of which 75,000 acres are in the southwest area and 131,000 in the closed basin. The Rio Grande Drainage District area of 30,000 acres in the closed basin drains to Rio Grande, but the other closed basin systems drain to the sump of that basin. The drainage systems of the Rio Grande District and the San Luis Valley Irrigation District have made possible the cultivation of the lands north of Alamosa and east of the chief agricultural region lying between Monte Vista and Center and on the higher slopes below the Rio Grande canal. In the southwest area drainage has been effective in relieving seepage over much of the area below the Monte Vista and Empire canals with the exception of a strip about 6 miles wide just west of Rio Grande where wild hay is grown.

The total irrigated and water-consuming acreage as mapped in the closed basin is 733,000 acres, and in the southwest area 483,000 acres. Of these totals, 334,000 acres in the closed basin and 235,000 acres in the southwest area are served from Rio Grande. Comparing with these figures the gross acreage under drainage systems as given in table 105, it will be seen that the drained area in the closed basin represents 18 and 39 percent, respectively, of the basin's total watered area and the portion served from Rio Grande, and that the southwest drained area represents 16 and 32 percent, respectively, of the total southwest area and its portion served from Rio Grande.

TABLE 105.—*Drainage systems in San Luis Valley*

System	Gross area acres	Year completed	Mileage of drains
TRIBUTARY TO RIO GRANDE [1]			
Parma	6,000	1913	9
Carmel Drainage District	5,040	1914	32
McLean	2,050	1915	17
Monte Vista town	900	1917	2
Norton	11,000	1918	40
Rio Grande Drainage District [2]	30,000	1920	52
Adams Lane	1,000	1922	2
Manassa town	1,440	1923	5
San Luis Valley Drainage District no. 1 (La Jara)	9,300	1923	[illegible]
Waverly Drainage District	12,900	1923	42
Bowen Drainage District	13,400	1924	[illegible]
Morgan Drainage District	11,600	1924	30
Total	104,800		[illegible]
TRIBUTARY TO SUMP, CLOSED BASIN			
Sylvestre	10,400	1910	12
Gibson	24,000	1913	27
San Luis Valley Irrigation District	67,000	1929	42
Total	101,400		[illegible]

[1] All in southwest area except Rio Grande Drainage District.
[2] In closed basin but outlet is to Rio Grande. Drainage diverted above outlet for irrigation, drains to sump of closed basin.

The development of drainage in San Luis Valley has been such as to afford an opportunity for extensive rediversion of the drain water to irrigate lower lying lands, or to check the drains during the irrigation season so as to hold up the water table in the area where subirrigation is practiced. The effect has been to reduce what would be a normal river return. It appears probable that a continuation of this diversion and reuse of drain water may be anticipated under future drainage development. This applies more particularly perhaps to the closed basin than to the southwest area. As further drainage is developed along the eastern border of the present irrigated lands occupying the western half of the closed basin, opportunity will be afforded for the progressive reclamation to the east of the lands which were cultivated many years ago but were subsequently abandoned when they became seeped. Much of the eastern lands can probably be reclaimed and irrigated from drain diversions in this way, and with future storage development for the valley limited in purpose to equalization of the water supply of the present irrigated acreage, the drainage water is practically the sole source available for such eastern extensions. However, since, as shown by table 77, the consumption per acre in the closed basin by irrigated lands and native vegetation is about the same, the drainage of an area of native vegetation should supply an equivalent area of irrigated crops.

In the Middle Valley the present open drain system of the Middle Rio Grande Conservancy District was completed between 1930 and 1935. It drains the area from Cochiti to the northern boundary of the Bosque del Apache Grant, except for one or two tracts along the river on the east side which are not included in the district. As indicated in the section of this report dealing with ground water the average lowering of the water table in the conservancy district due to the drainage construction was 3 feet, and the maximum average lowering for any one area of the district was 3.67 feet in the Peralta-Tome area. Drainage has not been completely effective over the whole district, as there are still numerous small areas where the water table is high. This is particularly true with respect to areas adjacent to the river outlets of riverside drains where the gradients of the latter are necessarily very flat, and in the bosque areas bordering the river in the lower divisions. There are no drainage systems in the Middle Valley outside of the conservancy district and, as indicated by the 1936 survey, the undrained area of high water table between the southern boundary of the district and San Marcial totals about 17,000 acres.

In the Elephant Butte-Fort Quitman section, drainage is effective and practically complete within the area of the Rio Grande Project from Percha Dam to the Hudspeth County Line. In the Hudspeth County Conservation and Reclamation District a complete system of open drains has been under construction during the past few years and is now virtually completed.

Proposed Sump Drain

There is one project for the salvage of waters now lost by evaporation and transpiration by nonbeneficial vegetation, which has in recent years received much consideration and study as to feasibility and probable water yield. It is the so-called sump drain, a trunk drain proposed to collect the waters in the sump area of the closed basin, San Luis Valley, and discharge them to Rio Grande a few miles above the Lobatos gaging station. The water thus added to the river would enter below all irrigation diversions in Colorado but would become available for diversions in New Mexico. In the Rio Grande Compact concluded in 1929, construction of the sump drain is advocated as a desirable feature in the economic development and conservation of the waters of the Upper Rio Grande Basin and as a helpful factor in the reaching of a permanent compact and accord among the three signatory States.

Various estimates of the average amount of water that would be added to Rio Grande annually by the sump drain have been made from time to time, beginning with the estimate of 300,000 acre-feet by Stannard and Miller of the Bureau of Reclamation and Department of Agriculture 1915. R. I. Meeker, engineering consultant for Colorado, estimated from 175,000 to 200,000 acre-feet in data presented at the Rio Grande compact meeting in Santa Fe, January 1929; and Debler, Fowler, and Stout, a committee of engineers appointed to report to the Federal Emergency Administration of Public Works in connection with an application filed for construction of the sump drain as a project of that agency, estimated 40,000 acre-feet in 1935.

As outlined in the Debler, Fowler, Stout report, the drain would follow quite closely the trough of the basin. It would drain the numerous shallow lakes which collect there during the wet season and serve to lower the water table by as much as 5 feet adjacent to the drain and stream channels. This would permit the flow of many of the streams now seeping the area to be carried to the sump as surface flow, and eliminate as well the present seeped condition which is responsible for the losses by evaporation and transpiration. Above Head Lake the development would comprise a storm-water channel with a depth of about 5 feet. Head and San Luis Lakes would serve as regulating basins to permit the temporary storage of possible flood flows either from San Luis Creek or the east side streams, and permit of a smaller drain capacity between the lakes and Rio Grande. The drain would cross the closed basin barrier in a deep cut and join Rio Grande at Hanson Bluff about 3 miles above the mouth of Trinchera Creek.

Sources of drainage recovery.—Reliance can probably be placed upon two sources only as a water supply available to the sump drain. One, the smaller, is the contribution from the west by the ditches and drains carrying waste and return flow from the area irrigated by diversion from Rio Grande, and the other, the main source, is the flow from the eastern streams which drain the western slope of the Sangre de Cristo Range. On the north, the areas along Saguache and San Luis Creeks are at present seeped. Practically all water reaching the sump area from these creeks is used in irrigation of large meadows in the northern part of the area. In all probability any recovery of water from these seeped areas would, in keeping with present practice, be rediverted for irrigation, and is, therefore, hardly to be counted upon for any contribution to the sump drain.

In 1936, as a part of the Rio Grande joint investigation, the Geological Survey made weekly measurements of all ditches and drains crossing the road running north from Alamosa on the section line 2 miles west of the line between ranges 10 and 11 east, during the period June 25 to November 28. The total discharge for the period June 22 to November 30 of 39 ditches and one drain entering the sump area across this line of measurement is estimated to have been about 10,000 acre-feet. A portion of this is used for irrigation east of the line of measurement but most of it is lost by evaporation and by transpiration by brush. Based on these measurements for the 6 months of record, it is considered that a contribution to the sump drain, after irrigation requirements in the sump area have been met, of 10,000 acre-feet per year from the irrigated acreage of the closed basin that is served from the Rio Grande may be conservatively assumed.

The water available to the sump drain from the eastern streams is represented by the possible saving of the water from these streams now seeping the sump lands, after the demands for irrigation have been met. The sump areas of native vegetation fed by eastern streams are about a third in grass and two-thirds in brush, with a consumptive use including precipitation as taken from the data of the Bureau of Agricultural Engineering (table 76) of about 1.2 acre-feet per acre per year. Precipitation in this part of the valley averages between 8 and 9 inches per year. About 0.4 of the demand of the native vegetation is thus being supplied from ground water sustained by the seepage and overflow of the streams. The extent to which this supply can be reduced by construction of the sump drain depends upon the depth of the drain and lateral system, if any, and its general effectiveness in lowering the water table. This remains at this juncture more or less a matter of conjecture. In the subsequent analysis assumption is made of savings of 75 percent of the present depletion by native vegetation, including grass and brush but not trees or bosque. Trees or bosque, being adjacent to the streams, would probably continue to obtain water as at present. It seems likely that this percentage would represent an upper limit for the savings.

In Appendix B, which gives the details of the estimates of water production from run-off as summarized in the section of this report on water supply, the run-off, at the foothill line, of the eastern streams of the closed basin was estimated by dividing them into three groups. Group A was taken to include those tributary to San Luis Creek from the Villa Grove gaging station to and including San Isabel Creek; group B those from North Crestone Creek to Deadman Creek, inclusive; and group C the remaining creeks to the southern boundary of the closed basin. The mean annual run-off of group A was estimated to be 30,000 acre-feet; group B, 32,700 acre-feet; and group C, 38,000 acre-feet. The southern streams of group C, Medano, Zapato, and Uraco Creeks, enter a much wider valley area than do the northern streams, and there are a few well-developed ditch systems in this section that serve extensive tracts. It is doubtful whether these streams would contribute anything to the sump drain. Hence, in estimating the flow of the eastern streams available to the drain, half only of group C run-off was taken, making the total estimated mean annual run-off at the foothill line 81,700 acre-feet.

As described in the ground-water report of the Geological Survey, Part II, the streams of San Luis Valley are, below the foothill line, subject to percolation losses to both the shallow ground water and the artesian aquifers underlying the valley. These losses occur as the streams pass over the porous alluvial fans below the mouth of the canyons. No adequate measurements of the stream losses of this character are available, but as some indication of their magnitude in the case of the eastern streams, comparison was made of the records of discharge at two gaging stations maintained on Trinchera Creek above Mountain Home Reservoir. The upper station is at Turner's Ranch and the lower just above the reservoir. The records are available only for the months April to November of each year and for the period 1923 to 1936. In this period and for these months they show a mean loss between the stations of 3,600 acre-feet. The mean run-off at the upper station for the same months of this period was 15,500 acre-feet. Between the stations there is a large hay ranch, of which perhaps 1,200 to 1,500 acres are irrigated. The consumptive use by native hay lands in this district is assumed by the Bureau of Agricultural Engineering at 1.5 acre-feet per acre. Precipitation amounts to about 10 inches per year, which gives a stream-flow depletion of about 0.7 acre-foot per acre. For 1,500 acres this would be only 1,000 acre-feet per year, which leaves 2,600 acre-feet of the loss between stations unaccounted for. By prodigal use of water so that evaporation losses would be increased, this depletion might amount to considerably more than 1,000 acre-feet, but hardly enough more but that the loss to be attributed to deep percolation would be less than 10 percent of the flow at the upper station. Lacking further data and based upon this comparison, percolation losses to the artesian aquifers from the eastern streams was assumed at 10 percent of the run-off at the foothill line, thus reducing the estimated inflow of these streams to the sump area from 81,700 acre-feet to 73,500 acre-feet.

Using the Bureau of Agricultural Engineering estimates of unit consumptive use (table 76), and the irrigated and water-consuming acreages in the consumptive area supplied by the eastern streams (considered to be all in Saguache County) as given in table A of Part III, and correcting for precipitation, the sump depletion of the inflow of the eastern streams was derived as shown in table 106. The close agreement between the indicated total depletion of 72,300 acre-feet and the inflow as estimated in the previous paragraph affords some confirmation of the correctness of the latter estimate since, at present, this inflow is entirely consumed.

Estimated recovery by sump drain.—Using the data of the preceding paragraphs, the recovery by the sump drain was estimated on the basis that it would recover 75 percent of the ground water fed by eastern streams now consumed by the evapo-transpiration of grass and brush areas and 75 percent of the pooled water surface losses. The estimate follows:

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	Acre-feet	
	Losses	Inflow
Estimated inflow from eastern streams at foothill line		81,700
Percolation loss to artesian basin	5,200	
Depletion by crops, native vegetation, and other water-consuming areas	37,200	
Inflow from west side available to drain		10,000
Total	45,400	91,700
Net recovery by drain		46,300

TABLE 106.—*Estimated water consumption in the area*[1] *supplied by eastern streams of the closed basin, San Luis Valley*

Classification	Acreage	Consumptive use per year		Mean annual precipitation on the area (acre-feet)	Annual stream-flow depletion (acre-feet)
		Acre-feet per acre	Total acre-feet		
(1)	(2)	(3)	(4)	(5)	(6)
Irrigated	30,504	[2] 1.52	46,400	21,400	25,000
Native vegetation:					
Grass	32,793	1.0	32,800	23,000	9,800
Brush	57,058	1.3	74,200	40,000	34,200
Bosque-trees	113	3.8	400	100	300
Total native vegetation	89,964	[2] 1.19	107,400	63,100	44,300
Water surfaces	1,002	3.5	3,500	700	2,800
Miscellaneous [3]	5,318	[2] .73	3,900	3,700	200
Total	126,788	[2] 1.28	161,200	88,900	72,300

[1] Taken as the area supplied by those streams which would contribute to the proposed sump drain and considered to be all in Saguache County.
[2] Computed weighted mean of a number of classifications.
[3] Includes bare lands, village areas, and lands temporarily out of cropping.

Columns 2 and 3: From data of the Bureau of Agricultural Engineering as given in table A of part III and table 78.
Column 5: Average mean annual precipitation taken as 0.7 foot.

As previously stated, the estimated saving of 75 percent as used in the above analysis should probably be considered as an upper limit. In view of this, and the uncertainties which manifestly enter into this derivation, it seemed best to adopt a round figure of 40,000 acre-feet as the estimate of average recovery to be anticipated.

In addition to this average annual recovery by the sump drain of 40,000 acre-feet, there is the possible recovery of flood waters from San Luis and Saguache Creeks for which no allowance was made in the analysis. There would probably be some accretion also from drainage of sump lands adjacent to the drain in Alamosa County, not accounted for in the estimate of 10,000 acre-feet from the west side.

In the event of construction of the sump drain, it is likely that the present drainage systems in the closed basin would be extended and that ultimately the main drain would be extended beyond the limits now proposed. Much of the drainage water would be rediverted, so that even with a greatly expanded drainage system it is doubtful if the total discharge to Rio Grande of the sump drain would much exceed the foregoing estimate of 40,000 acre-feet per year.

In the earlier years following construction of a sump drain the yield undoubtedly would be greater until the accumulated water in soil storage had been withdrawn, which might take several seasons.

There are few data upon which to base an estimate of the monthly distribution of the sump drain flow. Since the chief source would be the salvaged flow of the eastern streams, the monthly distribution of the drain flow would very likely be quite similar in character to that of the stream flow. There would be some modification due to the smaller amounts of drainage and waste coming in from the west with a distribution of different character. Taking these considerations into account and using available stream and drainage records, a possible distribution was derived as shown in table 107.

Quality of sump drain water.—In the quality of water investigations, the data of which are summarized in a previous section and reported in detail in Part IV, analyses were made of water samples taken in 1936 from the streams and drains tributary to the sump area, from ground water in this area, and from San Luis Lake. With respect to the salinity of the stream flow, the interpretive report of the Bureau of Plant Industry states:

> Water samples have been taken from six of the streams that discharge into the northern part of the valley from the Sangre de Cristo Mountains on the east, from Crestone to Sand Creek.
>
> The conductance of these is very low, ranging from 4.6 to 10.4. The dissolved constituents are chiefly silica and calcium bicarbonate, so that these waters probably contribute very little salinity to the valley lands. Of the streams entering the northern part of the valley from the west, four have been sampled, from Kerber to La Garita Creeks. The conductances of these samples range higher than those from the streams on the east, from 9.1 to 64.1 with the highest conductance found in Kerber Creek. Detailed analysis of samples from Saguache and Carnero Creeks show that here also the chief dissolved constituents are silica and calcium bicarbonate. These findings indicate that currently the streams discharging into the northern part of the San Luis Valley are contributing very little potential salinity to the valley lands.

TABLE 107.—*Estimated total and possible monthly distribution of annual yield of proposed sump drain, San Luis Valley, Colo.*

Month	Monthly distribution	
	Percent	Acre-feet
January	3	1,200
February	5	2,000
March	5	2,000
April	8	3,200
May	10	4,000
June	15	6,000
July	15	6,000
August	14	5,600
September	9	3,600
October	7	2,800
November	6	2,400
December	3	1,200
Year	100	40,000

The same report comments also on the drainage salinity and that of San Luis Lake as follows:

Samples from two stations on the Rio Grande Drain show conductances ranging from 27.5 to 56.9. The area north of Center is served by the Gibson Drain, which has been sampled at two stations where the conductances ranged from 29.6 to 36.6. The area lying to the east of Center, toward the valley trough, is served by the San Luis Valley Irrigation District Drain which discharges into San Luis Lake. This drainage system has been sampled at six stations with conductances ranging from 39.3 to 67.8. Samples have been taken also from two stations on San Luis Lake where conductances ranging from 63.9 to 108 were found. Detailed analyses of samples from the lake show that the chief salt constituents are sodium and magnesium combined with bicarbonate, sulphate, and chloride.

The report of analytical data gives the results of conductance tests in 1936 on water samples from 43 shallow wells in townships 40 and 41 north, range 11 east, which include San Luis and Head Lakes and a portion of the sump area west and north of the lakes which would contribute to the sump drain. These tests show a range in conductance from about 30 to as high as 800, with a rough average of about 170. The wells showing some of the higher conductances are close to San Luis Lake, although, as noted above, the conductances of the lake water itself, as sampled in 1936, did not exceed 108. Detailed analyses made of samples from 6 of the 43 wells, with an average conductance of 166, show averages of 1.55 tons of salts per acre-foot, sodium and chloride percentages of 87 and 6, respectively, relatively high amounts of bicarbonates, and low amounts of calcium, magnesium, and sulphates.

Presumably the salinity of the sump drain water would at first be largely of the same character as tha of the present shallow ground water in the vicinity Based on the average of 1.55 tons of salts per acre-foo as given above, this means that the estimated 40,00(acre-feet flow of the drain would carry into Rio Grand(annually about 60,000 tons of salts with a markedly unfavorable preponderance of sodium combinations ir its constituent parts. Table 52 of the section of this report on quality of water indicates that in the period 1931 to 1936 an average of 638,000 tons of salt was carried past El Paso annually in Rio Grande. The probable maximum inflow of 60,000 tons of salt annually from the sump drain represents, then, 9 percent of the salt carried past El Paso. This does not mean, however, that there would be an increase of 9 percent in the salt content at El Paso, since part of the salts from the drain would inevitably accumulate in the Middle Valley.

It is to be anticipated that in time the drain water would become fresher, with the salinity diminishing to a content more nearly approaching that of the surface and drain waters entering the sump. From the concentrations indicated for the latter by the 1936 investigation, this might mean a reduction in the concentration of the drain flow to 1 ton of salt per acre-foot or lower, with a corresponding improvement in the salt constituents characterized by lower sodium and higher calcium percentages.

PART I

SECTION 7.—AVAILABILITY AND USE OF WATER UNDER GIVEN CONDITIONS

Previous sections of this report have established the available water supply in the Upper Rio Grande Basin; the uses and requirements for water, including estimates of the required diversion demand of the major units of the basin; the opportunities for water storage; and the possibilities of additional water supplies by transmountain diversion and by salvage of present losses. Using the data thus developed, it remains to determine the effect upon, and conditions of water supply and use in, the San Luis, Middle, and Elephant Butte-Fort Quitman sections, for the various possible combinations of draft, storage development, transmountain diversion, and salvage involved in a solution of the water problems of the Upper Rio Grande Basin; and to compare the conditions so determined with those of the past and the present. Accordingly, this section presents the results of analyses of a number of given sets of conditions as listed in table 108, and as outlined in more detail in the following paragraphs:

Various Given Conditions

Condition No. 1

Present storage capacity above Rio Grande area of San Luis Valley ....acre-feet..	130, 000
Diversion demand on the Rio Grande in San Luis Valley ....acre-feet..	650, 000
Return to Rio Grande in percent of total Rio Grande diversions	16

Period of analysis, 1892–1904 and 1911–35.

TABLE 108.—*Various given conditions for which analyses of availability and use of water are made, Upper Rio Grande Basin*

Condition number	Storage: Reservoirs	Storage: Capacity 1,000 acre-feet units	Diversion demands: Basin units	Diversion demands: 1,000 acre-feet units	Other conditions	Period of analysis	Determination of—
1	Present San Luis Valley	[1] 130	Rio Grande area—San Luis Valley.	[2] 650	Return flow to Rio Grande 16 percent of diversions.	1911-35	Effect on San Luis Valley and Lobatos.
2	Present San Luis Valley	[1] 130	San Luis Valley	([3])	Present conditions in San Luis Valley.	1892-1904	Effect on Middle Valley, San Marcial, and Rio Grande project.
	El Vado	198	Middle Valley	580		1911-35	
	Elephant Butte	2, 274	Rio Grande project and Mexico.	773			
3	Present San Luis Valley	[4] 100	Rio Grande area—San Luis Valley.	650	Return flow to Rio Grande 16 percent of diversions.	1911-35	Effect on San Luis Valley and Lobatos.
	Vega-Sylvestre	240					
4	Present San Luis Valley	100	Rio Grande area—San Luis Valley.	650	Return to Rio Grande in San Luis Valley 16 percent of diversions.	1892-1904	Effect on San Luis Valley, Lobatos, Middle Valley, San Marcial, and Rio Grande project.
	Wagon Wheel Gap	1, 000	Middle Valley	580		1911-35	
	El Vado	198	Rio Grande project and Mexico.	773			
	Elephant Butte	2, 274					
5	Present San Luis Valley	100	Rio Grande area—San Luis Valley.	650	Return to Rio Grande in San Luis Valley 8 percent of diversions.	1892-1904	Effect on Lobatos, Middle Valley, San Marcial, and Rio Grande project.
	Wagon Wheel Gap	1, 000	Middle Valley	580		1911-35	
	El Vado	198	Rio Grande project and Mexico.	773			
	Elephant Butte	2, 274					
6	Conejos	162	Conejos area—San Luis Valley	230	Return flow 35 percent of diversions.	1911-35	Effect on Conejos area.
7	Present San Luis Valley	100	Rio Grande area—San Luis Valley.	650	Return to Rio Grande in San Luis Valley 16 percent of diversions—Conejos return, 35 percent.	1911-35	Effect on Lobatos, Middle Valley, and San Marcial.
	Wagon Wheel Gap	1, 000	Conejos area—San Luis Valley	230			
	Conejos	162	Middle Valley	580			
	El Vado	198					
8	Present San Luis Valley	100	Rio Grande area—San Luis Valley.	[5] 750	No increase in total return flow over that with 650,000 demand.	1911-35	Effect on Rio Grande area in San Luis Valley.
	Wagon Wheel Gap	1, 000					
	Vega-Sylvestre	240					
9	Conejos	162	Conejos area—San Luis Valley	[5] 300	No increase in total return flow over that with 230,000 demand.	1911-35	Effect on Conejos area.
10	Present San Luis Valley	100	Rio Grande area—San Luis Valley.	[5] 750	No increase in total return flow in San Luis Valley over that with 650,000 and 230,000 demands.	1911-35	Effect on Lobatos, Middle Valley, San Marcial, and Rio Grande project.
	Wagon Wheel Gap	1, 000	Conejos area—San Luis Valley	[5] 300			
	Vega-Sylvestre	240	Middle Valley	580			
	Conejos	162	Rio Grande project and Mexico.	773			
	El Vado	198					
	Elephant Butte	2, 274					
11	Present San Luis Valley	100	Rio Grande area—San Luis Valley.	650	Return to Rio Grande in San Luis Valley 8 percent of diversions. Sump drain annual discharge to Rio Grande of 40,000 acre-feet.	1892-1904	Effect on Lobatos, Middle Valley, San Marcial, and Rio Grande project.
	Wagon Wheel Gap	1, 000	Middle Valley	580		1911-35	
	State line	400	Rio Grande project and Mexico.	773			
	El Vado	198					
	Elephant Butte	2, 274					

[1] Upper Rio Grande.
[2] Ideal monthly distribution.
[3] Lobatos flow depleted for present conditions as in table 18.
[4] 100,000 acre-feet considered effective.
[5] Maximum possible development.

This analysis is to show the effect on the water supply of the area now served from Rio Grande in San Luis Valley of any attempt, with the present limited storage capacity, to divert water in accordance with an ideal irrigation demand rather than to take it, as at present available. In this analysis and the subsequent analyses for other conditions, the periods used were 1892–1904 and 1911–35. In order to determine the effect on Lobatos of given conditions above Alamosa, the change at Alamosa was applied to past Lobatos flow. The record of past flow at Alamosa, needed to derive the changes at that station, does not go back of 1912. Without using estimated flow, this limited the period of analysis to 1912–35. Because 1911 was a year of high run-off and, in all operation studies, reservoirs could safely be assumed to have filled, the period 1911–35 was adopted and estimated Alamosa flow used prior to June 1912. Although the period 1911–35 includes two severe drought years, 1931 and 1934, there were probably more critical years in the period 1892–1904, particularly the succession of dry years 1899, 1900, 1901, 1902, and 1904. It was important, therefore, that some estimate, at least, be derived of the effects of the various assumed sets of conditions, in this earlier critical period. Such estimates were derived in the various analyses but it is to be noted that with respect to effects on Lobatos flow and the Middle and Elephant Butte-Fort Quitman sections, they are based on the use of an estimated monthly flow at Alamosa as given in table 130 of Appendix A. Earliest available stream-flow records indicate that reservoirs may be safely assumed to have filled at the beginning of the 1892–1904 period and this assumption was made in the operation studies.

Condition No. 2

Present storage capacity above Rio Grande area of San Luis Valley____acre-feet__	130, 000
Present storage capacity afforded Middle Valley by El Vado Reservoir____acre-feet__	198, 000
Present storage capacity afforded Rio Grande project by Elephant Butte Reservoir____acre-feet__	2, 274, 000
Present conditions of diversions and irrigation in San Luis Valley____	
Diversion demand for Middle Rio Grande Conservancy district____acre-feet__	580, 000
Diversion demand on Elephant Butte Reservoir for Rio Grande project and Mexican treaty obligation acre-feet__	773, 000

Period of analysis, 1892–1904 and 1911–35.

This analysis is to show the effect upon the water supply of the Middle and Elephant Butte-Fort Quitman sections of present irrigation development in San Luis Valley, with diversions to Middle Rio Grande Conservancy District and Rio Grande Project in accordance with the adopted demands. In this and all other analyses annual evaporation from El Vado Reservoir was taken as 3.5 feet, or 2.0 feet deducting precipitation, and that from Elephant Butte Reservoir as 6.0 feet (refer to table 25), or 5.2 feet deducting precipitation. A seepage allowance of 5,000 acre-feet per month was used for Elephant Butte Reservoir and a monthly distribution of the arroyo inflow to it was estimated from the annual data of table 202 in Appendix B.

Condition No. 3

Present effective storage capacity above Rio Grande area of San Luis Valley____acre-feet__	100, 000
Vega-Sylvestre Reservoir____do____	240, 000
Diversion demand on the Rio Grande in San Luis Valley acre-feet__	650, 000
Return to Rio Grande in percent of total Rio Grande diversions____	16

Period of analysis, 1911–35.

This analysis is to show the effect on the water supply of the San Luis Valley area served by Rio Grande, and on the flow at Lobatos of operation of Vega-Sylvestre Reservoir. The analysis was not continued to determine the effect on Middle Valley and Elephant Butte-Fort Quitman sections as the resulting mean annual flow at Lobatos was very nearly the same as that resulting from operation of Wagon Wheel Gap Reservoir, Condition No. 4, for which complete analysis was made. For simplicity of analysis the storage of present reservoirs was considered as combined with that of Vega-Sylvestre (and with Wagon Wheel Gap in subsequent studies). The present smaller reservoirs might not fill in the same proportion as the larger ones and allowance was made for this by taking the effective capacity of present reservoirs at 100,000 acre-feet. Annual evaporation from Vega-Sylvestre Reservoir (and Wagon Wheel Gap also) was taken at 1.9 feet, or 0.6 foot deducting precipitation.

Condition No. 4

Present effective storage capacity above Rio Grande area of San Luis Valley____acre-feet__	100, 000
Wagon Wheel Gap Reservoir____do____	1, 000, 000
Present capacity El Vado Reservoir____do____	198, 000
Present capacity Elephant Butte Reservoir__do____	2, 274, 000
Diversion demand on Rio Grande in San Luis Valley acre-feet__	650, 000
Diversion demand for Middle Rio Grande Conservancy District____acre-feet__	580, 000
Diversion demand on Elephant Butte Reservoir for Rio Grande project and Mexican treaty obligation acre-feet__	773, 000
Return to Rio Grande in San Luis Valley in percent of total Rio Grande diversions____	16

Period of analysis: effect on Middle Valley, 1892–1904 and 1911–35; effect on Rio Grande Project, 1892–1904.

This analysis is to show the effect on the water supply of the three sections of the basin, of operation of Wagon Wheel Gap Reservoir with diversions to the major units of the three sections in accordance with the adopted demands. The effect on Rio Grande Project for the period 1911–35 was not analyzed as the resulting mean annual flow at San Marcial was practically the same as given under Condition No. 2.

Condition No. 5

The items of this condition are exactly the same as for Condition No. 4, except that the return flow to Rio Grande in San Luis Valley is taken as 8 percent only of the total Rio Grande diversions in the valley. Although, as described in the development of the diversion demand for the Rio Grande area of San Luis Valley, the return flow has averaged better than 16 percent in the 3 years 1934, 1935, and 1936, and this amount of return is considered to represent very conservatively that to be anticipated in the future, there are a number of years in the period previous to 1934 for which data are available, when the return, as indicated by table 36, was less than 16 percent. The average for the period 1928 to 1936, inclusive, for the return above Alamosa is 7.6 percent of total diversions above Alamosa. Because this return flow is such an important item in the water available to lower sections, and because the allowance for it constitutes one of the fundamental assumptions of the analyses, a return of 8 percent as a minimum remotely possible but not probable was used in certain of the analyses.

Condition No. 6

Reservoir capacity on the Conejos River___acre-feet__	162, 000
Diversion demand on Conejos River__________do____	230, 000
Return flow to Conejos in percent of Conejos diversions____	35
Period of analysis, 1911–35.	

This analysis is to show the effect on the water supply of the Conejos area and consequently on that of Rio Grande, of storage regulation, and diversions in accordance with an ideal irrigation demand. This effect is combined with that of Wagon Wheel Gap development as shown under Condition No. 7. In the previous description of investigations of proposed storage projects it was indicated that the Conejos investigations were not yet complete. Hence, final data on storage possibilities were not available for this analysis. The assumption was made that a reservoir of at least 100,000 acre-feet capacity would be found feasible on the lower river, and to this was added the capacity of the upper Conejos Reservoir No. 6, 32,000 acre-feet, and the Mogote off-stream reservoir tentatively estimated at 30,000 acre-feet capacity. For simplicity of the operation study, all three were considered as one reservoir located at the Mogote gaging station. Evaporation was taken at 2.0 feet, or 1.4 feet deducting precipitation. No analysis could be made for the early period 1892–1904 because of the lack of records.

Condition No. 7

Present effective storage capacity above Rio Grande area of San Luis Valley______________acre-feet__	100, 000
Wagon Wheel Gap Reservoir______________do____	1, 000, 000
Conejos Reservoirs________________________do____	162, 000
El Vado Reservoir_________________________do____	198, 000
Diversion demand on Rio Grande in San Luis Valley____________________________acre-feet__	650, 000
Diversion demand on Conejos in San Luis Valley____________________________acre-feet__	230, 000
Diversion demand for Middle Rio Grande Conservancy District__________________acre-feet__	580, 000
Return to Rio Grande in San Luis Valley in percent of total Rio Grande diversions_________________	16
Return to Conejos in percent of diversions_________	35
Period of analysis, 1911–35.	

This analysis is to show the effect on the flow at Lobatos and on the water supply of the Middle section, of the combined operation of Wagon Wheel Gap and Conejos Reservoirs with diversions to the major units of San Luis and Middle sections in accordance with the adopted demands. The effect of this combination on the Rio Grande Project was not analyzed as the resulting mean annual flow at San Marcial was very nearly the same as that given by the analysis under Condition No. 2.

Condition No. 8

Present effective storage capacity above Rio Grande area of San Luis Valley______________acre-feet__	100, 000
Wagon Wheel Gap Reservoir______________do____	1, 000, 000
Vega-Sylvestre Reservoir__________________do____	240, 000
Diversion demand on Rio Grande in San Luis Valley____________________________acre-feet__	750, 000
Return to Rio Grande the same as for Condition No. 4; i. e., 16 percent of 650,000 acre-feet.	
Period of analysis, 1911–35.	

This analysis is to show the effect on the water supply of the Rio Grande area in San Luis Valley of the combined storage of Wagon Wheel Gap and Vega-Sylvestre Reservoirs and a diversion demand estimated to represent the maximum possible development. The mean annual run-off of Rio Grande near Del Norte in the period 1911–35 was 755,000 acre-feet. Allowing 5,000 acre-feet for reservoir evaporation, the maximum diversion demand for the normal year was taken at 750,000 acre-feet. Under this condition it was hypothecated that no restrictions whatever be placed upon development in San Luis Valley. Since the extension of development would, of necessity, be principally in the closed basin area, no reliance could be placed on any more return flow to Rio Grande than in the case of the 650,000 acre-feet diversion demand. Although both Wagon Wheel Gap and Vega-Sylvestre Reservoirs were used, because of the drought period ending in 1904, only 1,000,000 acre-feet storage was assumed to be on hand at the beginning of the 1911–35 period.

Condition No. 9

Reservoir capacity on Conejos River --- acre-feet	162,000
Diversion Demand on the Conejos River --- do	300,000
Return to Conejos the same as for Condition No. 6; i. e., 35-percent of 230,000 acre-feet.	
Period of analysis, 1911–35.	

This analysis is to show the effect on the water supply of the Conejos area of the same storage regulation as under Condition No. 6 (probably about the maximum as limited by physical conditions) but with a diversion demand estimated to represent the maximum possible development. It would be necessary that the increased diversions be made up by utilization of reservoir spills and the supply that cannot be diverted by present canals. This increase was estimated at 70,000 acre-feet, which, added to the demand of Condition No. 6, gave 300,000 acre-feet. The 1936 survey of irrigated and other water-consuming areas indicates but little opportunity for increased depletion on the Conejos proper, and it was assumed that the expansion of irrigated acreage implied by the maximum demand would be principally to irrigable lands south of Antonito in New Mexico. In this case any more return flow to the Conejos than with the 230,000 acre-feet demand would be doubtful, and no more was assumed in the analysis. Records were not available to extend this analysis to the earlier critical period, 1892–1904.

Condition No. 10

Present effective storage capacity above Rio Grande area of San Luis Valley --- acre-feet	100,000
Wagon Wheel Gap Reservoir --- do	1,000,000
Vega-Sylvestre Reservoir --- do	240,000
Conejos Reservoirs --- do	162,000
El Vado Reservoir --- do	198,000
Elephant Butte Reservoir --- do	1,274,000
Diversion demand on Rio Grande in San Louis Valley --- do	750,000
Diversion demand on Conejos in San Luis Valley do	300,000
Diversion demand for Middle Rio Grande Conservancy District --- do	580,000
Diversion demand on Elephant Butte Reservoir for Rio Grande project and Mexican treaty obligation --- do	773,000
Return to Rio Grande and Conejos in San Luis Valley the same as for Conditions Nos. 4 and 6; i. e., 16 percent of 650,000 acre-feet, 35 percent of 230,000 acre-feet.	
Period of analysis, 1911–35.	

This analysis is to show the effect on Lobatos flow and on the water supply of Middle and Elephant Butte-Fort Quitman sections, of unrestricted and maximum possible development in the Rio Grande and Conejos areas of San Luis Valley. It is for hypothecated maximum diversion demands for these areas, and the adopted diversion demands for Middle Rio Grande Conservancy District, Rio Grande project and Mexico, and represents the combined effect of Conditions Nos. 8 and 9.

Condition No. 11

Present effective storage capacity above Rio Grande area in San Luis Valley --- acre-feet	100,000
Wagon Wheel Gap Reservoir --- do	1,000,000
State Line Reservoir --- do	460,000
El Vado Reservoir --- do	198,000
Elephant Butte Reservoir --- do	2,274,000
Diversion demand on Rio Grande in San Luis Valley do	650,000
Diversion demand for Middle Rio Grande Conservancy District --- do	580,000
Diversion demand on Elephant Butte Reservoir for Rio Grande project and Mexican treaty obligation do	773,000
Sump drain inflow to Rio Grande above Lobatos do	40,000
Return flow to Rio Grande in San Luis Valley in per cent of total Rio Grande diversions	8
Period of analysis, 1892–1904 and 1911–35.	

This analysis is to show the combined effect of operation of Wagon Wheel Gap Reservoir, State Line Reservoir, and the sump drain on the water supply of Middle and Elephant Butte-Fort Quitman sections, with the adopted diversion demands of the major units in these sections. The return flow to Rio Grande in San Luis Valley was taken as 8 percent of the total Rio Grande diversions in the valley, as under Condition No. 5. This was done in order to set up the most unfavorable contingency with respect to the lower sections. The operation of State Line Reservoir would be largely to eliminate shortages in the Middle section. Final data on storage capacity for it were not available but from a preliminary map of 1937 surveys a capacity of 460,000 acre-feet was indicated as probable below elevation 7,500 at the Ute Mountain dam site. Annual evaporation was taken as 3.7 feet, or 3.2 feet deducting precipitation.

Results of Analyses

The results of the analyses under Conditions Nos. 1 to 11 and comparisons between their effects are most readily presented by summarizations for each condition of (1) annual run-off of Rio Grande at Lobatos and San Marcial and of Conejos River at mouth; (2) monthly run-off at Lobatos for maximum, minimum, and mean years; and (3) amount and year of occurrence of shortages in San Luis, Middle, and Elephant Butte-Fort Quitman sections.

Annual Run-off at Key Stations Under Given Conditions

Tables 109, 110, and 111 show the annual run-off of Rio Grande at Lobatos and San Marcial and of Conejos River at mouth, respectively, for the years in the two periods of analysis, and for the Conditions indicated. The same data for Lobatos and San Marcial are also shown graphically by figures 40 and 41.

The effect on Rio Grande at lower stations of increased storage developments in San Luis Valley is to decrease the annual run-off in high water years by storage and to increase it during low years by release of water held over from the abundant years. It will be observed that for Condition No. 4, which includes Wagon Wheel Gap Reservoir and the adopted diversion demands in all sections, there is no decrease in the mean annual flow from that under Condition No. 2, which represents present development in San Luis Valley, neither at Lobatos nor at San Marcial, but rather a small increase. For the hypothecated Conditions Nos. 5 and 10, substantial reductions in the mean annual flow at these two stations are indicated.

TABLE 109.—*Annual run-off of Rio Grande near Lobatos under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number [1]							
	1	2	3	4	5	7	10	11
1892	------	371.0	------	438.2	386.2	------	------	426.2
1893	------	260.0	------	329.3	277.3	------	------	317.3
1894	------	200.0	------	257.7	205.7	------	------	245.7
1895	------	389.0	------	455.1	403.1	------	------	443.1
1896	------	237.0	------	273.7	223.6	------	------	263.6
1897	------	617.0	------	501.0	449.0	------	------	489.0
1898	------	430.0	------	431.0	379.0	------	------	419.0
1899	------	174.3	------	203.2	159.0	------	------	199.0
1900	------	255.8	------	287.6	230.0	------	------	290.0
1901	------	241.7	------	283.7	245.3	------	------	233.3
1902	------	109.7	------	127.9	105.0	------	------	145.0
1903	------	447.0	------	388.4	336.4	------	------	376.4
1904	------	277.6	------	183.8	149.7	------	------	169.7
13-year mean	------	308.5	------	320.0	274.6	------	------	314.6
1911	1,015.2	1,008.9	681.6	658.7	606.7	569.6	438.6	646.7
1912	763.4	627.2	727.8	721.9	669.9	788.0	516.7	709.9
1913	370.4	243.2	281.5	262.5	210.5	295.1	269.5	250.5
1914	543.9	374.4	356.6	330.3	278.3	287.4	276.3	318.3
1915	440.0	333.0	362.6	357.7	305.7	351.3	317.6	345.7
1916	794.8	697.5	560.0	610.1	558.1	592.0	351.8	598.1
1917	706.5	725.4	712.5	720.2	648.2	761.9	390.9	708.2
1918	305.6	239.2	288.6	275.7	223.7	299.7	251.0	263.7
1919	605.8	439.2	466.7	426.3	374.3	438.1	377.0	414.3
1920	937.1	863.6	827.2	870.1	818.1	823.8	462.9	858.1
1921	742.1	523.9	641.2	636.8	584.8	663.4	330.6	624.8
1922	794.3	606.9	806.2	808.2	756.2	819.7	537.9	796.2
1923	722.4	639.5	591.9	576.6	524.6	549.8	398.3	564.6
1924	786.6	565.0	771.2	783.0	731.0	811.8	578.7	771.0
1925	442.5	359.0	347.1	317.9	265.9	332.4	314.9	305.9
1926	479.9	344.7	399.8	385.8	333.8	395.1	294.9	373.8
1927	770.8	711.8	535.3	553.7	501.7	522.0	340.5	541.7
1928	426.7	270.4	422.4	434.4	382.4	494.6	313.4	422.4
1929	694.3	394.8	409.0	502.1	450.1	482.1	318.7	490.1
1930	347.0	260.4	356.3	351.1	299.1	411.5	303.1	339.1
1931	187.7	149.5	155.5	176.0	124.0	231.0	193.9	164.0
1932	780.7	561.4	592.9	528.9	476.9	426.9	385.7	516.9
1933	311.5	232.0	300.5	292.2	240.2	324.1	272.9	230.2
1934	186.8	130.8	137.8	171.7	119.7	222.9	177.5	159.7
1935	492.1	430.1	404.9	380.6	328.6	269.0	256.7	368.6
25-year mean	588.1	473.1	489.9	485.3	433.3	486.5	346.8	473.3

[1] Refer to table 108.

With the unrestricted development in San Luis Valley as represented by Condition No. 10, the reduction at Lobatos for the 25-year period is 28 percent from present conditions. At San Marcial, however, the corresponding reduction is only 13 percent.

The mean flow at Lobatos for Condition No. 1, which represents no additional storage in San Luis Valley but diversions there in accordance with the ideal demand is, of course, substantially greater than for Condition No. 2, present conditions, because under the ideal demand much of the supply becomes indivertible and greater shortages result.

TABLE 110.—*Annual run-off of Rio Grande at San Marcial under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number [1]					
	2	4	5	7	10	11
1892	1,133.4	1,158.4	1,131.3	------	------	1,054.5
1893	511.2	580.0	528.4	------	------	516.9
1894	396.7	447.3	403.2	------	------	415.1
1895	1,052.2	1,138.5	1,094.5	------	------	1,031.8
1896	647.1	658.7	636.4	------	------	606.5
1897	2,039.5	1,889.3	1,862.0	------	------	1,764.7
1898	884.9	893.0	831.7	------	------	854.9
1899	336.0	357.8	324.6	------	------	301.1
1900	366.8	384.0	355.2	------	------	262.0
1901	507.5	525.9	501.6	------	------	459.5
1902	227.8	234.8	221.3	------	------	199.6
1903	986.5	909.2	872.1	------	------	788.8
1904	882.4	763.7	764.3	------	------	750.8
13-year mean	769.4	766.2	732.0	------	------	692.8
1911	1,813.9	1,464.1	1,412.1	1,377.7	1,240.9	1,259.0
1912	1,606.3	1,574.8	1,543.2	1,619.2	1,347.9	1,499.0
1913	516.7	525.8	478.7	542.2	534.1	463.5
1914	892.7	884.2	807.6	878.6	850.1	809.4
1915	1,403.3	1,402.6	1,368.6	1,376.5	1,347.5	1,330.1
1916	1,656.4	1,594.5	1,525.1	1,595.9	1,351.5	1,522.2
1917	1,095.6	1,074.4	1,037.4	1,097.8	738.2	990.4
1918	386.5	409.5	368.4	419.7	359.9	350.1
1919	1,338.3	1,350.1	1,273.4	1,393.8	1,332.5	1,278.4
1920	2,307.2	2,298.9	2,261.2	2,239.0	1,878.1	2,291.2
1921	1,292.0	1,428.8	1,362.3	1,469.0	1,136.3	1,379.5
1922	1,008.9	1,176.6	1,149.5	1,159.3	877.5	1,107.2
1923	1,083.5	1,063.6	1,005.8	1,058.7	905.4	970.6
1924	1,392.3	1,563.7	1,518.0	1,565.6	1,332.5	1,514.6
1925	411.3	396.8	354.9	408.9	392.6	317.3
1926	1,066.7	1,081.5	1,020.4	1,094.9	993.9	1,036.0
1927	1,388.5	1,265.7	1,188.9	1,266.4	1,084.9	1,192.0
1928	675.3	807.4	780.3	829.8	648.6	726.3
1929	1,322.0	1,260.6	1,184.8	1,278.0	1,114.7	1,222.6
1930	775.0	825.3	798.2	854.9	746.5	744.3
1931	502.9	533.8	484.9	577.0	560.4	497.6
1932	1,328.1	1,291.8	1,242.1	1,210.0	1,148.4	1,157.7
1933	693.3	712.4	680.5	730.1	678.8	654.7
1934	303.8	313.9	312.4	328.8	328.3	266.1
1935	893.9	834.2	782.7	722.7	724.3	746.8
25-year mean	1,082.3	1,085.4	1,037.7	1,083.7	946.2	1,013.9

[1] Refer to table 108.

TABLE 111.—*Annual run-off of Conejos River at mouth under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Measured [1]	Condition number [2]		Year	Measured [1]	Condition number [2]	
		6	9			6	9
1911	339.1	250.0	194.2	1925	91.3	105.8	90.3
1912	241.3	307.4	271.6	1926	185.0	194.3	94.1
1913	60.8	93.4	67.8	1927	251.6	219.9	127.8
1914	137.6	94.7	83.6	1928	109.6	169.8	113.0
1915	109.5	103.1	76.5	1929	212.1	192.1	109.7
1916	282.0	263.9	120.8	1930	119.5	179.9	120.1
1917	226.7	268.4	181.4	1931	34.2	89.2	52.1
1918	118.1	142.1	93.5	1932	308.0	206.0	165.2
1919	144.7	156.5	95.4	1933	110.9	142.8	91.6
1920	417.1	370.8	272.7	1934	20.6	72.0	45.3
1921	164.0	190.6	137.0	1935	203.0	91.4	85.1
1922	250.6	262.1	191.3				
1923	295.7	268.9	195.8	25-year mean	189.5	190.7	133.7
1924	304.1	332.9	266.3				

[1] Estimated 1911 to 1920.
[2] Refer to table 108.

The only difference between Conditions Nos. 5 and 11 with respect to the effect on Lobatos flow is the addition of the sump drain yield of 40,000 acre-feet which, of course, appears throughout in tables 109, 112, and 113. With respect to the effect on San Marcial flow, Condition No. 11 includes State Line Reservoir not included under Condition No. 5. This yields more water for the Middle Valley with a corresponding reduction for the Elephant Butte-Fort Quitman section. Hence, the mean flow at San Marcial under Condition No. 11, as shown in table 110, is less than under Condition No. 5.

As shown by table 111, the storage development on the Conejos River with the adopted diversion demand ideally distributed as under Condition No. 6 results in practically no change in the mean annual flow of Conejos River at its mouth from that of the present. Condition No. 9, the maximum possible development, results in a reduction from the measured mean flow of 29 percent.

As indicated in both tables 109 and 110, the mean annual flows for the period 1892–1904 are much lower than for the period 1911–35 and the earlier period appears to have been much the more critical of the two. Over a generation elapsed between the critical years of the two periods.

Monthly Run-off at Lobatos Under Given Conditions

Tables 112 and 113 show the monthly run-off of Rio Grande near Lobatos for minimum, mean, and maximum years of the two periods and for the Conditions indicated. These data are also shown by the graphs of figures 42 and 43. The maximum and minimum years used are those of maximum and minimum flow at the Del Norte station. It will be noted that all of the Conditions involving increased storage in the San Luis section result in an improvement over the present conditions of No. 2, in the regimen of flow at Lobatos from month to month. This is particularly noticeable in the summer and fall months of the minimum year. It represents the effect of storage in regulating the supply to a monthly distribution more in agreement with irrigation demands by reducing peaks and building up the flow during the summer months, and by holding water over from wet to dry years. The resulting improvement in return-flow distribution is directly reflected in the improved regimen at Lobatos.

Referring to table 113, in the maximum year 1911 a June run-off of 180,000 acre-feet under present conditions is reduced to 118,000 acre-feet under Condition

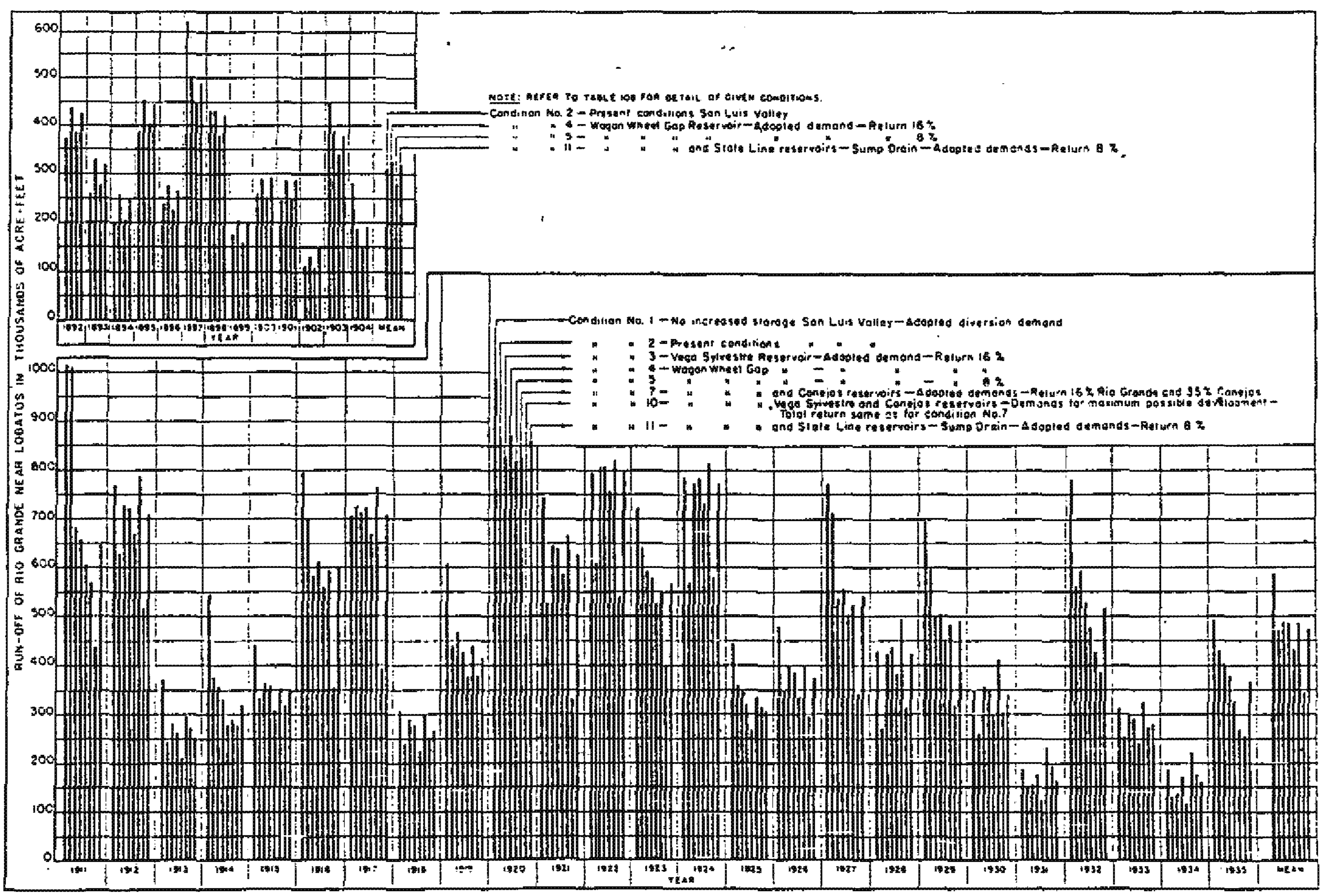

Figure 40.—Annual run-off of Rio Grande near Lobatos, Colo., under various given conditions of storage and irrigation draft.

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No. 4 and to 100,000 acre-feet under the extreme Condition No. 10. In the minimum year 1934 a July run-off of 700 acre-feet under present conditions is increased to 16,500 and 23,000 acre-feet under Conditions Nos. 4 and 10, respectively. The mean year shows less striking changes, but clearly indicates the improvement in the flow of the late summer months. The data of table 112 for the earlier period, 1892–1904, show similar changes, although the improvement in the flow from May to October in the minimum year under Condition No. 5 is very slight. The improvement shown in the minimum year under Condition No. 11 is largely due to the added inflow of the sump drain. Because the same quantity was added for the latter in all years, the improvement shown is probably too high by the amount that the flow of the sump drain might have been reduced in a minimum year.

In general, the indication of the data of tables 112 and 113 is that where increased storage in San Luis Valley does not reduce the mean annual outflow at Lobatos it is equivalent to an increase in storage capacity for the Middle Valley in regulating the supply to better conform to the irrigation demands of that valley.

Because of the regulation afforded by the large storage capacity of Elephant Butte Reservoir, releases in accordance with the irrigation demand can be made independently of monthly changes in inflow to the

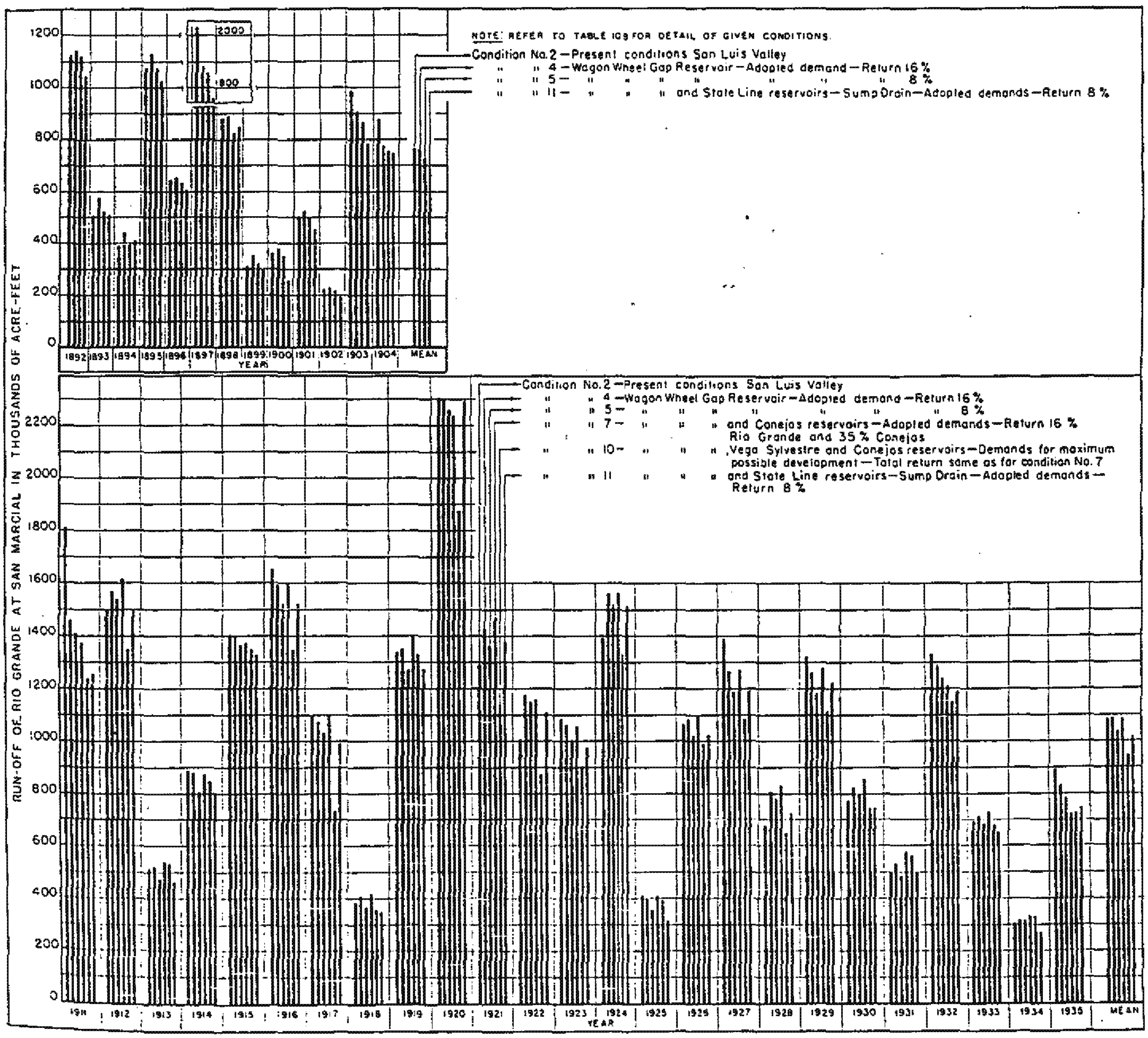

FIGURE 41.—Annual run-off of Rio Grande at San Marcial, N. Mex., under various given conditions of storage and irrigation draft.

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TABLE 112.—*Monthly run-off of Rio Grande near Lobatos for minimum, mean, and maximum years, 1892–1904, under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Month	Condition number[1]			
	2	4	5	11
MAXIMUM YEAR (1897)[2]				
January	16.0	12.7	11.7	12.9
February	13.0	11.0	10.0	12.0
March	41.0	23.1	22.1	24.1
April	38.0	40.8	39.2	42.4
May	139.0	130.4	126.2	130.2
June	97.0	107.6	97.7	103.7
July	25.0	42.6	32.7	38.7
August	3.0	18.8	10.0	15.6
September	14.0	15.1	8.9	12.5
October	134.0	43.9	39.7	42.5
November	56.0	35.2	32.6	35.0
December	41.0	19.8	18.2	19.4
Year	617.0	501.0	449.0	489.0
MINIMUM YEAR (1902)[3]				
January	11.1	12.6	11.6	12.8
February	8.9	10.0	9.0	11.0
March	18.8	17.9	16.9	18.9
April	17.3	15.1	13.5	16.7
May	23.5	30.9	26.7	30.7
June	3.7	9.5	6.4	12.4
July	0.7	0.6	0.1	6.1
August	0.6	1.1	0.3	5.9
September	1.0	5.1	2.8	6.4
October	5.3	6.6	3.4	6.2
November	9.1	10.2	7.6	10.0
December	9.7	8.3	6.7	7.9
Year	109.7	127.9	105.0	145.0
MEAN YEAR				
January	13.7	12.6	11.6	12.8
February	13.4	11.3	10.4	12.4
March	27.2	21.6	20.5	22.5
April	32.3	35.5	33.9	37.1
May	73.8	77.4	73.2	77.2
June	60.2	62.6	53.5	59.5
July	12.9	23.7	17.8	23.8
August	4.0	14.0	8.0	13.6
September	6.6	12.0	7.4	11.0
October	27.8	15.9	11.7	14.5
November	19.1	16.8	14.2	16.6
December	17.5	14.0	12.4	13.6
Year	308.5	320.0	274.6	314.6

[1] Refer to table 108.
[2] Year of maximum flow at Del Norte.
[3] Year of minimum flow at Del Norte.

TABLE 113.—*Monthly run-off of Rio Grande near Lobatos for minimum, mean, and maximum years, 1911 to 1935, under various given conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Month	Condition number[1]							
	1	2	3	4	5	7	10	11
MAXIMUM YEAR (1911)[2]								
January	27.1	18.5	18.1	15.1	14.1	14.4	14.8	15.3
February	24.5	17.1	16.5	13.5	12.5	12.9	13.3	14.5
March	35.9	27.1	25.2	23.2	22.2	21.8	22.1	24.2
April	45.1	24.4	22.5	20.2	18.6	16.2	16.2	21.8
May	220.5	129.0	114.4	102.4	98.2	43.4	37.4	102.2
June	248.3	180.0	117.6	117.6	107.7	119.3	100.3	113.7
July	77.9	145.0	82.3	82.1	72.2	61.6	42.1	78.2
August	19.9	19.6	30.4	30.4	21.6	35.9	35.9	27.2
September	33.4	25.6	25.7	25.7	19.5	26.7	26.7	23.1
October	189.4	335.0	138.5	138.1	133.9	118.9	72.3	136.7
November	52.5	43.6	51.7	51.7	49.1	56.9	30.9	51.5
December	40.7	43.7	38.7	35.7	37.1	41.6	26.6	38.3
Year	1,015.2	1,008.9	681.6	658.7	606.7	569.6	438.6	646.7
MINIMUM YEAR (1934)[3]								
January	24.3	18.0	20.7	18.7	17.7	18.6	17.5	18.9
February	22.0	21.2	19.3	17.5	16.5	18.0	16.8	18.3
March	29.0	27.5	22.7	20.7	19.7	22.1	20.9	21.7
April	44.5	27.7	10.3	10.3	8.7	11.1	11.1	11.9
May	11.2	10.7	11.9	11.9	7.7	17.1	17.1	11.7
June	1.7	0.5	7.9	16.4	6.5	31.3	30.0	12.5
July	0.4	0.7	0.5	16.5	6.6	31.4	23.0	12.6
August	1.7	1.2	1.5	15.3	6.5	24.5	2.7	12.1
September	6.9	1.9	6.7	12.0	5.8	13.5	5.8	9.4
October	11.2	5.0	9.8	9.8	5.6	11.3	9.9	8.4
November	19.7	4.7	15.0	13.4	10.8	15.4	14.3	13.2
December	14.2	11.4	11.3	9.2	7.6	8.4	8.4	8.8
Year	186.8	130.6	137.8	171.7	119.7	222.9	177.5	159.7
MEAN YEAR								
January	23.1	19.0	13.5	17.0	16.0	18.0	15.3	17.2
February	23.3	21.2	19.4	18.2	17.2	18.5	15.8	19.2
March	33.9	28.5	29.0	26.8	25.8	26.9	23.2	27.8
April	41.8	28.9	31.7	31.7	30.1	29.2	21.0	33.2
May	148.0	102.6	115.5	113.5	109.3	94.4	48.7	113.3
June	137.1	113.5	120.4	125.3	115.4	122.8	65.3	121.4
July	31.6	46.6	37.3	38.5	28.6	42.2	38.2	34.6
August	18.2	15.5	24.1	25.4	16.0	34.9	33.0	22.2
September	27.6	18.2	21.2	20.3	14.1	25.6	23.8	17.7
October	43.6	35.2	26.0	25.2	21.0	26.2	21.0	23.8
November	33.9	23.7	25.6	23.6	21.2	26.9	23.3	23.6
December	26.2	25.2	21.2	19.6	18.0	20.9	18.2	19.2
Year	588.1	478.1	489.9	485.3	433.3	486.5	346.8	473.2

[1] Refer to table 108.
[2] Year of maximum flow at Del Norte.
[3] Year of minimum flow at Del Norte.

reservoir as measured at San Marcial. The latter are, therefore, without effect on the water supply of the Elephant Butte-Fort Quitman section except insofar as improved distribution of flow to the Middle Valley may permit of greater diversions in that section with a possible reduction in the total amount of water available to the Elephant Butte-Fort Quitman section.

Water Shortages under Given Conditions

Tables 114, 115, and 116 show the water shortages by years in the San Luis, Middle, and Elephant Butte-Fort Quitman sections under the various Conditions and for the periods 1892–1904 and 1911–1935. Comment is made in the order of Condition numbers. It is to be noted that the period 1904–1911 comprises a series of wet years with run-off well above normal in most cases. For this reason, although the analyses do not cover this period, it is certain that in it no shortages would have occurred under any of the Conditions except No. 1 and possibly No. 9.

Condition No. 1.—Under this Condition shortages in the supply for the area served from Rio Grande in San Luis Valley would have occurred every year in the 25-year period 1911–35. This is due to lack of coordination between river flow and ideal distribution of the diversion demand. It clearly shows that a monthly schedule of diversions conforming to the irrigation demand cannot be practiced without regulation of the stream flow. Lacking the latter, unbalanced early season diversions must continue if advantage is to be taken of the stream flow as it occurs.

Condition No. 2.—Under present development in San Luis Valley shortages would have occurred in the Middle Valley in 6 years of the period 1892–1904 and

TABLE 114.—*Water shortages in San Luis section, Upper Rio Grande Basin, under various conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number [1]					
	1	3	4	6	8	9
1892	--------	--------	0	--------	--------	--------
1893	--------	--------	0	--------	--------	--------
1894	--------	--------	0	--------	--------	--------
1895	--------	--------	0	--------	--------	--------
1896	--------	--------	20.1	--------	--------	--------
1897	--------	--------	0	--------	--------	--------
1898	--------	--------	0	--------	--------	--------
1899	--------	--------	87.1	--------	--------	--------
1900	--------	--------	159.6	--------	--------	--------
1901	--------	--------	190.7	--------	--------	--------
1902	--------	--------	424.6	--------	--------	--------
1903	--------	--------	0	--------	--------	--------
1904	--------	--------	285.9	--------	--------	--------
Maximum year in percent [2]	--------	--------	65	--------	--------	--------
1911	103.2	0	0	0	0	0
1912	170.8	0	0	0	0	0
1913	246.1	0	0	0	0	66.2
1914	104.9	0	0	0	0	18.3
1915	110.7	0	0	0	0	17.4
1916	64.1	0	0	0	0	0
1917	51.4	0	0	0	0	0
1918	208.4	0	0	0	0	0
1919	104.6	0	0	0	0	0
1920	66.8	0	0	0	0	0
1921	32.3	0	0	0	0	0
1922	86.4	0	0	0	0	0
1923	89.2	0	0	0	0	0
1924	140.3	0	0	0	0	0
1925	143.7	0	0	0	0	3.2
1926	117.3	0	0	0	0	0
1927	45.4	0	0	0	0	0
1928	149.1	0	0	0	0	0
1929	63.9	0	0	0	0	0
1930	199.7	0	0	0	0	0
1931	355.4	255.1	0	6.8	0	112.2
1932	38.7	0	0	0	0	0
1933	218.2	19.3	0	0	0	0
1934	424.1	357.3	0	36.3	141.2	151.3
1935	112.7	1.0	0	0	62.3	0
Maximum year in percent [2]	65	55	0	16	19	50

[1] Refer to table 108.
[2] Maximum shortage in percent of diversion demand.

TABLE 115.—*Water shortages in Middle section, Upper Rio Grande Basin, under various conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number [1]					
	2	4	5	7	10	11
1892	0	0	0	--------	--------	0
1893	0	0	0	--------	--------	0
1894	51.2	0	28.1	--------	--------	0
1895	0	0	0	--------	--------	0
1896	64.5	13.9	48.7	--------	--------	0
1897	0	0	0	--------	--------	0
1898	0	0	0	--------	--------	0
1899	16.7	0	12.7	--------	--------	0
1900	106.7	70.7	96.4	--------	--------	0
1901	0	0	0	--------	--------	0
1902	190.9	151.9	173.3	--------	--------	0
1903	0	0	0	--------	--------	0
1904	186.4	162.2	192.5	--------	--------	0
Maximum year in percent [2]	33	28	33	--------	--------	0
1911	0	0	0	0	0	0
1912	0	0	0	0	0	0
1913	0	0	0	0	0	0
1914	0	0	0	0	0	0
1915	0	0	0	0	0	0
1916	0	0	0	0	0	0
1917	0	0	0	0	0	0
1918	0	0	0	0	0	0
1919	0	0	0	0	0	0
1920	0	0	0	0	0	0
1921	0	0	0	0	0	0
1922	0	0	0	0	0	0
1923	0	0	0	0	0	0
1924	0	0	0	0	0	0
1925	0	0	0	0	0	0
1926	0	0	0	0	0	0
1927	0	0	0	0	0	0
1928	0	0	0	0	0	0
1929	0	0	0	0	0	0
1930	0	0	0	0	0	0
1931	25.5	0	15.4	0	0	0
1932	0	0	0	0	0	0
1933	0	0	0	0	0	0
1934	236.6	160.7	225.2	79.9	119.0	0
1935	0	0	0.1	0	0	0
Maximum year in percent [2]	41	28	39	14	20	0

[1] Refer to table 108.
[2] Maximum shortage in percent of diversion demand.

2 years of the period 1911–35. The indicated maximum shortages in the two periods are 191,000 acre-feet, or 33 percent of the diversion demand in 1902, and 237,000 acre-feet, or 41 percent, in 1934. Although these maxima are not excessive for an isolated year, the succession of shortages in the drought years in the early period represents a serious situation which could be, in part, relieved by storage.

In the Elephant Butte-Fort Quitman section shortages would have occurred in 1902, 1903, and 1904 with the maximum of 383,000 acre-feet in 1904, representing 50 percent of the diversion demand. No shortages are indicated in the later period.

Condition No. 3.—Shortages in the Rio Grande area of San Luis Valley, with Vega-Sylvestre Reservoir and present storage, would have been 39 and 55 percent of the diversion demand in 1931 and 1934, respectively. These heavy shortages and the large number of reservoir spills developed in the operation study for the 1911–35 period indicate that Vega-Sylvestre Reservoir would be inadequate to regulate the supply to the adopted diversion demand.

Condition No. 4.—Although under this Condition no shortages in the Rio Grande area of San Luis Valley are indicated in the 1911–35 period, some that are very severe are shown in the early period. There would have been shortages in 6 of the 13 years of this period with a maximum of 425,000 acre-feet, or 65 percent of the diversion demand, in 1902. Following 1904, however, there would have been a period of 33 years (including 1936 and 1937) without a shortage.

In the Middle Valley, shortages would have occurred in 1896, 1900, 1902, 1904, and 1934, with the maximum of 162,000 acre-feet, or 28 percent of the demand, in 1904. These shortages are substantially less than those shown under Condition No. 2, indicating the improvement of Middle Valley conditions that would be brought about by storage in the San Luis section as under Condition No. 4. A shortage free period of 30 years, 1905 to 1933, inclusive, is indicated here.

In the Elephant Butte-Fort Quitman section the maximum shortage in 1904 of 454,000 acre-feet, or 59 percent of the diversion demand, is 71,000 acre-feet more than the shortage in the same year under Condition No. 2. This increase is due to the greater use in the Middle Valley made possible by the more favorable monthly distribution of flow at Lobatos.

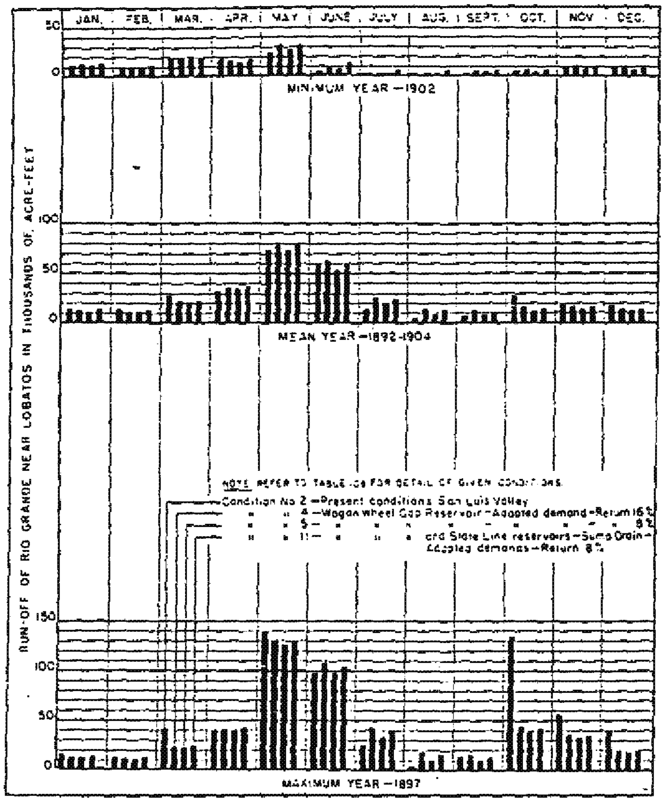

FIGURE 42.—Monthly run-off of Rio Grande near Lobatos, Colo., for minimum, mean, and maximum years, 1892–1904, under various given conditions of storage and irrigation draft.

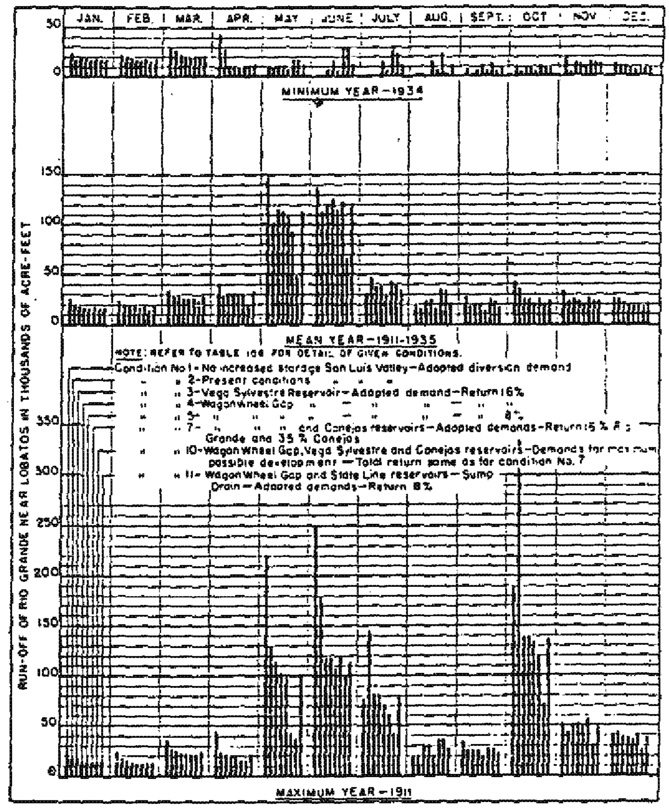

FIGURE 43.—Monthly run-off of Rio Grande near Lobatos, Colo., for minimum, mean, and maximum years, 1911 to 1935, under various given conditions of storage and irrigation draft.

Condition No. 5.—Shortages under this Condition are no different in San Luis Valley than under Condition No. 4. In the Middle Valley shortages are somewhat higher and occur in 3 more years than under Condition No. 4, but except for the shortage of 192,000 acre-feet in 1904, they are still all less than those under Condition No. 2. The shortage of 225,000 acre-feet or 39 percent, in 1934 is the maximum for any year in both periods.

In the Elephant Butte-Fort Quitman section the shortages occur in the same 3 years as under Condition No. 4 but are more severe. The maximum in 1904 of 480,000 acre-feet is 62 percent of the diversion demand. No shortages are indicated in the 1911–35 period, but the operation study showed a minimum content of Elephant Butte Reservoir of 364,000 acre-feet in 1935 as compared to 665,000 under Condition No. 4 (estimated by comparison with data of Condition No. 2) and 700,000 acre-feet under Condition No. 2.

Condition No. 6.—Shortages in the Conejos area under this Condition, in the 1911–35 period, are indicated for 2 years only, 1931 and 1934. The maximum of 36,000 acre-feet is 16 percent of the diversion demand. If the Mogote storage were eliminated, reducing the storage capacity to 132,000 acre-feet it is estimated that the maximum shortage in 1934 would have been about 33,000 acre-feet. Comparison of the data for years of low run-off in table 111 indicates decided improvement in the flow of Conejos River at its mouth due to storage regulation.

Condition No. 7.—Under this Condition, as shown in table 113, improvement in regulation of outflow at Lobatos is greater than under Condition No. 4. There is a shortage in the Middle Valley in the 1911–35 period in one year only, 1934, of 80,000 acre-feet. This is 81,000 acre-feet less than the shortage in the same year under Condition No. 4.

Condition No. 8.—With both Wagon Wheel Gap and Vega-Sylvestre Reservoirs, and greatest possible development in the Rio Grande area of San Luis Valley, this Condition shows a shortage in this area of 141,000 acre-feet, or 19 percent, in 1934, as compared to no shortages in the same period under Condition No. 4. Analysis for the early period was not made, but comparison with shortages in this period under Condition No. 4 indicates probable shortages under Condition No. 8 of from 35 to 70 percent of the diversion demand in 1899, 1900, 1901, 1902, and 1904.

Condition No. 9.—For maximum development in the Conejos area this Condition shows shortages in 6 years in the 1911–35 period as compared to only 2 years under Condition No. 6. The maximum of 151,000 acre-feet, or 50 percent, in 1934 is 115,000 acre-feet greater than the shortage in the same year under Condition No. 6.

Condition No. 10.—This is the Condition of unrestricted and maximum development in San Luis Valley. It shows a shortage in the Middle Valley in the 1911–35 period in 1 year only, 1934, amounting to 119,000 acre-feet, or 20 percent. This is more than the shortage under the comparable Condition No. 7 but less than that under Conditions Nos. 4 and 5, due to a somewhat better distribution of Lobatos flow in the summer and fall months.

No shortages are indicated in the 1911–35 period in the Elephant Butte-Fort Quitman section, but the operation study showed that the content of Elephant Butte Reservoir would have been reduced to 88,000 acre-feet in 1935.

Condition No. 11.—With respect to its effect in San Luis Valley, this Condition is no different than Conditions Nos. 4 and 5. In the Middle Valley, it shows that with the addition of storage in State Line Reservoir and inflow from the sump drain, no shortages occur in any year of the two periods of analysis.

In the Elephant Butte-Fort Quitman section, shortages in the early period in 1902, 1903, and 1904 are greater than under any of the Conditions Nos. 2, 4, and 5 because, with the elimination under Condition No. 11 of the shortages occurring in the Middle Valley under Conditions Nos. 2, 4, and 5, the greater consumption thus permitted in the Middle Valley is directly reflected in a reduction of flow to Elephant Butte Reservoir. The maximum shortage is 538,000 acre-feet, or 70 percent of the diversion demand, in 1904. In this period the operation studies showed that Elephant Butte Reservoir would have been dry from April to October, inclusive, 1902, in September and October 1903, and from April to August, inclusive, 1904. No shortages are indicated in the 1911–35 period. Elephant Butte Reservoir would have been drawn to a content of 205,000 acre-feet in September 1935.

In the operation study under this Condition, draft from State Line Reservoir to satisfy the Middle Valley demand was given priority over draft from El Vado Reservoir because there would be less loss by evaporation from water held in El Vado Reservoir than from water in State Line Reservoir. Under this procedure it turned out that no draft whatever was required on El Vado Reservoir in any year of the two periods. It remained full, therefore, in all years. Had the operation study been made (1) to draw to fullest extent on El Vado Reservoir to meet the Middle Valley demand (2) to complete satisfaction of this demand, if necessary, by drawing on State Line Reservoir, and finally (3) to draw on the latter reservoir to satisfy the Elephant Butte-Fort Quitman section demand to the fullest extent possible, the resulting shortage in the Elephant Butte-Fort Quitman section in 1902 would have been less by approximately the amount of residual storage in

TABLE 116.—*Water shortages in Elephant Butte-Fort Quitman section, Upper Rio Grande Basin, under various conditions of storage and irrigation draft*

[Unit 1,000 acre-feet]

Year	Condition number [1]				
	2	4	5	10	11
1892	0	0	0	----------	0
1893	0	0	0	----------	0
1894	0	0	0	----------	0
1895	0	0	0	----------	0
1896	0	0	0	----------	0
1897	0	0	0	----------	0
1898	0	0	0	----------	0
1899	0	0	0	----------	0
1900	0	0	0	----------	0
1901	0	0	0	----------	0
1902	151.1	133.3	284.1	----------	507.5
1903	5.0	6.2	7.0	----------	17.8
1904	382.6	454.4	490.5	----------	537.6
Maximum year in percent [2]	50	59	62	----------	70
Minimum storage in Elephant Butte Reservoir	[3] 0	[3] 0	[3] 0	----------	[3] 0
1911	0	----------	0	0	0
1912	0	----------	0	0	0
1913	0	----------	0	0	0
1914	0	----------	0	0	0
1915	0	----------	0	0	0
1916	0	----------	0	0	0
1917	0	----------	0	0	0
1918	0	----------	0	0	0
1919	0	----------	0	0	0
1920	0	----------	0	0	0
1921	0	----------	0	0	0
1922	0	----------	0	0	0
1923	0	----------	0	0	0
1924	0	----------	0	0	0
1925	0	----------	0	0	0
1926	0	----------	0	0	0
1927	0	----------	0	0	0
1928	0	----------	0	0	0
1929	0	----------	0	0	0
1930	0	----------	0	0	0
1931	0	----------	0	0	0
1932	0	----------	0	0	0
1933	0	----------	0	0	0
1934	0	----------	0	0	0
1935	0	----------	0	0	0
Maximum year in percent [2]	0	----------	0	0	0
Minimum storage in Elephant Butte Reservoir	700	[4] 665	364	88	205

[1] Refer to table 108.
[2] Maximum shortage in percent of diversion demand.
[3] Reservoir emptied in 3 consecutive years.
[4] Estimated.

El Vado and State Line Reservoirs as found at the end of that year. This was 198,000 and 167,000 acre-feet, respectively, or a total of 365,000 acre-feet, which would have reduced the 1902 shortage from 508,000 to 143,000 acre-feet, although Elephant Butte Reservoir would still have been emptied in that year. No relief would have been afforded for the 1903 and 1904 shortages.

Use of Transmountain Diversions

No analyses were made to show the effect of water brought to the San Luis section by the Animas-Rio Grande, Weminuche Pass, or San Juan-South Fork Rio Grande transmountain diversions prior to increase in storage capacity in Rio Grande drainage above the valley over that of the present. The largest mean annual importation of the three diversions would be 130,000 acre-feet under the Animas-Rio Grande project. The improvement in the regulation of water supply to be effected by this 130,000 acre-feet costing over 10 million dollars is not to be compared to that resulting from Wagon Wheel Gap Reservoir, providing 1,000,000 acre-feet storage at commensurate total cost. With Wagon Wheel Gap Reservoir constructed, the net effect of transmountain diversions which might be made in order to expand development in the valley would be to improve conditions in the lower sections over those under Condition No. 4 by the amount of any spills which might occur in the operation of terminal reservoirs, particularly if there were no increase in storage capacity over that which would be available in the present and Wagon Wheel Gap Reservoirs. In dry years the transmountain diversion supply would be reduced so that if encroachments were not made to further deplete the Lobatos flow, there would doubtless be heavy shortages in the new area brought under irrigation by the imported water.

As indicated by the shortages under the various Conditions, the San Juan-Chama transmountain diversion would be beneficial principally in relieving the shortages of Middle and Elephant Butte-Fort Quitman sections in a critical period such as that of 1899–1904 and in a year such as 1934, although, by the same token that there were shortages in these years, the San Juan supply, and hence the diversion, would probably be correspondingly short. However, for the Elephant Butte-Fort Quitman section, Elephant Butte Reservoir would provide the necessary regulation to overcome these diversion shortages, and for the Middle section, terminal storage could be provided to insure delivery to Rio Grande of the mean diversion yield every year. There would be opportunity for use of the imported water in development of new lands during the period of a generation or more when no shortages are indicated under any of the given conditions, but the new lands would of necessity suffer severe shortages in the minimum years when the transmountain diversion would be used to alleviate the shortages of the present developed areas.

PART I

APPENDIX A—PRECIPITATION, EVAPORATION, AND STREAM FLOW RECORDS

TABLE 117.—*Precipitation in Upper Rio Grande Basin*

[Records of annual precipitation in inches as published by United States Weather Bureau]

SAN LUIS SECTION

	Garfield [1]	Salida [1]	Marshall Pass [1]	Cochetopa [1]	Westcliffe [1]	Hermit Lake [1]	Cathedral [1]	Saguache	Lake City [1]	Ironton [1]	Savage Basin [1]	Eureka [1]	Ames [1]	Silverton [1]	Wagon Wheel Gap River Valley	Wagon Wheel Gap Exp. Station	Hermit (near)
1887								10.69									
1888								4.41									
1889								7.05									
1890					8.61												
1891																	
1892																	
1893																	
1894								5.79									
1895								14.01									
1896					13.27			2.68									
1897					21.36			8.84									
1898		11.34			16.88			8.06							12.26		
1899		9.02			12.81			5.96							12.25		14.53
1900		9.20	12.46		16.31			6.25							7.83		10.49
1901		9.76	13.48		17.59			6.58							9.73		
1902		7.01	18.57		15.24			7.09							10.28		
1903		10.14	15.11		15.85			6.51									
1904		14.36	16.33		15.95			7.26									
1905		12.84			14.98			3.76									
1906		17.74			16.09			12.50	17.61						25.05		
1907		12.92			11.73			11.19	15.06			25.56		27.23	16.56		
1908		10.19			11.71				12.70			28.85		25.50			
1909		15.46			15.42				16.83			32.22		29.30			
1910	17.61	12.30	9.72	9.87	10.11	20.52		7.78	14.36	25.30		22.57		24.24			16.00
1911	26.34	16.45	18.70	13.32	11.71	49.89		11.46	17.05	33.38		28.63		44.78		23.64	25.18
1912	20.65	12.71	23.64	10.06	10.81	43.26		8.31	13.96	28.35		20.20		27.44		15.32	16.27
1913	23.16	15.39	16.04	12.26	14.52	37.81		11.43	15.40	23.68		16.80		26.85		17.99	20.99
1914	26.21	13.49	15.56	14.70	18.16			14.97	17.17	25.41		20.19	29.17	27.11		24.26	19.70
1915	23.78	16.26	14.91	7.53	14.50			11.31		20.21	42.47		24.80	22.05		19.62	18.96
1916	25.21	14.94	19.99	12.40	11.20			7.71		28.79	52.62		35.10	34.84	22.24	20.09	23.66
1917	18.83	6.94			12.13			9.92		18.38	35.61		15.59	16.65	10.32	14.72	15.46
1918	26.31	11.69			16.17		9.73	13.43		21.28	48.78		23.79	21.95	12.37	18.15	21.12
1919	22.59	12.46			22.26		11.73	10.12		21.68	32.56		27.89	26.84	17.04	18.21	22.55
1920	23.86	10.20			13.17			11.63			37.83		27.24	20.73		17.54	23.10
1921	22.52						13.82				29.03		27.73	31.66		15.84	15.41
1922	21.44	10.52					12.75				33.02		23.32	18.42		19.95	15.59
1923	28.80						15.31	15.64			33.09		26.08	28.15		18.65	21.39
1924	17.25							6.48			38.67		22.41	19.87		12.42	11.75
1925	18.17										40.64		23.61	36.34		19.44	14.86
1926	19.97										27.95		28.43	28.71			13.21
1927	27.62										46.50		32.43	34.56			22.46
1928	20.34						11.04	7.66			37.06		20.20	22.80			16.71
1929	27.47						14.06	7.31			37.88		24.39	26.88			16.36
1930	19.25						14.67	8.19			35.30		24.11	18.42			17.21
1931	18.31						11.17	10.52					15.90	22.72			18.35
1932	21.57	10.54					12.24	9.34					21.13	28.39			11.55
1933	21.51	11.05			34.25		11.82	7.47					18.20	21.69			16.57
1934		7.92			14.22			5.15					13.50	19.12			10.73
1935		10.65			28.06			11.70					20.39	22.30			17.88
Mean	22.45	11.91	16.20	11.76	15.80	40.12	12.58	8.87	15.57	24.64	38.18	24.41	23.58	23.95	14.17	18.39	17.43
Estimated mean, 1890–1935	20.0	11.6	16.1	10.5	16.3		12.1	8.9	14.6	21.9	36.7	22.6	24.0	25.0	14.8	15.5	16.9

	Garnett	Del Norte	Cascade [1]	La Veta Pass	Monte Vista	Pagosa Springs (near) [1]	Palisade Lake [1]	Bianca	Cuchara Camps [1]	Platora	La Jara	Pagosa Springs [1]	North Lake [1]	San Luis	Manassa	Stonewall [1]	Cumbres
1887																	
1888																	
1889					5.01												
1890					6.59								16.54				
1891	9.20				9.17					37.67			23.89	18.55			54.70
1892	4.63				8.54								21.82	11.04			25.05
1893	4.46				6.22						7.15		25.90	10.97			
1894	6.33				6.23						6.75		22.28	10.58			
1895	10.37				9.62						9.44		32.55	15.76			
1896	3.61												24.00	12.31			
1897	6.25												31.76	13.53			
1898	4.60												27.31	14.20			
1899	6.96												18.49	10.04			
1900	3.54												23.08	10.16			
1901	4.30												21.31	13.02			
1902	8.18												15.21	7.45			
1903	5.18												19.17	6.98			
1904	9.51												22.70	9.56			
1905	7.08												23.00	10.14			
1906	9.05												19.47	10.55	5.40	20.94	
1907	7.62		42.60									23.02		7.91	7.43	18.62	

[1] Not actually in Rio Grande drainage but adjacent.

TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

SAN LUIS SECTION—Continued

	Garnett	Del Norte	Cascade[1]	La Veta Pass	Monte Vista	Pagosa Springs (near)[1]	Palisade Lake[1]	Blanca	Cuchara Camps[1]	Platoro	La Jara	Pagosa Springs[1]	North Lake[1]	San Luis	Manassa	Stonewall[1]	Cumbres
1908	4.89		34.04									21.67		11.07	5.93	14.50	
1909	9.44		43.55	23.31				9.87	23.63			25.86		12.62	6.36	18.62	
1910	5.11		30.03	15.51				7.20	15.02	22.03		16.14	15.55	9.64	4.91	10.95	26.67
1911	9.08		49.79	24.60				13.27	23.74	40.33		32.10	20.54	17.64	10.09	20.69	46.56
1912	4.80		33.10	17.18					28.51	22.57		19.15	18.49	9.73	5.05	18.97	24.2[illegible]
1913	8.43		30.37	17.46				9.24	27.14	27.46		19.72	24.49	10.10	6.78	19.13	26.10
1914	8.90		40.30	21.56				9.87	25.79	31.23		21.58	28.92	11.03	11.57	25.20	32.45
1915	7.91		32.59	22.91				10.95	27.12	28.91		25.48	20.66	12.00	8.35	19.52	29.2[illegible]
1916	5.80		44.70	29.98				7.07	22.94	39.07		34.84	30.09	10.92	7.28		36.66
1917	5.64		25.33	15.70					18.82	26.22			15.57	6.76	2.64		21.52
1918	8.44		29.73	22.65			35.18		32.98				27.56	11.48	8.19		33.32
1919	7.53		31.52	14.43			40.83		23.26				30.72	9.23	7.43		35.67
1920	6.72	7.58	23.08	17.85			37.23		28.31	30.17				12.21	7.59		27.9[illegible]
1921	8.09	7.67	26.34	28.77			39.26		22.22						6.04		29.43
1922	5.06		27.56	14.59			34.11		25.60					8.56	4.95		29.34
1923	7.66		25.54	26.17			32.96		40.21					10.06	8.74		27.39
1924	4.89	6.66	20.43	14.73			23.45		15.57				12.61		6.83		27.73
1925	6.96	7.53	28.90	16.79			35.50	6.69	21.41				18.74		6.14		28.3[illegible]
1926	6.18		27.23	34.32			30.05	10.12	28.61				22.42		5.10		27.61
1927	8.85	9.06	33.56	33.87			48.45		18.44				21.45		6.48		25.5[illegible]
1928	8.07	7.59	16.07	33.40				4.94	28.49				20.51		6.30		26.64
1929	8.48	12.39	26.60	22.83				10.59	25.37				22.63		6.32		35.37
1930	6.97	6.29	19.53	25.60					22.14				26.65		5.40		36.46
1931	5.95	8.76	27.05	25.06		34.22			20.58				26.73		7.36		40.19
1932	5.42	6.31	23.72	20.71					16.93				19.47		5.17		39.22
1933	6.31	11.13	17.13	16.21					21.46				17.21		6.72		34.88
1934	4.59	4.76	11.39	9.89					18.15				13.22		5.14		21.74
1935	7.21	10.13	21.76	12.02		36.32			23.19				17.97		9.68		40.21
Mean	6.76	8.14	29.26	21.41	7.34	35.27	35.70	9.07	23.91	30.57	7.78	23.96	22.02	11.15	6.81	18.71	32.05
Estimated mean 1890-1935	6.7	8.1	27.4	21.3	7.7		37.7	8.7	23.9	26.7		22.5	22.2	10.4	6.6	20.3	31.[illegible]

MIDDLE SECTION

	Costilla	Dulce[1]	Monero[1]	Chama	San Antone Ranger Station	Sunshine Valley (near)	Cerro	Anchor Mine	Tierra Amarilla	Red River Canyon	Eagle Rock Ranger Station	Aspen Grove Ranch	Tres Piedras	Elizabethtown[1]	Bateman's Ranch	Servilleta (near)	Vallecitos	Therma (near)[1]	Taos Canyon
1889			14.15	14.83									14.60						
1890			18.05	20.61									20.60						
1891			25.11	32.82															
1892			13.39	19.58															
1893			20.63	24.70															
1894			13.62	20.18															
1895			18.01	27.55															
1896			12.54	18.65									13.91						
1897			20.94	33.07									27.13						
1898			13.21										14.51						
1899			15.34																
1900																			
1901																			
1902																			
1903																			
1904																			
1905				16.85									16.09	19.93					
1906		19.34		25.17						19.11			16.58	16.71					
1907		17.89		25.30						24.31			15.16	13.26					
1908		14.88		20.21						20.72			15.23	17.21					
1909		16.40		21.31						20.85		13.31	12.86	20.57	15.17				21.5[illegible]
1910		12.98		17.30		11.39				17.87		21.78	12.05	14.20	15.32				19.57
1911		24.62		30.49		18.16		31.01		24.16		28.81	21.53	27.09	29.26				25.8[illegible]
1912		12.66		18.95		12.88		36.66		22.32		18.43	9.42	15.06	20.06				16.5[illegible]
1913		19.09		23.02		11.86		32.18		25.38		17.55	16.58	18.10	23.69				20.1[illegible]
1914	13.95	21.05		26.01		11.79		43.10		28.12	16.59	25.21	15.64	20.78	21.50				23.64
1915	12.59	18.48		26.50		14.40		37.24		18.88	17.28	19.66	19.63	19.73	21.51				19.2[illegible]
1916	12.50	18.70		32.34		11.10		31.11		21.44	14.42	36.48	17.63	21.06	33.04		25.76		22.2[illegible]
1917	7.59	12.83		15.93	8.59			28.91		17.97	10.91	17.16	12.69	10.70	15.08		11.71		12.2[illegible]
1918		20.52		21.23	14.91	18.42		33.97		23.78	17.00	23.55	18.10	20.14	31.49				22.5[illegible]
1919	14.86	24.99		26.75	20.30	17.07		42.12		27.61	17.72	31.21	20.62	21.85	29.30				25.7[illegible]
1920	13.29	22.88		22.27	13.42	15.08		25.22		22.42	16.39	17.35	16.96	14.21	27.52	13.52	17.05		20.7[illegible]
1921	18.51	18.41		23.80	11.41	20.37				25.82	18.42	24.47	18.60	17.21	24.50	10.12	21.14		24.5[illegible]
1922		12.85		18.76	12.76	16.17				17.79	14.37	20.15	11.58	14.43	17.32	8.80	12.95		13.7[illegible]
1923		23.57		23.76	17.91	20.02				22.67	18.80	30.61	19.25	23.81	31.53	14.71	27.70		15.7[illegible]
1924		18.03		17.65	12.56	13.05				24.60	14.06	21.52	13.93	10.70	21.12	10.18	10.63		15.6[illegible]
1925		20.20		21.91	11.76	10.45				20.99	13.65	21.30	12.01	15.14	23.14	11.56	11.84		19.4[illegible]
1926		19.15		20.05	17.24	12.74				21.12	12.57	26.78	16.94	13.33	22.67	15.63	16.26		15.2[illegible]
1927		24.33		29.49	18.45	12.80				27.55	18.28	30.79	20.80	14.70	29.92	17.35			20.7[illegible]
1928		11.90		11.32	15.33	11.44				18.95	12.61	19.87	10.28	15.09	17.15	10.49			19.4[illegible]
1929		15.67		25.25		12.68				25.73	17.25	26.58	17.77	20.63	24.73				24.5[illegible]
1930		14.19		17.66		12.44				23.09	16.67	21.93	15.28	18.99	19.53				15.5[illegible]
1931		28.61		27.24						24.23		23.55	17.84	18.18	27.84				21.2[illegible]
1932		18.03		18.65			12.18			22.98		23.59	11.63	16.21	23.44			16.62	17.1[illegible]
1933		14.90		17.22			10.41		16.46	16.76		19.56	10.91	12.60	21.34			11.44	15.5[illegible]
1934		12.77		14.65			18.13		12.57	18.33		13.88	11.05	13.26	18.66			13.75	17.5[illegible]
1935		22.59		22.37			15.40		22.92	19.40		25.79	18.57	18.07	23.76			20.81	21.2[illegible]
Mean	13.33	18.42	16.52	22.29	14.55	14.12	14.03	34.15	17.31	22.17	15.71	23.09	15.94	17.20	23.37	12.48	17.23	15.65	19.5[illegible]
Estimated mean 1890-1935	12.7	18.5	16.1	22.3	15.0	14.1		21.2		22.5	10.0	23.5	17.0	17.3	24.4	13.4	18.4		[illegible]

[1] Not actually in Rio Grande Drainage but adjacent.

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TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

MIDDLE SECTION—Continued

	Gavilan (near)	Taos	El Rito	Lindrith [1]	Aurora [1]	Black Lake [1]	Capulin Ranger Station	Haynes [1]	Embudo	Regina	Chacon [1]	Penasco	La Jara Ranger Station	Truchas	Espanola	Cundiyo	Selsor Ranch	Hot Sulphur Springs	Alamos Ranch
1889		11.10							11.19										
1890		13.73							11.59										
1891		14.21							13.47										
1892		9.53							8.15										
1893		10.26							5.34									19.06	
1894		11.81																19.94	
1895		18.60													12.60			21.42	
1896		13.36													8.08			13.66	
1897															10.92				
1898															7.78				
1899															6.25				
1900															10.20				
1901		16.74													11.00				
1902		10.75													7.37				
1903		11.75																	
1904		11.77																	
1905		15.09													11.19				
1906		13.52													10.90				
1907		13.74													15.55				
1908		15.31													10.24				
1909		15.45			19.34	15.49					17.34			10.99	9.99	9.96			
1910		8.94			12.71	10.02					13.22			13.35	6.02	7.24			12.02
1911		18.78			25.17	18.46					26.51			21.97	15.38	15.55			23.99
1912		9.77			18.89	14.27					22.43			14.10	9.05	9.07	12.99		15.52
1913		11.72			27.04	16.62					22.36			15.85	7.66	8.97	23.77		22.39
1914		11.70			26.66	15.84		15.15		18.30	21.54			20.65	11.10	10.87	21.73		17.88
1915		13.46			23.37	16.38		11.75		15.84	17.10			16.32	11.44	10.38	23.11		24.02
1916		14.07			20.05	16.75	16.69	8.96		18.11	25.30			17.21	13.44	6.20	26.91		30.22
1917		8.71			13.93	12.16	12.18	6.78		11.04	15.54			7.39	5.85	4.97	13.13		9.36
1918		15.91			22.36	20.03	18.36	9.08		20.90	25.53			17.67	11.05	9.42	20.46		15.95
1919		17.37			27.22	21.13	20.29			25.63	29.47			20.34	16.02	11.69	31.23		29.17
1920		13.28			21.30	16.15	14.30	9.50		16.91	20.51			18.35	13.23	7.07	22.10		17.81
1921		16.10		16.12	25.07	20.52	23.11	17.43			25.46			16.74	10.86	11.80	23.72		
1922		9.06		4.94	16.51	10.91	10.24	8.39		9.52	14.22			11.46	6.68	4.80	13.67		9.96
1923	17.67	14.28		13.00	24.62	18.98	15.77	16.12		16.43	23.12		19.89	17.24	11.69	9.72	23.15		21.12
1924	13.70	10.60		14.17	15.68	11.49	10.50	11.60		14.22	16.85		12.65	11.49	5.35		19.25		15.17
1925	13.94	11.56		9.09	19.62	17.14	10.59	15.46		15.83	20.38		14.46	16.05	5.59		19.11		17.46
1926		11.72		7.38	19.72	16.00	11.72	13.13		16.01	23.22		17.25	15.08	9.92		21.25		19.40
1927	20.07	12.98		26.69	20.48	19.86	17.11			18.86	10.65		16.01	15.23	5.41		26.22		17.32
1928		9.86		16.66	19.79	13.27	9.13			11.93	16.18		12.72	13.50	7.97		16.59		14.45
1929	18.69	15.55		24.67	20.34	10.20	20.07			20.09	23.41		20.92	24.07	16.00		27.03		20.50
1930	14.96	12.09		15.07	22.23	17.52	14.25			12.54	20.37		16.35	12.22			18.80		16.92
1931	25.77	13.47	12.56		18.27	21.58				21.25	22.03	21.51		17.50			27.42		24.92
1932	13.76	11.07	10.68		19.42	16.36				12.64	10.60	16.38		14.73			24.26		16.63
1933	17.40	10.78	9.84		19.90	15.21				15.29	14.33	16.24		12.05			21.88		18.75
1934	17.16	10.94	12.36		15.70	13.42				14.90	13.15	17.09		11.17			19.93		13.54
1935	22.25	13.39			18.73	17.42				19.25	24.33	18.84		14.95			30.19		19.36
Mean	17.77	12.88	11.36	14.78	20.53	16.38	14.95	11.80	10.55	16.46	20.49	18.01	16.28	15.47	10.05	9.19	22.00	15.58	18.55
Estimated mean 1890–1935	18.1	13.0		15.6	20.6	16.8	15.0	12.2	11.7	16.8	21.0	18.3	16.8	16.1	9.8	9.2	22.2		19.0

MIDDLE SECTION—Continued

	Nambe	Frijoles Canyon	Lee Ranch	Jamez Springs	Winsor's Ranch [1]	Bland	Santa Fe	Santa Fe Canyon	Crownpoint [1]	Woodbury	Fort Wingate [1]	Galisteo	McGaffey Ranger Station [1]	Bernalillo	Bluewater	Diener	Stanley (near) [1]	San Rafael	Albuquerque
1850							9.10												4.92
1851							13.23												5.31
1852							21.72												13.81
1853							21.77												7.10
1854							24.80												12.51
1855							24.18												10.54
1856							23.07												4.15
1857							8.52												5.20
1858							11.35												16.30
1859							9.49												5.95
1860							8.83												3.78
1861							15.81												3.81
1862							11.32												
1863							7.75												12.66
1864							21.80				11.64								5.54
1865							23.15				10.38								10.35
1866							11.52				10.82								7.98
1867							7.70				23.30								6.68
1868							8.92				14.37								
1869							12.08				19.14								
1870							13.93				16.59								
1871							12.15				22.25								
1872							9.87				21.47								
1873							10.23				26.00								
1874							19.93				7.55								
1875							18.97				10.73								
1876							15.07				11.33								
1877							13.15				10.09								
1878							19.55				20.87								7.67

[1] Not actually in Rio Grande drainage but adjacent.

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TX_MSJ_000173

TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

MIDDLE SECTION—Continued

	Nambe	Frijoles Canyon	Los Ranch	James Springs	Winsor's Ranch [1]	Bland	Santa Fe	Santa Fe Canyon	Crownpoint [1]	Woodbury	Fort Wingate [1]	Galisteo	McGaffey Ranger Station [1]	Bernalillo	Bluewater	Diener	Stanley (near) [1]	San Rafael	Albuquerque
1879							11.44				6.37								8.61
1880							9.89				11.06								
1881							22.25				13.93								
1882							11.37				14.32								
1883							14.76				14.44								
1884							19.67				16.45								
1885							14.81				14.05								
1886							15.90				12.44								
1887							13.38				16.14								
1888							12.03				11.40								
1889	8.92						7.89				12.22			5.89					5.40
1890	12.34						12.88				17.87			10.29					8.72
1891	16.60						16.79				14.27			8.90					
1892	8.10						11.62				8.72			6.43					6.94
1893							14.94				9.62								7.42
1894							13.31				14.48	16.71							5.72
1895					22.90		20.24				17.14	14.29		10.64					9.78
1896					22.08		14.28				10.63	12.22		7.89	10.17				7.02
1897					25.49		20.40				18.94	17.55		11.49	12.40				9.74
1898					23.19		12.97				13.89	9.30		5.82	8.07				8.39
1899					19.05		10.05				8.40	11.69		6.89	9.90				7.34
1900					23.70		15.89			9.86	9.40	11.96		5.64	9.08				5.90
1901					26.82		17.41			15.39	9.72	16.09		10.88	9.05				10.19
1902					20.66		13.36			9.72	12.37	7.91			7.05				4.94
1903					19.54		9.79				10.34	8.50							5.83
1904					21.34		14.19				15.96							8.41	6.82
1905					26.32		17.22				21.21							19.26	15.73
1906					25.62		16.60				22.96							12.12	8.36
1907					27.97		15.15				19.17							18.57	9.18
1908					26.36		12.79				15.68				9.43			12.23	7.61
1909					24.05		12.26				15.00				12.66		8.66	21.40	4.42
1910				13.44	19.93		8.65	9.46			9.84				7.24		6.31	8.87	7.41
1911				23.25	31.75		17.12	21.24			18.71		18.71		17.23		23.31	18.01	11.94
1912				14.58	18.15		10.29	15.83					16.01		5.14		11.02	9.20	6.09
1913				17.25	26.42		15.01	19.84					24.39		7.98		12.59	11.15	6.67
1914				21.76	28.50		17.26	18.99	12.85						10.05		13.39	15.94	11.39
1915				21.22	22.85	19.91	17.86	18.50	8.57						8.76		17.14	16.73	9.86
1916				22.96	23.43	21.09	16.41	20.45	11.59				16.55		9.84		16.28		11.54
1917				9.25	17.22	11.34	5.03		5.03				11.15		6.34		7.60		3.29
1918				18.48	24.27	18.32	15.25		5.00				14.75		9.08		12.02		7.63
1919				24.29	37.25	20.55	20.88		16.99				19.75		10.65		17.75		15.03
1920				18.28	22.86	21.47	13.24		8.25				11.41				11.38		6.36
1921				16.82	31.60	17.49	17.80		11.66				24.02			21.86	12.72		10.29
1922				11.77	17.60	12.89	10.29		7.68				14.31			38.22	6.41		4.09
1923				18.85	24.87	18.66	14.23	18.71	15.86				18.73	8.82		26.65	15.65		7.95
1924		12.31	19.60	14.60	21.49		8.92	11.68	14.53				10.46	6.47		21.83	5.29		8.37
1925		14.56	20.69	16.16	26.62		12.64	16.02	11.18				14.03		7.07	20.52	8.34		5.48
1926		17.70	22.55	18.10	28.50		12.97	19.86	9.71				22.06		10.45	22.82	12.65		9.21
1927		15.75	23.09	17.83	23.48		14.17	16.43	17.26				23.28		18.40	23.31			7.67
1928		12.68	14.02	15.70	24.61		13.08	23.04	11.41				14.20		8.95				8.41
1929		19.19	24.51	20.04	22.14		21.62		13.49				20.88		14.04		19.42		12.58
1930	9.00	14.18	19.22	14.87	25.14		13.24		7.28				15.74		7.43		8.35		8.31
1931	14.76	23.68	31.85	28.12	31.14		15.90		15.55				13.93		13.47				[illegible]
1932		14.26	21.33	16.02	24.59		[illegible]		[illegible]				[illegible]		[illegible]		[illegible]		[illegible]
1933		14.51	29.45	19.36	22.74		[illegible]		[illegible]				[illegible]		14.79		12.94		11.39
1934			17.68	17.76	18.07		13.26		7.63				16.66		9.65		5.95		6.98
1935		14.83	27.83	22.80	23.90		12.89		11.60				20.43		14.46		11.84		11.04
Mean	11.62	15.80	22.69	18.16	24.49	19.07	14.43	17.70	11.25	11.66	14.45	12.61	17.80	8.16	10.54	25.03	12.26	14.32	8.21
Estimated mean 1890-1935	12.7	16.2	23.4	18.1	24.5	18.8	[2] 14.3	18.5	11.2		15.1	12.2	18.3	8.5	10.7	25.3	12.6	13.4	8.5

[1] Not actually in Rio Grande drainage but adjacent.
[2] Actual 46-year record.

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TX_MSJ_000174

TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

MIDDLE SECTION—Continued

	San Fidel	Tijeras Canyon Ranger Station	Barton [1]	Laguna	Rio Grande Industrial School	Moriarty (near) [1]	Rea Ranch	Tajique (near) [1]	Estancia (near) [1]	Los Lunas (near)	Mountainair [1]	Bernardo	Datil [1]	Magdalena	Monte Prieto [1]	Socorro	Rosedale (near)	San Marcial
1850				9.69														7.12
1851				15.12														5.44
1852																		7.86
1853																		5.76
1854																		7.89
1855																		12.56
1856																		13.43
1857																		13.43
1858																		4.63
1859																		24.58
1860																		4.83
1861																		10.65
1862																		19.68
1863																		
1864																		
1865																		7.72
1866																		7.47
1867																		8.95
1868																		17.44
1869																		11.30
1870																		9.14
1871																		7.2[illegible]
1872																		8.18
1873																		5.85
1874																		9.08
1875																		13.31
1876																		12.68
1877																		12.45
1878																		6.08
1879																8.94		8.94
1880																14.36		16.86
1881																15.33		15.33
1882																		
1883																		
1884																		10.00
1885																		
1886																		
1887																		
1888																		
1889									15.10	8.31				8.78			9.50	7.28
1890									12.18	7.38				13.43			12.28	7.17
1891									11.12	16.27						13.96	12.78	13.96
[illegible]									8.03	6.11						4.31	9.57	4.31
[illegible]										8.40						8.06	11.19	8.06
[illegible]										4.55						5.07	10.88	3.44
[illegible]										12.30						13.55	15.98	12.08
1896										7.65						10.58	18.93	6.55
1897										7.36						10.61	18.18	10.13
1898										11.57						9.12		10.08
1899										7.05						7.71		6.78
1900										8.05						7.05		4.39
1901										14.77						10.06		1.08
1902										[illegible].71	14.26					[illegible].28		[illegible].33
1903										[illegible].38	[illegible].91							[illegible].57
1904									10.32	10.45	10.90					10.34		4.16
1905				21.27					16.41	13.65	22.82		24.17	21.96		22.40	22.45	21.79
1906				12.05					14.76	11.67	17.06		11.95	12.22		11.60	16.57	9.23
1907				12.07					14.91	15.85	22.86		14.11	15.98		17.85	20.90	16.06
1908				8.35					14.01	5.27	16.57		14.00	14.76		6.29	16.34	6.46
1909				10.60		8.85			9.88	4.25	16.50			12.85		8.11	12.86	6.22
1910		11.35		9.06		8.52	12.55		9.44	4.81	12.56			10.28		7.62	13.56	6.83
1911		17.46		12.90	13.50	19.57	23.87		19.13	11.87	20.49			19.88		16.12	27.59	15.66
1912		11.66		8.47	5.03	14.48	20.49		11.09	5.47	14.72			13.98		8.01	21.53	9.48
1913		16.56		8.68	7.28	13.54	23.22		10.29	7.77	14.27			13.96		8.10	15.16	6.89
1914		18.70	19.63	15.44	10.04	15.07	29.73		15.13	10.21	19.48			23.84		17.81	21.40	8.38
1915		17.94	20.98	13.13	9.67	18.72	39.82		15.23	12.13	16.48			15.81		16.57	21.84	16.37
1916		17.80	21.72		10.28	14.49	39.42		17.35	10.14			16.15	17.10		16.38	17.89	9.93
1917		8.93	6.53		8.23	8.04	16.67		7.73	2.15	10.80		8.67	6.67		4.69	10.15	3.25
1918		17.52	15.34		8.88	8.84	29.32		17.09	9.94	22.19		11.67	11.55		12.22	17.13	5.62
1919		24.05	26.56	14.48	13.50	15.24	27.84		16.33	10.84	16.77		16.19	16.17		16.31	21.04	9.32
1920	11.20	12.09	17.30	13.81	6.16			19.39	13.93	6.27	15.41		16.43	13.39		8.61	15.00	5.61
1921	10.35	13.97	16.53	10.85	8.49			20.47	16.42	9.28	15.18		13.68	7.73		12.53	10.50	10.46
1922	3.15	7.81	8.04		3.66			12.10		3.24			7.33	4.25		4.86	5.37	4.18
1923	15.89	16.14	14.53					22.07	12.65	9.07	19.42		14.41	16.20		8.80	14.56	7.20
1924	4.93	10.50	12.72	5.81				19.67	6.89	5.83			7.48	7.68		5.04	10.20	5.72
1925	8.55	8.47	10.88					18.00	9.94	8.37			9.60	7.99		4.12	9.34	5.79
1926	10.78	15.91						23.67	13.63	8.11	17.23		10.72	9.49		11.24	15.35	10.31
1927	13.06	14.87		8.66				16.39	13.29	9.40			13.17	8.61		6.68	13.05	9.09
1928	11.10	12.34		8.65				18.56	11.05	10.28	12.91		11.24	10.56		6.98	11.29	6.07
1929	12.25	18.25		12.94				28.17	17.77	14.07	17.59		16.39	16.76		12.23	14.37	11.29
1930	7.95	11.01		7.14				15.70	10.77	5.08	16.41		9.20	7.87		6.52	10.98	7.98
1931	14.68			13.26				22.22	18.91	10.44	16.99		18.54	18.20		15.90	16.71	11.30
1932	12.83			10.89				23.19	17.72	10.15	19.09		15.35			10.30	12.70	10.03
1933	11.96	16.27		14.64				20.80	11.56	7.30	15.15		14.66		10.96	12.42		7.89
1934	7.23	12.59		7.43				10.88	8.37	4.34	6.82	5.47	14.01		7.21	6.79		5.50
1935	12.93	21.41						25.54	12.49	6.07	17.19	5.77	13.51	15.51	14.89	12.14		8.36
Mean	10.62	14.73	15.90	11.46	8.31	13.21	26.24	19.49	13.18	8.62	16.25	5.62	13.48	13.12	11.02	10.27	15.00	9.09
Estimated mean 1890-1935	11.0	14.6	15.9	10.7	8.2	12.7	25.8	20.3	12.8	[2] 8.6	15.4		13.0	12.4		10.2	14.5	[2] 8.4

[1] Not actually in Rio Grande drainage but adjacent.
[2] Actual 46-year record.

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TX_MSJ_000175

TABLE 117.—*Precipitation in Upper Rio Grande Basin*—Continued

ELEPHANT BUTTE—FORT QUITMAN SECTION

	Glorietta Ranch	Chloride Ranger Station	Hermosa	Elephant Butte Dam	Graham's Ranch[1]	Hillsboro	Kingston	Garfield	Lake Valley	Hatch	Jornada Exper'l Range	Agricultural College	Cambray[1]	Chamberino	Newman[1]	Lanark[1]	El Paso	Clint	Fort Hancock	Quitman
1850																				
1851												11.08								
1852												12.63								
1853												9.04								
1854								14.60				8.07								
1855								13.44				7.51								
1856								12.51				9.22					21.81			
1857								20.56				10.40								
1858								10.58				5.11					5.00			
1859												5.52					4.83			8.31
1860												3.61								4.22
1861												10.48								
1862																				
1863																				
1864				22.66																
1865				7.30								7.30								
1866												7.79								
1867												9.89					2.84			
1868				8.55								9.71								
1869				10.67								12.60								
1870				11.08								12.50								
1871				7.30								6.92					7.61			
1872				12.28								8.33					7.68			
1873				8.97								3.49					5.77			
1874				13.35								6.13					7.24			
1875				8.67								5.69					6.48			
1876												8.85					9.46			
1877												11.07								
1878												8.07								
1879												7.30					6.80			
1880												7.10					15.37			
1881												15.05					18.17			
1882												9.23					8.27			
1883																	12.92			
1884																	18.29			
1885																	7.31			
1886												11.05					8.06			
1887												7.42					6.76			
1888												11.09					9.79			
1889						13.15						7.07					7.10		7.17	
1890						13.96						6.93					8.49		4.89	
1891						8.35											2.22		3.33	
1892						7.85						6.51					5.32		6.96	
1893						15.89						10.82					10.88		14.96	
1894								4.95				4.47					4.24		7.18	
1895				9.11		12.23		11.87				9.47					10.20		12.40	
1896				10.84		12.21		7.94				7.99					9.79			
1897				16.89		17.13		11.74				8.96					12.41			
1898				14.38		10.54		11.13				11.21					6.16			
1899				7.72		4.60		5.45				9.67	4.97			6.50	7.80			
1900				6.03		6.43		6.02				8.40	6.94			7.44	7.95			
1901				8.49		9.19						11.96	7.71			16.36	8.68			
1902				6.19								10.90	6.64			5.08	10.15			
1903				3.76								10.29	3.02			14.06	11.33			
1904				12.18		13.20						[illegible]	[illegible]			[illegible]	[illegible]			
1905		20.55		16.96		23.77		13.51	25.09			17.09	[illegible]			14.13	17.30			
1906		14.98		8.72		19.10		12.27	16.19			8.80	11.44			5.59	14.99			
1907		18.02		9.78		13.27		9.86	12.12			6.42	10.51			5.83	8.41			
1908		12.40		8.13		12.08		8.86	10.73			5.97	6.42			5.90	6.94			
1909				6.68		7.12		5.43	7.93			4.94	9.00		5.37	4.82	4.33			
1910	11.34			5.79		5.40		4.81	6.31			4.02	8.38		4.73	5.10	4.02			
1911	19.55			13.51		15.89		11.21	17.83			5.80	11.28		10.45	10.70	10.88			
1912	13.40			10.95				14.91	14.67			9.20	13.15		16.43	11.79	10.14			
1913	9.48		20.36	12.27				9.81	17.06			11.73	8.58		8.64	6.58	7.09			
1914	12.61		20.07	15.12				11.50	22.36		11.78	11.85	13.11		19.65	7.19	17.02			
1915	14.22		18.57	13.87			16.20	10.79	11.63		7.66	7.37	8.74		9.82	4.20	10.26			
1916	16.58		21.06	13.73			25.30	13.27	14.73		8.88	7.78	8.89		10.15	6.72	7.77			
1917	9.53		9.32	3.53			11.88	3.58	5.01		3.54	5.58	5.74		4.88	4.46	6.49			
1918	11.75		17.88	10.76			18.69	10.16	15.31		8.76	7.23	11.28		5.60	10.52	8.21			
1919	12.96		18.65	11.64			20.59		10.95		12.78	8.05	9.01		12.04	12.82	9.87	11.46		
1920	11.32		19.53	7.83			15.99	10.53	13.94		12.02	8.18	8.00		7.86	9.85	6.21	6.64		
1921	10.53	14.52	16.96	9.00			13.47	9.23	11.29		5.72	7.64	6.18		8.25	7.08	6.92	5.95		
1922	7.08	8.39	8.58	3.77			11.76	6.89	7.09		6.69	5.58	4.82		5.50	3.01	4.30	3.68		
1923	14.54	18.83	24.86	12.50			22.48	11.89	17.49		9.48	10.36	12.17	7.21	6.88	8.34	8.13	8.59		
1924	8.12	8.62	11.16	4.77		5.74	13.14	15.19	6.23		5.97	4.83	5.58	6.27	5.06		7.28	5.31		
1925	8.56	15.39	22.95	5.99		14.99	20.91	8.06			6.93	7.80	8.82	7.28	8.28		6.51	6.69		
1926	14.93	19.33	21.29	14.00		16.43	18.91				17.73	14.35	16.02	12.68	11.20		11.73	13.34		
1927	9.87	12.22	15.60	6.87		16.83	14.12	7.77	11.28		7.69	9.47	9.50	5.54	4.72		6.25	5.33		
1928	8.60	19.33		10.96		14.86	19.26		14.62		9.78	9.37	7.16	4.28	10.16		8.21	9.39		
1929		18.82		11.18		13.07	19.04		16.64		11.04	9.22	9.72	8.15	10.50		9.29	8.47		
1930		13.26		8.82		6.72	15.86		11.44		5.73	6.88	5.30	5.86	8.37		6.09	5.83		
1931		17.09		11.42	11.74	18.61	24.52		17.35	16.13	12.24	13.26	12.31	11.42	14.18		10.79	14.41		
1932		16.68		11.00	9.73	13.60	22.37		15.49	7.48	12.75	8.83	12.89		8.51		10.94	10.80		
1933		13.37		8.08	12.93	12.12	18.36		15.08	8.57	8.59	4.71					8.93	6.10		
1934		11.89		5.74	6.69		17.38		12.58	4.03	5.18	4.62					2.73	2.31		
1935		12.64		9.75	10.67	11.12	20.54		14.82	8.20	10.98	12.67					5.66			
Mean	11.88	15.07	17.79	9.99	10.35	12.43	18.14	10.37	13.56	8.87	9.18	8.89	8.94	7.63	9.05	8.20	8.74	7.83	8.11	6.26
Estimated mean 1890–1935	12.1	14.3	17.8	9.7	10.9	12.1	18.9	9.6	13.7	9.1	9.3	8.6	8.6	7.3	9.3	8.0	[2]8.4	8.8	9.2	

[1] Not actually in Rio Grande drainage but adjacent.
[2] Actual 46-year record.

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TABLE 118.—*Evaporation at Wagon Wheel Gap, Colo.*

Standard Weather Bureau class A evaporation pans. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December
STATION A-1, ELEVATION 9,601, NORTHERN EXPOSURE												
1919								3.11	1.66			
1920						3.73	3.52	2.60	[1] 1.54	[2] 0.36		
1921						3.81	3.19	1.83	1.98	[3] .53		
1922					[4] 0.96	4.20	4.16	2.41	2.00	[3] .48		
1923					[5] .43	5.16	3.49	2.15	[6] 1.51			
1924						5.20	3.75	3.07	2.27			
STATION A-2, ELEVATION 9,600, SOUTHERN EXPOSURE												
1919								5.31	4.13	[3] 2.71		
1920						4.59	4.87	4.65	3.98	[7] 1.90		
1921						5.18	4.80	3.88	5.12	[8] 2.91		
1922					[4] 1.34	5.41	5.84	4.56	4.58	[9] 3.95		
1923					[5] .52	6.68	6.26	4.57	3.68	[10] 2.23		
1924						7.30	6.16	6.00	5.14	[11] 1.58		

[1] 27 days.
[2] 1st to 10th, inclusive.
[3] 1st to 20th, inclusive.
[4] 25th to 31st.
[5] 28th to 31st.
[6] 1st to 28th.
[7] 1st to 19th.
[8] 1st to 27th.
[9] 20 days.
[10] 1st to 25th, inclusive.
[11] 1st to 11th, inclusive.

Records from U. S. Forest Service. Stations maintained in connection with the Wagon Wheel Gap Experiment Station on the Rio Grande above San Luis Valley.

TABLE 119.—*Evaporation at Garnett, San Luis Valley, Colo.*

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December
1927						8.84	8.02	6.18	5.00	3.74		
1928				5.76	7.68	10.68	9.24	7.80	6.00	[1] 4.44		
1930				[2] 1.72	9.22	9.43	7.93	6.84	5.94	4.36		
1931				[3] 4.69	8.47	10.46	9.42	7.87	5.93	4.74	[4] 1.27	

[1] 1st to 26th, inclusive.
[2] 8 days.
[3] 15th to 30th, inclusive.
[4] 1st to 15th.

Records from Colorado State Engineer.

TABLE 120.—*Evaporation near Therma, N. Mex.* [1]

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1930		1.60	1.47		7.31	8.59	6.22	4.65	5.57	4.33	[2] 2.29	0.60	
1931				[illegible]	[illegible]	[illegible]	[illegible]	6.43	[illegible]	[illegible]			
1932	1.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70.36
1933													
1934				5.93	7.02	12.20		7.00		5.85			
1935				5.63	6.80	9.41	8.28	6.80	5.30	4.83			

[1] Station on west shore Eagle's Nest Reservoir in Taos County.
[2] Partially estimated.

Records previous to 1934 from New Mexico State Engineer.
Records from April 1934 to October 1935 from U. S. Weather Bureau.

TABLE 121.—*Evaporation at Santa Fe, N. Mex.*

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1913					8.36	6.65	7.23	6.37	5.54	5.15	3.29	2.66	
1914	1.96	2.20	3.85	5.65	5.95	10.19	8.24	5.97	6.28	4.41	4.43		
1915													
1916													
1917	3.14	2.88	5.38	7.22	7.64	11.89	9.95	9.04	6.79	5.94	3.36	2.39	75.82
1918	1.08	2.80	3.81	6.13	9.78	10.24	9.29	8.17	6.68	4.30	1.96	1.47	65.21
1919	1.59	1.02	2.70	5.60	8.29	9.38	6.81	7.47	5.43	3.84	2.80	1.57	56.40
1920	1.89	2.10	3.91	5.86	8.52	9.04	8.61	7.50	6.53	4.64	2.01	1.71	61.72
1921	1.38	2.32	4.53	6.44	8.88	8.68	8.13	6.64	6.91	4.93	3.26	1.48	63.58
1922	1.42	2.16	3.60	8.77	10.18	10.45	10.26	8.92	7.12	5.18	1.80	1.25	68.18
1923	1.81	.96	3.44	6.28	8.58	10.60	8.75	6.71	4.77	3.82	1.97	1.06	58.75
1924	.92	2.34	2.96	5.64	8.35	11.99	8.81	9.28	7.76	6.16	3.30	1.20	68.60
1925	1.54	2.28	5.08	8.22	9.01	10.29	9.53	7.47	6.75	4.47	2.03	.77	67.44
1926	.83	3.01	3.94	4.76	5.92	8.78	9.18	9.44	6.71	4.83	2.93	1.02	61.35
1927	1.72	2.10	4.03	6.70	12.24	9.31	9.31	8.09	5.40	5.29	2.87	1.08	68.20
1928	1.45	1.93	4.31	6.02	6.84	11.21	10.01	7.55	7.51	4.58	1.59	1.66	64.66
1929	1.26	1.86	3.73	7.06	9.67	11.85	8.41	6.86	6.62	4.51	1.89	1.41	65.21
1930	1.40	2.71	3.60	7.28	8.59	10.74	8.19	7.22	6.86	4.28	1.98	1.20	64.00
1931	1.28	2.46	3.73	5.80	8.63	10.73	8.99	7.43	5.53	4.51	2.17	1.82	62.73
1932	1.83	2.56	3.44	7.06	8.81	10.00	9.15	5.59	4.69	2.44	[1] 2.08	[1] 1.13	58.78
1933	[1] 1.35	[1] 2.36	4.36	[1] 6.47	7.66	8.36	8.89	7.65	6.39	3.91	[1] 2.08	[1] 1.13	60.61
17-year mean	1.50	2.19	3.93	6.33	8.68	10.21	8.96	7.71	6.38	4.56	2.36	1.38	64.19
Percent of mean annual	2.34	3.41	6.12	9.86	13.52	15.91	13.96	12.01	9.94	7.10	3.68	2.15	100.00

[1] Estimate as published in Water Bulletin No. 3 of International Boundary Commission.

Records previous to January 1917 from reports of New Mexico State Engineer.
Records from January 1917 to October 1933 from U. S. Weather Bureau except as noted.

25.54 37.34 66.75 107.60 147.59 173.54 152.27 131.03 108.51 77.62 40.09 23.36

TABLE 122.—*Evaporation at Los Griegos station, near Albuquerque, N. Mex.*

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1926									7.02	5.00	4.03	1.27	
1927	1.45	3.22	6.22	8.36	13.24	10.20	11.24	9.12	8.70	5.54	3.28	1.45	80.12
1928	2.02	2.90	6.17	8.62	8.10	12.73	11.01	8.38	7.33			.78	
1929													
1930	1.76	4.28	5.29	7.87	11.47	9.53	10.55	9.33	8.00	5.53	2.91	1.44	77.96
1931	1.32	1.73	5.90	7.61	10.14	11.78	11.34	8.29	6.69	5.70	4.61	2.09	77.40
1932	1.63	2.48	5.40										

Records previous to December 1927 from report of chief engineer, Middle Rio Grande Conservancy District, 1928
Records from December 1927 to December 1928 from U. S. Weather Bureau.
Records from January 1930 to March 1932 from reports of New Mexico State Engineer.

TABLE 123.—*Evaporation at Elephant Butte Dam, N. Mex.*

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1916					16.79	16.87	11.83	9.55	9.11	7.24	4.90	3.34	
1917	2.14	4.13	9.64	12.93	13.50	15.29	13.25	11.81	9.00	8.91	5.12	3.96	109.68
1918	3.18	5.64	8.21	11.32	15.71	14.25	13.54	11.60	10.17	6.72	3.69	[1] 1.71	105.74
1919	[2] 1.40	[1] 4.85	7.20	9.19	12.66	12.08	11.14	11.13	7.88	7.82	3.98	2.73	92.66
1920	1.92	3.91	8.37	10.47	14.16	12.47	13.50	10.66	9.96	8.61	3.66	3.47	101.16
1921	3.56	4.88	8.16	10.98	14.26	13.07	10.24	9.87	9.74	9.41	5.34	3.68	103.19
1922	3.67	5.64	8.06	11.19	14.34	14.09	13.85	12.19	8.97	7.63	3.80	2.75	108.05
1923	3.85	3.31	6.76	11.10	14.49	17.06	12.33	9.10	7.83	7.44	2.76	3.83	99.80
1924	2.55	3.85	7.64	8.76	11.57	14.97	10.74	11.40	10.57	8.65	5.04	2.78	98.52
1925	2.44	4.66	8.24	11.08	11.74	15.38	11.96	10.80	9.29	6.81	4.15	2.51	99.06
1926	1.73	4.90	5.30	6.99	9.83	13.16	12.02	11.01	7.27	5.93	4.16	1.96	84.25
1927	3.09	4.76	7.85	10.22	14.83	13.42	12.38	8.98	7.61	6.61	4.74	2.42	96.91
1928	2.80	2.80	7.71	9.10	9.81	14.48	12.10	9.02	8.32	5.67	2.75	2.18	87.64
1929	3.45	4.19	7.31	11.13	12.01	14.20	9.93	7.98	7.45	4.54	2.51	2.31	87.01
1930	2.52	4.37	6.23	9.75	11.71	12.01	9.56	9.10	8.09	6.37	3.05	1.78	84.54
1931	1.72	2.25	6.75	6.71	10.34	11.56	10.42	8.33	6.54	5.90	3.48	1.98	75.98
1932	2.24	4.68	6.20	9.61	11.20	11.86	9.72	8.99	7.87	4.72	3.64	2.23	82.96
1933	2.34	3.18	7.22	8.29	11.77	9.93	13.10	11.17	9.89	6.65	4.51	3.84	91.89
1934	3.29	5.23	8.57	11.27	14.78	17.48	16.69	14.08	11.30	8.29	4.94	2.70	[illegible]8.02
1935	3.22	4.17	9.20	12.30	12.58	16.80	15.97	10.85	8.05	8.50	4.86	2.40	[illegible]90
19-year mean	2.69	4.28	7.61	10.13	12.70	13.90	12.23	10.46	8.73	7.13	4.00	2.76	[illegible].50
Percent of mean annual	2.79	4.43	7.88	10.49	13.15	14.40	12.67	10.83	9.04	7.38	4.14	2.80	100.00

[1] Estimated from record for partial month.
[2] From U. S. Bureau of Reclamation.

Records from U. S. Weather Bureau except as noted.
NOTE.—Evaporation from 1926 to July 1933 is stated to have been influenced by the shade of trees growing near the evaporation pan. Station was relocated on July 7, 1933

TABLE 124.—*Evaporation at Jornada experimental range, New Mexico* [1]

[Floating evaporation pan 36 inches square and 18 inches deep. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1929						14.70	11.28	8.53	7.83	8.88	2.97	2.93	
1930	3.31	4.98	7.05	9.55	13.22	13.22	11.04	9.21	9.18	7.13	4.11	1.93	93.9[illegible]
1931	2.04	2.67	7.81	8.19	11.44	12.79	11.03	9.54	9.52	7.52	4.23	2.14	88.92
1932		4.28									3.91	2.33	
1933	2.48	3.67	8.71	9.98	12.36	11.35							
1934													
1935	3.16	3.91	7.97	11.09	11.47	13.41	13.94	9.70	7.18	7.00	3.86	1.89	94.5[illegible]

[1] Meteorological station of U. S. Forest Service 18 miles northeast of Las Cruces.

Records previous to January 1932 from reports of New Mexico State Engineer.
Records from January 1932 to December 1935 from U. S. Weather Bureau.

TABLE 125.—*Evaporation at agricultural college, near Las Cruces, N. Mex.*

[Standard Weather Bureau class A evaporation pan. Unit, inches]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1918									[1] 5.91	6.86	3.62	2.18	
1919	2.65	4.19	7.75	9.91	12.25	13.50	12.89	11.48	7.47	5.53	3.90	2.66	94.1[illegible]
1920	2.22	4.05	7.46	10.40	11.90	11.62	12.90	9.88	8.94	6.10	3.01	3.13	91.7[illegible]
1921	3.80	4.58	8.58	10.23	11.64	12.35	10.54	9.60	7.84	6.35	4.38	3.23	93.1[illegible]
1922	3.30	5.84	8.24	10.11	12.69	13.62	12.24	11.02	8.08	5.72	3.45	2.72	[illegible].03
1923	3.37	2.93	8.88	9.55	12.36	11.28	11.30	8.96	7.09	6.18	3.00	1.83	[illegible]74
1924	2.94	4.39	7.09	8.15	10.10	13.09	9.06	8.72	8.92	7.08	4.18	2.44	[illegible]1[illegible]
1925	2.73	5.34	8.06	9.39	8.69	10.24	9.14	8.35	6.80	4.99	2.50	2.89	[illegible]6[illegible]
1926	1.91	4.65	5.15	7.29	9.04	10.56	10.13	9.30	7.24	4.59	3.63	2.09	75.5[illegible]

[1] 17 days.

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TABLE 125.—*Evaporation at agricultural college, near Las Cruces, N. Mex.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1927	3.22	4.42	7.25	9.28	11.64	10.28	10.29	7.89	6.84	5.80	4.38	2.17	83.46
1928	3.03	4.15	8.16	9.66	9.52	11.78	10.82	7.80	6.92	5.22	2.67	2.78	81.93
1929	3.20	4.31	7.11	8.88	10.41	11.60	9.12	7.75	7.05	5.01	2.59	2.55	79.58
1930	2.75	4.74	6.43	8.54	10.86	11.89	9.90	9.05	7.76	5.93	3.74	2.17	83.76
1931	2.59	2.99	7.15	7.73	13.84	11.92	10.25	8.49	7.48	6.88	3.56	2.84	80.72
1932	2.99	4.00	7.63	11.20	13.36	14.22	13.40	12.26	9.42	5.66	4.16	2.50	100.82
1933	2.75	4.16	9.41	10.28	14.15	12.28	13.54	11.08	9.79	6.20	4.14	3.54	101.32
1934	3.22	4.99	7.76	11.12	12.93	14.54	14.94	13.10	10.48	7.21	4.68	2.82	107.79
1935	3.45	3.93	8.41	11.61	11.66	15.13	15.37	12.02	7.43	7.18	4.41	2.62	103.22
17-year mean	2.95	4.33	7.56	9.57	11.89	12.29	11.58	9.87	7.97	5.98	3.73	2.62	90.34
Percent of mean annual	3.27	4.79	8.37	10.59	13.16	13.60	12.82	10.93	8.82	6.62	4.13	2.90	100.00

Records from U. S. Weather Bureau.

TABLE 126.—*Run-off of Rio Grande at Thirty-Mile Bridge, Colo.*

[Drainage area 163 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1909						(1)	27.3	15.2	27.8				
1910						(1)	10.6	6.2	4.0	3.8	2.5		
1911				(1)	39.8	78.6	44.1	11.4	7.6	(1)			
1912				(1)	47.0	79.7	34.6	15.0	5.8	4.8	.5		
1913			0.2	3.9	31.5	26.1	32.7	16.9	7.7				
1914				.3	25.8	69.6	47.7	21.2	6.0	5.8	4.1		
1915	0.9	0.8	.9	.9	13.0	61.3	50.0	24.3	3.1	13.2	2.7	1.2	172.3
1916	3.2	2.8	5.4	7.9	29.8	24.2	40.8	24.8	5.6	36.1	16.7		
1917	1.0	.3	.3	.4	9.4	109.0	56.0	21.2	9.6	9.1	5.1	.4	221.8
1918	.5	.4	.5	5.7	31.7	39.9	14.3	11.1	3.0	4.0	(1)		
1919	.2	.3	.3	2.9	38.4	34.0	31.5	30.8	7.7	5.7	.6	.2	152.6
1920	.2	.2	.2	.6	30.5	79.1	51.8	19.8	7.3	6.8	1.6	.5	198.0
1921	.5	.4	.5	7.9	22.4	102.0	46.9	25.3	7.8	14.8	3.0	[2].5	232.0
1922					29.0	60.7	46.4	24.4	7.7	6.0	[2].9	[2].6	
1923	[2].6	[2].6	[2].6	6.5	31.6	25.6	43.5	26.2	3.7				
1924													
1925					(1)	45.9	38.5	19.0	13.1				
1926					(1)	66.6	39.3	29.9	7.3	.3	1.8	[2].6	
1927	[2].6	[2].6	[2].6	5.6	21.6	67.2	40.5	24.2	16.5	21.8	[3]1.7	[3]1.7	212.6
	[3]1.7	[3]1.6	[3]1.7	18.0	80.3	54.9	36.1	14.6	6.3	3.8	2.6	[3]2.1	173.7
	[3]2.1	[3]1.9	[3]2.1	6.9	16.0	52.6	44.5	24.7	17.1	20.8	3.7	[2].5	192.9
	[2].5	[2].4	[2].5	9.3	35.6	48.2	19.6	19.0	4.8	6.2	[2].2	[2].2	144.5
	[2].2	[2].2	[2].2	4.4	17.3	30.9	8.8	4.4	4.4	5.1	.9	[2].2	77.0
1932	[2].2	[2].2	[2].2	11.8	13.6	49.2	41.6	32.9	7.4	8.0	[2].2	[2].2	165.5
1933	[2].2	[2].2	[2].2	7.1	22.9	44.5	30.9	9.8	4.8	4.8	[3]1.5	[2].2	127.1
1934	[2].2	[2].2	[3]1.1	18.6	31.9	8.3	3.3	4.0	7.5	2.8	1.3	[2].1	79.3
1935	[2].1	[2].1	1.4	8.5	13.8	26.4	36.1	29.0	5.5	3.1	[2].4	[2].4	124.8

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey; previous to October 1913 from Water Supply Paper No. 358.
Records from October 1913 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 127.—*Run-off of Rio Grande at Wason, Colo.*

[Drainage area 700 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890 [1]	7.0	5.0	13.0	30.0	148.0	152.0	66.0	30.0	17.0	19.0	13.0	10.0	512.0	113.6
1891 [1]	9.0	7.0	14.0	47.0	116.0	165.0	74.0	32.0	22.0	34.0	14.0	11.0	545.0	120.9
1892 [1]	9.0	7.0	10.0	34.0	95.0	82.0	30.0	23.0	12.0	11.0	9.0	6.0	329.0	73.0
1893 [1]	4.0	4.0	7.0	17.0	74.0	65.0	15.0	18.0	13.0	11.0	9.0	6.0	243.0	53.9
1894 [1]	5.0	4.0	9.0	30.0	88.0	36.0	14.0	20.0	16.0	15.0	10.0	7.0	254.0	56.4
1895 [1]	6.0	5.0	14.0	67.0	85.0	89.0	44.0	35.0	19.0	17.0	13.0	10.0	404.0	89.7
1896 [1]	9.0	8.0	17.0	51.0	90.0	27.0	16.0	15.0	21.0	19.0	11.0	7.0	290.0	64.4
1897 [1]	7.0	6.0	15.0	35.0	124.0	183.0	48.0	24.0	26.0	59.0	25.0	14.0	515.0	114.2
1898 [1]	12.0	9.0	15.0	64.0	98.0	175.0	71.0	28.0	15.0	11.0	8.0	6.0	510.0	113.2
1899 [1]	5.0	4.0	19.0	19.0	56.0	36.0	29.0	30.0	16.0	19.0	15.0	7.0	255.0	56.6
1900 [1]	4.0	5.0	7.0	13.0	101.0	104.0	23.0	14.0	12.0	14.0	9.0	6.0	312.0	69.2
1901 [1]	6.0	4.0	6.0	23.0	94.0	72.0	24.0	24.0	19.0	11.0	10.0	6.0	299.0	66.4
1902 [1]	4.0	3.0	7.0	20.0	49.0	17.0	4.0	11.0	10.0	10.0	8.0	5.0	148.0	32.8
1903	[3]8.0	[3]7.0	[3]1.0	[1]24.0	[1]102.0	[1]208.0	[1]72.0	[1]26.0	[1]22.0	[1]15.0	[3]6.0	[3]6.0	497.0	110.3
1904	[3]1.0	[3]3.0	[3]2.0	[1]21.0	[1]48.0	[1]22.0	[1]11.0	[1]33.0	[1]29.0	[1]58.0	[3]9.0	[3]6.0	243.0	53.9
1905	[3]8.0	[3]4.0	[3]14.0	[1]25.0	[1]130.0	[1]246.0	[1]47.0	[1]29.0	[1]17.0	[1]18.0	[1]11.0	[1]7.0	546.0	121.2
1906 [1]	5.0	4.0	10.0	36.0	133.0	199.0	83.0	37.0	30.0	36.0	20.0	10.0	603.0	133.6
1907	[3]13.0	[3]11.0	[3]12.0	[3]46.0	102.0	226.0	213.0	62.7	37.4	20.7	14.0	[3]7.0	764.8	169.7
1908	[3]6.0	[3]5.0	11.0	38.7	73.2	137.0	55.6	48.9	18.6	13.9	9.7	[3]4.0	411.6	91.3
1909	[3]6.0	[3]5.0	[3]8.0	30.1	184.0	219.0	70.1	38.7	76.2	26.7	16.8	[1]14.0	644.6	143.0
1910	11.1	8.3	29.7	53.6	143.0	107.0	26.8	19.9	14.2	14.2	11.8	9.4	449.0	99.6
	9.2	5.1	9.5	29.0	110.0	182.0	114.0	47.6	28.2	79.9	24.6	14.3	656.4	145.7

Footnotes at end of table.

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TABLE 127—*Run-off of Rio Grande at Wason, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	An[illegible] in [illegible] of
1912	11.1	9.4	10.1	20.2	151.0	195.0	84.5	42.1	18.5	17.8	9.1	[1] 6.0	574.8	127.6
1913	[2] 5.0	[2] 5.0	[2] 9.0	19.5	76.9	72.5	50.3	34.7	19.8	[1] 23.0	[1] 14.0	[1] 11.0	349.7	77.6
1914	[2] 9.0	[2] 8.0	[2] 8.0	18.0	105.0	182.0	96.0	51.9	37.2	40.0	14.1	6.3	575.5	127.7
1915	5.7	5.7	7.0	16.9	80.8	143.0	91.6	53.7	32.7	28.6	11.5	6.5	461.7	102.5
1916	9.2	9.3	17.5	38.1	96.4	110.0	86.7	69.5	23.1	74.4	35.5	[2] 10.0	571.7	126.9
1917	[2] 9.0	[2] 8.0	[2] 16.0	17.0	62.7	237.0	122.0	52.4	25.9	18.9	11.2	5.7	585.8	130.0
1918	5.8	5.0	8.4	15.8	70.7	88.7	41.0	41.1	23.4	13.9	9.0	[1] 6.0	328.8	73.0
1919	5.8	6.1	6.7	30.3	129.0	105.0	83.0	62.7	23.7	15.0	8.5	7.3	483.1	107.2
1920	[1] 8.0	[1] 8.0	7.1	13.7	147.0	221.0	112.0	52.5	21.5	18.9	13.1	9.8	632.6	140.4
1921	8.8	7.9	12.4	29.1	116.0	273.0	121.0	72.6	23.3	32.2	15.3	9.2	730.8	162.2
1922	[1] 9.0	[1] 8.0	[1] 9.0	[1] 21.0	149.0	167.0	80.6	60.0	25.3	14.8	8.3	6.8	558.8	124.0
1923	7.1	5.8	9.2	22.6	105.0	120.0	82.4	64.6	31.4	23.7	18.3	15.9	506.0	112.3
1924	11.1	7.2	11.1	38.3	132.0	127.0	81.8	50.3	14.6	15.6	6.8	6.0	501.8	111.4
1925	5.0	5.0	7.6	31.8	84.8	104.0	71.9	39.7	30.7	21.0	12.5	14.4	428.4	95.1
1926	10.5	6.9	8.3	18.5	77.5	126.0	75.6	55.2	21.2	10.9	9.5	7.7	428.1	95.0
1927	6.0	5.3	6.2	30.0	94.1	141.0	106.0	55.2	73.2	49.6	12.6	9.5	588.7	130.6
1928	8.9	7.7	9.2	31.2	87.9	104.0	57.9	36.8	17.5	14.6	10.7	6.8	423.2	93.9
1929	6.3	5.3	8.1	26.3	82.4	130.0	93.5	65.8	50.0	38.1	12.6	6.8	525.2	116.6
1930	5.5	5.6	8.0	33.6	78.2	102.0	59.8	41.6	16.8	18.6	8.4	5.0	378.1	83.9
1931	3.1	4.0	5.8	16.8	47.3	75.0	29.8	15.6	16.3	19.2	8.8	5.8	247.5	54.9
1932	5.1	5.2	6.8	31.4	104.0	126.0	87.3	81.8	25.0	17.2	5.7	4.9	500.4	111.0
1933	4.9	4.2	6.0	16.9	56.6	99.4	56.8	28.7	18.1	14.9	7.9	6.8	321.2	71.3
1934	5.5	4.2	8.0	45.0	71.9	22.1	12.7	13.5	13.6	9.3	6.1	4.7	216.6	48.1
1935	4.2	4.3	7.1	21.4	41.5	124.0	76.2	57.4	18.6	12.6	6.0	5.0	378.3	84.0
Mean	7.0	6.0	10.1	29.1	95.8	128.1	66.3	40.1	24.4	23.8	12.0	7.9	450.6	....
Percent of annual	1.55	1.33	2.24	6.46	21.26	28.43	14.71	8.91	5.42	5.28	2.66	1.75	100.0	....

[1] Estimated by reference to Rio Grande near Del Norte from monthly relation curves.
[2] Estimate based upon relation of missing months to remaining months of the year, as indicated by monthly means for all complete years.
[3] Estimated by reference to Rio Grande near Lobatos from monthly relation curves.

Records previous to October 1913 as published by U. S. Geological Survey in Water Supply Paper No. 358 except as noted.
Records from October 1913 to September 1934 from biennial reports of Colorado State engineer except as noted.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 128.—*Run-off of Rio Grande near Del Norte, Colo.*

[Drainage area 1,320 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual ru[illegible] in [illegible] of
1890	13.5	11.1	27.4	54.3	286.0	227.0	93.2	37.6	22.6	28.9	20.2	18.4	830.4	116.1
1891	16.9	13.9	26.7	83.9	302.0	247.0	104.0	40.8	31.4	51.9	22.8	19.1	859.9	121.6
1892	16.9	14.4	19.4	62.3	160.0	130.0	45.5	27.3	15.6	15.9	14.3	10.8	532.4	78.3
1893	9.8	9.7	15.4	31.7	120.0	104.0	24.3	19.99	16.1	16.2	14.3	10.8	392.2	55.5
1894	10.8	9.7	18.4	54.9	147.0	63.7	22.4	23.6	21.1	22.1	16.8	13.8	424.3	60.0
1895	12.3	10.6	26.7	119.0	141.0	139.0	54.6	45.2	26.7	25.8	20.4	18.4	649.7	91.9
1896	16.9	15.5	30.7	[illegible]	151.0	[illegible]	24.3	[illegible]	[illegible]	27.9	[illegible]	13.3	[illegible]	[illegible]
1897	13.3	[illegible]	[illegible]	[illegible]	117.0	102.[illegible]	[illegible]	[illegible]	[illegible]	30.[illegible]	[illegible]	34.0	[illegible]	116.[illegible]
1898	20.0	16.7	27.7	114.0	167.0	261.0	101.0	31.3	19.0	16.0	13.1	11.1	797.9	112.8
1899	11.1	10.0	18.4	36.8	84.7	64.9	43.2	36.7	22.0	29.2	23.8	12.6	393.4	55.7
1900	9.2	10.6	15.4	24.9	175.0	160.0	33.6	14.0	15.2	21.0	14.9	12.3	506.1	71.6
1901	12.3	9.7	13.8	42.2	158.0	116.0	38.5	28.5	26.5	16.1	16.8	10.8	487.2	68.9
1902	9.8	8.3	14.1	28.0	71.9	36.8	9.4	11.1	12.3	14.9	12.9	9.8	249.3	35.3
1903	[1] 3.5	[1] 5.0	[1] 10.0	44.5	174.0	309.0	102.0	32.3	30.6	21.5	[2] 17.0	[1] 11.0	760.4	107.5
1904	[1] 6.5	[1] 7.0	[1] 12.0	38.8	71.2	42.6	20.7	42.4	41.2	89.1	[2] 21.0	[1] 13.0	405.5	57.4
1905	[1] 15.0	[1] 12.0	[1] 27.0	45.2	210.0	362.0	67.1	35.5	22.4	26.4	17.6	12.3	852.5	120.6
1906	11.1	10.0	18.8	64.9	236.0	296.0	116.0	47.7	42.8	54.8	32.5	18.4	949.0	134.3
1907	[1] 20.0	[1] 17.0	[1] 25.0	[3] 96.0	[3] 161.0	[3] 261.0	[3] 279.0	[3] 92.8	[3] 48.4	[3] 30.4	[3] 20.8	[1] 14.0	1,164.4	164.7
1908	[2] 11.0	[2] 10.0	[4] 21.0	[5] 45.0	104.0	174.0	65.8	57.2	20.5	16.7	12.2	[1] 12.0	549.4	77.7
1909	[1] 13.0	[1] 12.0	[1] 19.0	[5] 49.0	195.0	284.0	93.5	53.1	96.8	40.6	24.9	24.4	909.3	128.6
1910	19.7	16.3	39.7	83.3	210.0	144.0	38.0	30.3	19.8	22.3	18.1	13.4	654.9	92.6
1911	15.2	13.8	20.7	57.0	204.0	287.0	172.0	59.5	89.7	151.0	32.3	25.0	1,076.7	151.5
1912	20.9	15.7	17.1	34.4	229.0	260.0	108.0	49.9	28.6	23.7	15.6	10.8	811.7	114.7
1913	[5] 10.0	[4] 8.5	[2] 15.0	[5] 48.0	144.0	126.0	65.7	42.2	29.2	34.6	22.8	18.6	564.6	79.8
1914	[2] 16.0	[2] 14.0	[5] 15.0	18.7	172.0	280.0	129.0	66.7	48.6	54.2	16.5	10.6	791.3	111.9
1915	11.1	12.4	15.9	37.2	106.0	206.0	116.0	62.1	39.3	33.0	17.4	12.5	668.9	94.6
1916	17.0	16.6	84.1	56.5	181.0	198.0	124.0	99.0	38.1	100.0	47.8	[2] 20.0	930.1	131.5
1917	[2] 18.0	[2] 16.0	[2] 18.0	37.9	114.0	359.0	184.0	65.2	33.8	25.2	17.6	10.8	899.5	127.2
1918	11.7	10.8	16.4	28.7	116.0	143.0	64.0	48.6	34.2	22.4	15.6	12.0	523.4	74.0
1919	12.6	11.7	18.0	61.9	223.0	162.0	116.0	77.5	31.7	24.9	18.3	15.1	772.7	109.3
1920	14.6	15.6	16.6	30.2	250.0	355.0	158.0	68.2	29.2	26.6	21.4	15.6	1,001.0	141.7
1921	15.5	13.7	24.9	43.0	183.0	371.0	156.0	99.0	50.9	42.6	23.3	15.6	1,038.5	147.0
1922	15.9	15.2	18.1	39.8	274.0	306.0	119.0	81.8	33.4	20.0	15.0	13.9	951.1	134.6
1923	12.8	10.6	16.0	38.6	188.0	214.0	115.0	83.0	53.9	50.6	33.6	22.2	838.3	118.6
1924	17.8	15.5	17.2	68.4	227.0	202.0	103.0	58.2	18.0	19.1	11.4	12.4	770.0	108.9
1925	11.9	11.9	22.3	61.3	141.0	160.0	97.2	58.6	45.8	42.7	24.1	25.8	702.6	99.4
1926	17.8	13.3	14.8	34.3	128.0	198.0	103.0	71.9	37.0	30.2	16.3	14.1	668.7	94.6
1927	11.7	11.7	13.5	54.0	179.0	217.0	161.0	80.6	119.0	75.0	25.1	18.8	966.4	136.8
1928	18.1	17.3	22.4	49.0	168.0	165.0	108.0	48.8	26.0	22.1	17.9	15.1	676.7	95.8
1929	13.8	12.2	16.0	50.8	186.0	230.0	117.0	104.0	82.7	57.7	23.4	14.1	897.5	126.9
1930	12.3	12.2	15.4	56.6	108.0	140.0	75.6	58.6	23.6	24.5	12.7	12.1	551.6	78.0

[1] Estimated by reference to Rio Grande near Lobatos from monthly relation curves.
[2] Estimate based upon relation of missing months to remaining months of the year as indicated by monthly means for all complete years.
[3] Estimated by J. H. Baily from water commissioner's reports and comparison with Wason record.
[4] Estimated by reference to Rio Grande at Wason from monthly relation curves.
[5] Partial record extended or estimate based in part on discharge measurements.

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TABLE 128.—*Runoff of Rio Grande near Del Norte, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1931	8.3	9.3	12.3	28.2	73.8	99.4	35.4	18.7	23.1	30.4	12.2	10.2	361.3	51.1
1932	11.4	11.3	16.5	66.6	214.0	236.0	146.0	106.0	30.6	26.3	10.9	9.5	885.1	125.2
1933	10.2	8.6	14.4	23.6	81.2	169.0	79.3	39.4	27.1	24.2	14.7	12.9	504.6	71.4
1934	13.2	11.1	15.1	67.2	103.0	28.3	14.7	15.9	17.9	14.4	11.3	8.3	320.4	45.3
1935	8.5	9.1	15.3	87.1	81.9	333.0	128.0	72.2	27.9	19.5	12.7	8.3	683.5	96.7
Mean	13.5	12.2	19.5	52.4	163.2	197.5	92.3	51.9	34.3	36.2	19.6	14.5	707.1	
Percent of annual	1.91	1.73	2.76	7.41	23.08	27.93	13.05	7.34	4.85	5.12	2.77	2.05	100.0	

All records previous to October 1913 as published in U. S. Geological Survey Water Supply Paper No. 358 except as noted.
Records from October 1913 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 129.—*Run-off of Rio Grande near Monte Vista, Colo.*

[Drainage area, 1,590 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1926					48.8	77.4	18.4	1.6	1.6	2.6	14.7		
1927				18.2	48.3	107.0	89.8	13.6	98.2	57.3	18.3		
1928				15.5	58.3	48.1	12.4	2.9	3.2	2.3	9.9		
1929				19.5	56.0	74.4	29.1	60.1	64.3	35.0	22.4		
1930				15.6	29.6	36.4	14.4	13.0	1.5	3.9	11.6		
1931			(1)	1.9	19.5	27.4	7.7	2.9	4.2	3.8	[2] 5.5		
1932			[2] 11.7	16.8	66.4	100.0	39.4	14.6	3.4	4.4	12.0		
1933			(1)	2.8	22.0	44.0	13.9	4.4	4.4	3.2	10.1		
1934		[1] 7.8	3.4	18.4	33.8	7.2	4.4	3.6	3.2	.8	2.4	10.9	
1935	11.4	5.9	.5	4.6	27.0	104.0	31.6	8.5	4.7	4.6	9.7	9.2	221.7

[1] Partial record.
[2] Partially estimated.

Records from May 1926 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U S. Geological Survey.

TABLE 130.—*Run-off of Rio Grande at Alamosa, Colo.*

[Drainage area, 1,712 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1890 [1]	3.0	12.0	15.0	20.0	33.0	38.0	33.0	35.0	3.0	12.0	15.0	17.0	236.0
1891 [1]	[illegible]	14.0	22.0	35.0	19.0	119.0	54.0	20.0	[illegible]	59.0	23.0	14.0	103.0
1892 [1]	11.0	14.0	28.0	44.0	30.0	38.0	7.0	1.0	.2	1.0	2.0	5.0	249.2
1893 [1]	1.0	5.0	10.0	20.0	32.0	42.0	1.0	1.0	1.0	1.0	1.0	5.0	120.0
1894 [1]	1.0	2.0	15.0	17.0	18.0	5.0	1.0	1.0	.2	16.0	1.0	6.0	83.2
1895 [1]	10.0	9.0	18.0	38.0	24.0	55.0	27.0	26.0	12.0	9.0	15.0	13.0	254.0
1896 [1]	14.0	12.0	24.0	25.0	11.0	7.0	2.0	1.0	.2	2.0	4.0	8.0	110.2
1897 [1]	5.0	5.0	11.0	24.0	101.0	105.0	25.0	2.0	3.0	54.0	41.0	14.0	390.0
1898 [1]	11.0	8.0	16.0	33.0	18.0	70.0	62.0	3.0	2.0	.5	2.0	6.0	231.5
1899	[2] 10.0	[1] 8.0	[2] 18.0	[2] 14.0	[1] 5.0	[1] 2.0	[2] 2.0	[2] 1.0	[2] 2.0	[2] 2.0	[2] 9.0	[2] 10.0	83.0
1900 [2]	7.0	9.0	10.0	7.0	24.0	45.0	1.0	1.0	.3	.2	1.0	10.0	115.5
1901 [2]	10.0	9.0	12.0	6.0	32.0	21.0	2.0	1.0	.5	.5	1.0	5.0	100.0
1902 [2]	6.0	6.0	10.0	6.0	5.0	3.0	1.0	1.0	.2	.1	.4	1.0	39.7
1903 [2]	.3	1.0	1.0	7.0	32.0	268.0	37.0	1.0	2.0	1.0	4.0	4.0	358.3
1904 [2]	3.0	4.0	3.0	3.0	1.0	2.0	1.0	2.0	6.0	73.0	10.0	11.0	119.0
1905 [2]	14.0	12.0	33.0	18.0	209.0	318.0	8.0	3.0	1.0	2.0	7.0	9.0	634.0
1906 [2]	10.0	10.0	11.0	17.0	84.0	158.0	48.0	17.0	15.0	41.0	31.0	20.0	462.0
1907 [2]	21.0	19.0	28.0	46.0	80.0	299.0	240.0	76.0	53.0	24.0	18.0	14.0	918.0
1908	[1] 5.0	[1] 6.0	[2] 24.0	[2] 14.0	[2] 8.0	[2] 22.0	[2] 9.0	[2] 23.0	[2] 10.0	[2] 11.0	[2] 8.0	[2] 9.0	149.0
1909 [2]	12.0	12.0	17.0	24.0	91.0	166.0	18.0	15.0	107.0	38.0	23.0	17.0	540.0
1910 [2]	16.0	13.0	46.0	47.0	86.0	19.0	2.0	1.0	.5	3.0	7.0	11.0	251.5
1911 [2]	15.0	14.0	13.0	10.0	34.0	143.0	159.0	21.0	27.0	148.0	33.0	20.0	637.0
1912	[2] 21.0	[2] 18.0	[2] 21.0	[2] 19.0	[2] 133.0	186.0	40.0	9.0	4.8	10.5	15.4	[2] 11.0	488.7
1913	[1] 6.0	[1] 8.0	[1] 14.0	[2] 22.0	11.3	25.0	1.4	.4	1.7	23.6	19.2	[1] 8.0	140.6
1914	[2] 10.0	[1] 12.0	[2] 18.0	[2] 14.0	52.3	115.0	39.3	28.4	30.5	31.9	15.3	[1] 12.0	376.7
1915	10.6	10.9	16.5	15.7	36.0	67.2	30.0	12.7	12.7	12.4	15.0	14.1	243.8
1916	17.5	18.8	30.8	15.5	60.8	40.6	10.7	59.8	11.5	74.4	54.0	[2] 20.0	404.4
1917	[1] 18.0	[1] 14.0	[2] 18.0	18.1	41.0	217.0	92.8	10.1	5.8	7.8	16.8	14.0	473.4
1918	11.4	12.2	18.6	5.7	3.8	6.8	4.9	.8	15.8	4.3	12.7	14.3	111.2
1919	11.7	10.6	19.5	53.5	123.0	30.3	16.8	11.0	1.9	5.9	16.8	17.2	318.2
1920	15.8	16.9	19.9	20.2	113.0	248.0	56.6	7.5	5.9	14.4	23.0	17.2	560.4
1921	15.7	14.7	29.0	12.7	43.9	333.0	58.9	39.7	29.2	18.7	20.8	18.9	636.2
1922	20.6	17.7	20.5	13.1	99.6	130.0	21.0	1.8	1.1	1.3	12.7	15.6	355.0
1923	14.7	17.1	19.6	14.8	16.0	49.8	30.6	29.6	37.9	57.2	36.7	24.5	328.5
1924	16.0	16.1	17.9	63.1	119.0	37.5	6.0	1.4	1.1	2.0	10.8	13.0	303.9
1925	9.2	11.2	25.3	10.3	6.1	8.2	4.0	5.8	14.4	18.6	22.3	20.9	156.5
1926	16.6	15.6	21.0	15.5	18.1	41.1	5.2	.9	.8	1.7	11.5	15.4	163.4
1927	10.8	15.6	17.4	13.6	9.3	51.4	87.9	5.0	86.9	60.9	27.7	20.6	407.1

[1] Estimated by reference to estimated flow of Rio Grande at Lobatos, from monthly relation curves. (See table 131.)
[2] Same as footnote 1, except reference is to measured flow at Lobatos.

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TABLE 130.—*Run-off of Rio Grande at Alamosa, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	A
1928	17.8	17.3	23.1	12.7	28.9	23.3	3.1	2.2	1.3	1.4	10.1	11.7	152.9
1929	11.6	11.1	16.4	14.8	18.2	35.8	3.9	50.1	59.4	40.6	29.2	19.8	310.9
1930	12.9	17.8	14.6	7.6	5.2	3.3	7.6	3.5	1.0	1.4	7.7	8.3	90.9
1931	7.7	12.5	16.9	2.4	1.7	3.3	2.9	1.5	1.2	.9	3.6	11.0	65.6
1932	10.5	12.5	18.3	3.3	24.8	63.7	24.1	2.5	1.9	1.9	11.5	15.1	190.1
1933	12.3	9.7	10.1	.7	2.0	7.0	2.7	2.3	1.3	1.0	4.2	13.4	66.7
1934	10.7	13.1	4.5	1.2	2.2	3.0	1.8	1.7	1.0	.6	.9	8.2	48.9
1935	7.3	6.9	.9	.9	3.2	50.0	6.5	1.6	1.5	3.1	5.8	11.1	98.8
Mean	11.4	11.6	17.7	18.6	46.5	82.4	27.9	11.3	12.8	19.5	14.3	12.7	286.7
Percent of annual	3.96	4.05	6.17	6.49	16.22	28.74	9.73	3.94	4.46	6.80	4.99	4.43	100.0

Records from June 1912 to October 1913 from U. S. Geological Survey Water Supply Paper No. 358, except as noted.
Records from October 1913 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 131.—*Run-off of Rio Grande near Lobatos, Colo.*

[Drainage area, 4,800 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890 [2]	13.0	18.0	27.0	78.0	203.0	171.0	65.0	28.0	16.0	19.0	24.0	27.0	689.0	125.2
1891 [2]	25.0	22.0	38.0	89.0	246.0	213.0	101.0	34.0	13.0	80.0	35.0	22.0	918.0	166.8
1892 [2]	18.0	22.0	45.0	113.0	200.0	130.0	16.0	1.0	1.0	1.0	4.0	9.0	560.0	101.8
1893 [2]	4.0	8.0	19.0	51.0	124.0	103.0	1.0	1.0	4.0	1.0	[3] 2.0	[3] 9.0	327.0	59.4
1894	[3] 3.0	[3] 2.0	[3] 27.0	[3] 45.0	[3] 83.0	[3] 15.0	[3] 1.0	[3] 1.0	[3] 1.0	[3] 25.0	[3] 2.0	[3] 10.0	215.0	39.1
1895 [2]	16.0	14.0	31.0	92.0	106.0	126.0	53.0	42.0	22.0	15.0	24.0	21.0	562.0	102.1
1896 [2]	21.0	19.0	41.0	65.0	58.0	7.0	4.0	2.0	1.0	7.0	8.0	14.0	247.0	44.9
1897 [2]	9.0	8.0	21.0	62.0	224.0	195.0	50.0	5.0	7.0	74.0	58.0	22.0	735.0	133.5
1898 [2]	17.0	12.0	28.0	84.0	82.0	147.0	112.0	11.0	6.0	3.0	6.0	10.0	518.0	94.2
1899	[3] 16.0	[3] 13.0	[3] 31.0	[3] 37.0	[3] 32.0	[3] 1.0	2.6	3.3	6.1	7.2	15.4	15.7	180.3	32.8
1900	12.3	13.9	18.4	20.2	106.0	108.0	1.2	.7	1.2	1.7	3.3	16.9	303.8	55.2
1901	15.4	13.9	22.3	16.8	124.0	66.0	5.0	3.4	2.6	3.0	2.1	9.2	283.7	51.6
1902	11.1	8.9	18.8	18.3	28.5	6.7	.7	.6	1.0	1.3	1.1	1.7	98.7	18.0
1903	1.5	1.4	2.1	18.7	124.0	379.0	72.4	2.9	5.4	3.9	8.3	7.4	627.0	114.0
1904	7.4	6.8	6.8	9.1	1.3	1.2	1.1	8.6	11.7	97.8	17.9	18.4	187.6	34.1
1905	21.5	18.0	55.2	46.0	350.0	430.0	16.7	10.0	3.8	6.3	13.6	15.4	986.5	179.3
1906	16.6	15.0	20.9	45.3	205.0	260.0	90.4	30.9	25.2	56.8	45.4	30.7	842.2	
1907	30.7	29.2	47.9	117.0	201.0	411.0	334.0	107.0	73.2	35.4	28.1	22.0	1,436.5	
1908	[4] 9.0	[4] 8.0	41.7	37.4	47.0	68.4	19.4	38.4	18.2	17.8	14.9	14.8	335.0	
1909	18.4	19.4	30.1	63.1	213.0	269.0	37.3	28.7	140.0	53.4	33.9	27.1	933.4	
1910	24.0	19.7	76.2	121.0	207.0	60.1	2.0	4.6	2.6	7.4	13.6	17.8	556.0	10[illegible]
1911	22.8	21.1	23.1	27.4	129.0	243.0	222.0	35.6	41.6	193.0	47.6	30.7	1,036.9	188.3
1912	30.6	28.0	36.7	50.0	262.0	806.0	49.5	17.3	11.7	17.4	21.6	18.4	849.2	154.4
1913	[4] 11.0	[4] 12.0	[4] 25.0	57.1	50.5	62.7	4.9	2.3	4.1	23.6	24.0	[3] 14.0	281.2	51.1
1914	[3] 16.0	[3] 18.0	31.6	38.5	102.0	155.0	48.4	43.7	48.6	45.1	25.5	[5] 19.0	591.4	107.4
1915	18.0	16.0	24.5	49.0	102.0	125.0	39.7	26.1	16.7	15.6	19.5	18.9	471.0	85.6
1916	22.6	26.2	47.8	51.5	164.0	114.0	37.7	83.8	25.5	94.1	65.5	[3] 32.0	764.5	138.9
1917	[3] 27.0	[3] 22.0	[3] 31.0	55.8	116.0	296.0	157.0	[illegible]	9.5	[illegible]	[illegible]	[illegible]	[illegible]	143.3
1918	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.5	[illegible]	[illegible]	19.7	[illegible]	[illegible]
1919	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.3	7.1	12.2	25.8	23.6	612.2	111.3
1920	23.1	27.4	31.1	32.0	266.0	408.0	119.0	22.1	17.0	23.2	37.4	33.3	1,040.6	189.1
1921	30.7	26.7	51.6	24.3	92.8	389.0	57.4	63.3	41.3	27.6	31.4	26.8	862.9	156.8
1922	29.6	28.7	33.0	25.5	197.0	258.0	41.0	5.9	4.9	6.0	20.2	24.1	673.9	122.4
1923	23.1	23.6	27.7	23.8	125.0	160.0	28.6	43.0	61.3	80.6	50.5	40.3	696.5	126.6
1924	24.0	38.5	43.5	172.0	329.0	81.5	10.0	4.6	4.2	7.6	17.2	20.9	753.0	137.0
1925	16.0	26.0	39.6	32.1	38.0	17.7	8.5	18.4	23.4	33.0	35.1	35.2	323.0	58.7
1926	26.6	30.0	38.8	43.4	113.0	107.0	14.7	3.7	3.7	5.0	16.6	23.2	425.7	77.4
1927	19.7	27.0	26.7	26.5	96.5	118.0	128.0	16.8	109.0	84.8	43.8	27.0	723.8	131.5
1928	24.2	24.5	39.2	27.7	94.1	61.0	2.6	3.4	4.1	4.6	17.9	22.1	325.4	59.1
1929	16.8	15.7	28.0	27.3	120.0	92.2	10.3	76.2	80.9	55.8	42.9	31.7	597.8	108.7
1930	18.6	24.3	32.6	44.4	38.0	33.0	11.9	16.3	8.5	9.0	15.6	21.2	270.4	49.2
1931	12.0	17.1	32.2	14.0	10.9	3.0	1.3	2.0	3.2	5.9	6.9	17.0	125.5	22.8
1932	16.2	21.7	32.3	28.4	168.0	170.0	86.7	11.0	9.3	11.0	20.8	21.0	596.4	108.4
1933	16.5	13.9	28.7	11.1	33.0	75.6	9.9	2.8	5.8	7.5	11.7	20.5	237.0	43.1
1934	20.0	22.2	16.5	8.7	6.7	1.8	.7	1.2	1.9	3.0	4.7	11.4	98.8	18.0
1935	12.6	13.0	6.2	1.9	45.5	166.0	48.7	9.3	9.2	12.3	16.3	19.1	360.1	65.4
Mean	17.9	18.5	31.4	48.6	128.9	146.0	47.4	19.9	20.3	28.6	22.4	20.3	550.2	
Percent of annual	3.25	3.36	5.70	8.83	23.43	26.54	8.62	3.62	3.69	5.20	4.07	3.69	100.0	

[1] Exclusive of closed basin area.
[2] Estimated by reference to Rio Grande at Embudo from monthly relation curves.
[3] Estimated by reference to Rio Grande near Del Norte from monthly relation curves.
[4] Estimate based upon relation of missing months to remaining months of the year as indicated by monthly means for all complete years, 1900 to 1912, inclusive.
[5] Partial record extended or estimate based in part on discharge measurements.

All records previous to October 1913 as published in U. S. Geological Survey Water Supply Paper No. 358 except as noted.
Records from October 1913 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

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TABLE 132.—*Run-off of Clear Creek below Continental Reservoir, Colo.*

[Drainage area, 43 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1929					7,930	4,630	6,460	3,600	2,160	1,780	1,190	806	
1930	633	[1] 555	[1] 615	3,270	5,870	4,210	3,440	2,530	1,260	1,080	[2] 714	[1] 615	24,792
1931	[1] 492	[1] 444	[1] 615	[2] 1,190	3,250	2,400	1,170	836	738	781	[2] 625	[1] 615	13,156
1932	[1] 492	[1] 460	[1] 492	[1] 1,190	6,520	5,130	3,830	3,850	1,390	676	[1] 476	[1] 492	24,998
1933	[1] 492	[1] 444	[1] 492	928	6,270	5,110	2,560	1,380	1,110	[1] 492	[1] 476	[1] 492	20,246
1934	[1] 492	[1] 444	[1] 492	3,760	3,180	1,080	1,030	615	[1] 476	[1] 492	[1] 476	[1] 492	13,029
1935	[1] 492	[1] 444	[1] 492	1,010	4,620	3,170	1,890	2,230	1,090	[2] 633	[1] 595	[1] 615	17,271

[1] Estimated.
[2] Partially estimated.

Records from May 1929 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 133.—*Run-off of South Fork Rio Grande at South Fork, Colo.*

[Drainage area 216 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1910								(1)	2.4	3.6	2.9	[2] 2.5	
1911	[2] 2.2	[2] 1.8	[2] 4.0	15.5	50.3	71.9	41.4	10.4	8.6	(1)	8.4	[2] 6.5	
1912	[2] 3.6	[2] 2.9	[2] 4.2	8.8	57.0	64.7	19.3	5.6	3.2	4.6	5.2	[2] 2.8	181.9
1913	[2] 2.0	[2] 2.1	[2] 2.6	[2] 17.2	36.9	33.0	7.1	3.6	4.6	5.5	4.2	2.3	121.1
1914				11.0	37.5	49.3	17.4	7.9	8.9	12.4	4.5	2.1	
1915	2.0	3.3	5.0	11.8	27.9	56.1	18.3	6.8	3.9	3.5	2.7	2.5	143.8
1916	3.1	3.1	7.9	18.9	53.1	73.2	27.1	12.7	8.6	18.6	(1)		
1917				12.6	31.4	100.0	46.5	9.7	5.1	3.2	2.8	2.0	
1918	1.9	1.9	4.3	8.9	29.4	42.7	12.8	6.2	5.5	2.8	3.5		
1919			(1)	18.8	53.4	35.8	17.1	7.8	3.8	3.5	4.1	3.7	
1920				8.3	73.2	101.0	35.3	8.5	3.6	3.4	3.5	3.1	
1921	2.6	2.6	7.3	9.2	37.8	72.0	20.2	12.1	7.1	3.0	2.1		
1922				12.5	73.2	83.9	18.3	7.3	2.5				

[1] Partial record.
[2] Estimated.

Records previous to October 1913 as published in U. S. Geological Survey Water Supply Paper No. 358.
rds from October 1913 to September 1922 from biennial reports of the Colorado State engineer.
on reestablished in 1936. See U. S. Geological Survey records for 1936.

TABLE 134.—*Run-off of Pinos Creek, near Del Norte, Colo.*

[Drainage area 62 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919				[1] 3.2	8.4	5.6	4.1	1.7	1.0	0.7	0.7		
1920			(2)	1.3	14.0	20.2	5.5	1.6	.7	.7			
1921			(2)	1.1	6.5	8.1	3.4	2.7	1.8	.8			
1922				1.5	13.5	18.7	2.0	1.1	.6	.7			
1923				1.5	8.4	8.2	2.9	2.3	1.9	1.6	[1] .9		
1924				4.9	12.9	7.7	1.8	.8	.5				

[1] Estimated.
[2] Partial record.

Records from biennial reports of the Colorado State engineer.

TABLE 135.—*Run-off of Rock Creek near Monte Vista, Colo.*

[Drainage area 38 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919				2.5	4.5	2.6	2.0	1.0	0.4	0.4	0.5		
1920			0.4	.8	5.7	4.7	1.8	1.0	.4	.4			
1921				.5	1.8	2.0	.8	.8	.4	.2			
1922				.5	3.1	2.5	1.0	.8	.4	.3			
1923				(1)	2.8	2.0	1.3	.9	.9	.9	.5		
1924				[2] 2.7	3.6	1.8	.7	.3	.2				
1935					3.2	3.3	1.0	.8	.4	.2			

[1] Partial record.
[2] Partially estimated.

Records from April 1919 to September 1924 from biennial reports of the Colorado State engineer.
Records from May 1935 to October 1935 are provisional records furnished by the Colorado State engineer.

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TABLE 136.—*Run-off of Alamosa Creek above Terrace Reservoir, Colo.*

[Drainage area 102 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1909				[1] 9.0	29.2	37.6	11.2			3.9	2.9	6.0	
1910				11.4	29.0	18.9	5.8	6.6	1.7	(2)			
1911				7.2	28.6	40.7	21.4	7.4	7.2	18.4			
1912		3.0	3.4	4.1	33.6	33.4	21.8	10.5	3.2	(2)			
1915				6.1	17.6	34.9	14.5	4.9	2.5	1.9			
1916				8.6	32.5	35.5	13.5	9.5	3.8	5.8	(2)		
1917		1.1	1.2	5.3	18.8	(2)	28.5	7.3	2.9	1.3	.8		
1918			2.1	3.4	18.8	24.3	10.2	4.1					
1919				9.3	34.1	22.9	12.4	5.6	2.0	1.0			
1923										[3] 3.5	[3] 4.5	[3] 4.2	
1924	[3] 3.6	[3] 2.7	[1] 6.0	7.8	35.9	24.8	6.4	2.7	1.4				
1925			(2)	9.9	27.9	19.9	9.4	5.4	3.5	3.1	(2)		
1926				4.3	23.1	27.3	8.9	4.2	1.5				
1927				7.0	32.3	31.0	14.5	5.7	8.3				
1934										1.0	.7		
1935				3.9	12.8	56.0	20.3	7.0	2.4	1.6	[1] 1.3		

[1] Partially estimated.
[2] Partial record.
[3] Estimated.

Records previous to October 1912 as published in U. S. Geological Survey Water Supply Paper No. 358.
Records from April 1915 to September 1927 from biennial reports of the Colorado State engineer.
Records from October 1934 to November 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 137.—*Run-off of Alamosa Creek below Terrace Reservoir, Colo.*

[Drainage area 120 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1915				2.3	15.0	39.5	17.7	5.7	3.0	2.3			
1916													
1917		1.0	0.5	1.2	6.6	66.1	30.0	10.6	2.8	1.4	0.8	(1)	
1918			2.1	3.4	18.8	24.9	9.5	[3] 4.0					
1919				(1)	26.8	26.3	12.4	5.7	2.1	1.3			
1920					27.1	52.8	29.1	12.0	4.7	2.5			
1921													
1922				5.2	28.5	37.3	13.0	7.2	3.3	[3] 1.5	[3] 1.5	[3] 1.5	
1923	[3] 1.5	[3] 1.4	[3] 1.5	3.1	29.0	29.6	17.5	6.8	6.1	[3] 3.8	[3] 3.7	[3] 3.8	10[illegible]
1924	[3] 3.8	[3] 3.6	[3] 3.8	8.2	35.7	32.1	10.4	4.8	1.4	1.0	1.2	[3] 1.2	
1925	[3] 1.3	[3] 1.2	[3] 1.3	9.5	23.8	18.4	10.3	5.7	3.5	2.9	2.1		
1926				3.2	17.8	25.8	11.3	7.9	2.2	1.0	[3] .6	[3] .6	
1927	[3] .6	[3] .6	1.9	6.8	31.2	20.4	14.8	9.5	4.5	5.7	[3] 3.4		
1928				4.5	17.8	20.4	9.2	7.0	1.7	1.1	1.0	[3] .4	
1929	[3] .4	[3] .4	.7	7.5	24.5	30.2	15.0	10.6	7.1	4.8	[3] 3.3	[3] 2.9	107.4
1930	[3] 2.8	[3] 1.8	[3] 1.7	8.1	17.5	19.0	5.6	9.1	2.8	2.1	[3] 1.2	[3] 1.2	72.9
1931	[3] 1.2	[3] 1.1	[3] 1.2	2.9	11.7	13.1	3.9	2.9	4.9	5.0	[3] .9	[3] .9	49.7
1932	[3] .9	[3] .9	[3] .9	11.1	25.6	33.0	21.8	14.3	4.5	2.8	[3] 1.8	[3] 1.1	118.7
1933	[3] .9	[3] .8	[3] .9	1.9	14.6	29.0	11.3	6.5	1.9	[3] 1.5	[3] .9	[3] .6	70.8
1934	[3] .6	[3] .7	1.6	12.5	11.4	2.7	1.5	1.8	1.3	1.1	.6	.4	36.2
1935	[3] .5	[3] .5	[3] 1.1	4.5	12.3	38.3	20.8	12.0	3.5	[illegible]	[illegible]	2.2	[illegible]

[1] Partial record.
[2] Partially estimated.
[3] Estimated.

Records from April 1915 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 138.—*Run-off of La Jara Creek near Capulin, Colo.*

[Drainage area 73 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1916				3.7	7.0	3.5	3.9	1.3	0.6	0.7			
1917				3.8	5.8	3.1	1.8	1.1	1.1	1.1	0.8		
1918													
1919				6.1	5.7	6.0	3.5	.8	.7	.7	.8		
1920				1.4	10.8	3.4	3.7	3.2	1.0	1.0	.9		
1921				[1] 1.8	4.9	1.3	1.1	.8	.6	.8			
1922				(2)	5.8	2.4	5.8	1.4	.6				
1923				(2)	8.9	1.8	5.1	2.4	1.7	1.4	1.2		
1924					[3] 4.6	2.7	4.8	1.7	1.0	.9	.7		
1925			[4] 1.0	3.9	3.4	1.0	.9	2.0	.4	.4	[4] .2		
1926					4.7	4.2	2.2	.6	.4	.4			
1927				3.3	4.7	1.8	1.4	.9	.9	.8			
1928			(2)	2.4	3.3	1.1	2.9	1.0	.7	[4] .5	[4] .4		
1929				4.1	4.8	1.0	2.0	1.0	1.1	.6			
1930							1.7	1.1	.7				
1931													
1932				3.8	7.1	.9	.4	1.2	.9	.5			
1933			(2)	.9	2.6	.9	1.0	2.2	.4	[4] .3	[4] .4		
1934			(2)	1.2	.7	.6	.5	.3	.2	.3	.2	0.2	
1935				1.6	4.2	1.4	.3	.3	.3	.4			

[1] 23 days.
[2] Partial record.
[3] Partially estimated.
[4] Estimated.

Records from April 1916 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

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TABLE 139.—*Run-off of La Jara Creek near mouth, Colo.*

[Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1924										[1] 1.3	[1] 1.9	[2] 2.3	
1925	[2] 1.6	[2] 2.3	[2] 3.4	2.8	1.5	0.7	1.6	3.6	2.5	1.7	2.9	[2] 2.5	27.1
1926	[2] 1.8	[2] 1.9	[2] 4.3	4.6	4.3	3.1	1.9	.8	1.1	.7	1.7	[1] 1.5	27.7
1927	[2] 2.0	[2] 2.2	[2] 2.8	[2] 1.0	1.0	2.7	2.3	3.9	4.4	5.1	3.7	[2] 3.2	34.3
1928	[2] 2.3	[2] 2.4	[2] 3.7	2.0	3.6	1.2	.3	.3	.6	.3	1.1	[2] 1.7	19.7
1929	[2] 1.6	[2] 1.3	[2] 3.7	3.1	4.2	2.0	2.1	4.7	5.0	[1] 2.5	[2] 4.2	[2] 4.0	38.4
1930	[2] 2.5	[2] 3.3	3.8	2.6	1.0	.3	.8	1.9	.6	2.3	[2] 2.1	[2] 2.1	23.3
1931	[2] 1.5	[2] 1.9	[2] 3.1	[2] .9	.2	0	0	0	0	1.3			
1932				2.7	5.6	4.2	3.9	1.2	1.1				

[1] Partially estimated.
[2] Estimated.

Records from biennial reports of the Colorado State engineer.

TABLE 140.—*Run-off of Trinchera Creek above Turners Ranch, near Fort Garland, Colo.*

[Drainage area 45 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1923				0.6	2.7	3.6	1.5	1.4	1.3	1.3	1.1		
1924					7.8	7.6	2.5	.8	.7	[1] .7	.5		
1925				1.6	2.3	1.6	1.0	.8	.6	.6			
1926				([2])	8.6	9.1	2.9	1.3	.7	1.0	[1] 1.0		
1927				1.0	3.8	3.4	1.7	1.0	.8	1.0	[3] .6	[1] 0.4	
1928	[1] 0.3	[1] 0.2	[3] 0.6	1.3	5.6	5.8	1.9	1.2	.9	.9	.7		
1929				.9	3.2	3.0	1.1	1.8	1.0	.9	.6		
1930				1.7	3.2	3.5	1.6	2.7	1.2	.8	[3] .7		
1931			[3] .4	.8	2.4	3.2	1.4	.7	.7	1.0	[3] .7		
1932				1.9	6.1	[3] 4.8	2.3	1.2	.8	.7	([2])		
1933			([2])	.7	3.8	7.6	2.4	1.0	.6	.6	.5		
1934				1.4	2.4	1.4	.8	.7	.5	.5			
1935			.5	.8	2.7	7.7	2.4	1.2	.8	[3] .8			

[1] Estimated.
[2] Partial record.
[3] Partially estimated.

Records from April 1923 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 141.—*Run-off of Trinchera Creek above Mountain Home Reservoir near Fort Garland, Colo.*

[Drainage area 61 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1923					1.4	2.3	0.7	0.9	1.0	0.8	0.8		
1924				[1] 1.4	6.3	3.9	1.2	.4	.4	.2	.4		
1925			([2])	.3	.9	[illegible]	.6	.5	[illegible]	[illegible]	.5		
1926				.5	5.5	10.4	2.4	.9	[illegible]	[illegible]	.3		
1927				.7	2.5	3.2	1.3	1.0	.5	.8	.6		
1928				.7	5.5	5.3	1.3	.8	.5	.2	.2		
1929				.4	2.4	2.5	1.1	1.4	1.1	.9	.7		
1930				.8	1.9	2.5	2.0	3.2	1.3	.8	[3] .5		
1931				[3] .6	[1] 1.7	2.5	1.1	.8	.6	.8	[3] .5		
1932			[1] 0.6	1.7	5.3	3.8	1.5	.8	.6	.6	([2])		
1933				.7	3.3	7.6	2.0	.8	.6	.6	.4		
1934				.8	1.7	1.3	.6	.5	.5	.5			
1935				.4	1.8	5.6	2.0	1.2	.7	.9			

[1] Partially estimated.
[2] Partial record.
[3] Estimated.

Records from May 1923 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934, to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 142.—*Run-off of Trinchera Creek below Smith Reservoir near Blanca, Colo.*

[Drainage area 396 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1928										0.1	0.1		
1929				0.9	1.6	0.7	0.6	0.4	0.1	.1			
1930				1.9	.2	.7	.6	.3	.1	.1	.1	[1] 0.1	
1931	[1] 0.1	[1] 0.1	[1] 0.1	1.7	3.2	1.0	.8	.2	.1	.1	[2] .1		
1932			1.6	6.7	7.3	.7	1.1	.7	.4	.1	.1		
1933				1.1	4.0	1.9	.5	.5	.1	.1	[2] .1	[1] .1	
1934	[1] .1	.2	1.6	2.6	.1	.3	.2	.1	.1	.1	.1	.1	5.6
1935	.0	.0	.0	.2	.5	1.6	.3	.7	.1	.1			

[1] Estimated.
[2] Partially estimated.

Records from October 1928 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 143.—*Run-off of Sangre de Cristo Creek near Fort Garland, Colo.*

[Drainage area 176 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	
1916			(1)	[2]2.5	5.6	[3]1.5	(1)	0.5	(1)	(1)			
1923					3.5	1.8	0.8	.9	0.9	1.4	1.2		
1924				[4]8.9	18.1	5.5	1.4	.5	.2	.9	.9		
1925				2.0	1.7	.8	.3	.3	.1	.2	.3		
1926				4.8	13.8	5.2	1.7	.4	.3	.4			
1927				3.2	3.3	1.2	.8	.5	.4	.6			
1928				2.0	11.5	4.1	1.0	.6	.1	.4	.5		
1929				2.3	4.9	1.6	.5	.7	.5				
1930													
1931										.5	[4].4		
1932				6.5	9.4	2.6	.9	.5	.1	.6	[4].4		
1933				[4]1.4	6.9	4.6	1.2	.5	.5	.5	[4].4		
1934				2.7	1.5	.3	.1	.0	.0				
1935				.9	4.9	2.8	.6	.7	.2	.9			

[1] Partial record.
[2] 26 days
[3] June 11 missing.
[4] Partially estimated.

Records from March 1916 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 144.—*Run-off of Ute Creek near Fort Garland, Colo.*

[Drainage area 32 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1907							2.4	1.1	1.6	1.2	1.0	0.7	
1908	0.4	0.6	0.7	1.1	1.8	2.3	2.1	1.4	.7	.7	.7	.4	12.9
1909	.3	.3	.6	1.0	3.3	4.4	2.0	1.5	2.5	.9	.8		
1916			(1)	(1)	(1)	[3]3.0	[3]1.7	[4]1.2	(1)	(1)			
1923					2.3	3.4	1.8	2.1	1.6	2.1	1.5		
1924				[2]3.3	6.6	5.2	2.2	.8	.5	.6	.5		
1925				1.2	1.4	1.0	1.4	1.2	.7	.6	.7		
1926				2.0	4.7	4.9	1.7	.6	.4	.3	[2].3		
1927				1.5	8.7	2.9	2.8	2.3	1.5	1.0	.7		
1928				1.0	4.2	3.5	1.7	1.7	.6	.5	.6		
1929				1.3	4.0	4.0	3.0	3.5	2.6	1.5	1.0		
1930				2.2	2.1	2.6	2.4	2.0	.4	.7	[2].5		
1931				1.4	4.1	4.6	1.7	.6	1.5	1.1	[3].8		
1932			[2].7	4.0	6.3	4.8	4.0	1.9	.8	.7			
1933			(1)	.8	2.1	4.1	1.4	1.7	1.2	.6	.5		
1934				2.0	2.4	.7	.5	.5	.7	.4			
1935				.6	1.8	6.7	2.9	1.8	.9	.9			

[1] Partial record.
[2] Partially estimated
28 days
24 days.

Records from July 1907 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to October 1905 are provisional records furnished by U. S. Geological Survey.

TABLE 145.—*Run-off of Conejos River near Mogote, Colo.*

[Drainage area, 282 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890 [1]	2.4	2.1	6.2	23.0	110.0	93.0	35.0	11.0	5.0	6.0	4.3	3.5	301.5	118.0
1891 [1]	3.0	2.6	6.1	35.0	84.0	101.0	39.0	12.0	7.5	13.0	4.6	3.7	311.5	121.9
1892 [1]	3.0	2.7	4.8	26.0	66.0	55.0	16.0	9.0	2.8	2.7	3.4	2.0	193.4	75.6
1893 [1]	1.7	1.8	4.1	13.0	50.0	45.0	7.0	7.0	3.0	2.8	3.4	2.0	140.8	55.1
1894 [1]	1.9	1.8	4.6	23.0	61.0	29.0	6.5	8.0	4.2	4.5	3.8	2.6	150.9	59.0
1895 [1]	2.2	2.0	6.1	50.0	58.0	59.0	23.0	13.0	6.0	5.9	4.4	3.6	233.2	91.2
1896 [1]	3.0	2.9	6.8	38.0	63.0	25.0	7.0	6.0	7.0	6.0	4.0	2.6	171.3	67.0
1897 [1]	2.5	2.1	6.2	27.0	90.0	83.0	25.0	9.0	9.0	25.0	7.0	4.8	290.6	113.7
1898 [1]	3.6	3.2	6.3	47.0	70.0	106.0	38.0	10.0	4.0	2.8	3.2	2.0	296.1	115.8
1899 [1]	2.0	1.9	4.6	16.0	35.0	30.0	15.0	11.0	4.8	6.0	5.0	2.3	133.6	52.3
1900 [1]	1.7	2.0	4.1	10.0	73.0	67.0	11.0	5.0	2.7	4.4	3.5	2.2	186.6	73.0
1901 [1]	2.2	1.8	3.8	18.0	66.0	50.0	12.0	9.0	6.0	2.8	3.8	2.0	177.4	69.4
1902 [1]	1.8	1.6	3.9	16.0	30.0	18.0	2.0	4.0	2.0	2.6	3.2	1.8	86.9	34.0
1903	[2].5	[2]1.5	[2]3.7	[2]18.0	79.4	138.0	39.7	10.6	9.3	8.5	[2]3.0	[2]1.5	313.7	122.7
1904	[2].9	[2]1.8	[2]4.0	16.8	31.3	19.0	4.7	19.4	13.9	31.7	[2]3.7	[2]2.7	149.9	58.6
1905	[2]2.9	[2]2.4	[2]6.2	17.7	94.9	132.0	32.5	13.1	5.2	4.4	4.1	[1]2.3	317.7	124.3
1906	[1]2.0	[1]1.9	[1]4.7	[2]23.0	82.4	[2]127.0	[1]44.0	[1]14.0	[1]11.0	[1]14.0	[1]6.0	[1]3.6	333.6	130.5
1907	[2]4.1	[2]3.0	[2]10.0	28.9	52.1	109.0	93.5	26.3	12.9	6.5	4.9	4.6	355.8	139.2

See footnotes at end of table.

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TABLE 145.—*Run-off of Conejos River near Mogote, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1908	[4]2.2	[4]2.1	[3]7.0	13.0	34.7	69.6	26.6	17.7	7.0	6.3	4.9	[3]2.4	193.5	75.6
1909	[3]2.4	[3]2.5	[3]5.0	[3]19.0	75.0	119.0	33.7	19.3	27.7	9.3	5.0	4.9	322.8	126.3
1910	3.6	2.8	10.4	29.9	75.0	43.9	10.9	10.5	3.8	3.9	3.3	3.7	201.9	79.0
1911	3.4	2.5	5.0	21.6	85.5	123.0	70.1	20.5	17.1	[3]46.0	[1]6.0	[3]5.0	405.7	158.7
1912	4.7	3.1	5.6	13.2	114.0	103.0	38.6	9.5	3.8	5.0	5.1	[1]2.0	307.6	120.3
1913	2.6	2.4	3.4	8.9	56.0	48.7	12.1	4.1	3.9	7.4	3.2	[1]4.8	157.5	61.6
1914	[4]2.9	[4]2.7	[3]7.0	17.7	56.6	80.3	28.1	18.9	17.0	13.1	4.4	[1]2.5	253.2	99.1
1915	2.3	2.8	3.7	18.4	45.4	92.8	43.0	12.9	6.0	5.0	3.6	2.5	238.4	93.3
1916	2.4	3.0	5.2	21.7	90.4	129.0	50.2	24.0	10.8	20.4	7.5	[4]4.0	368.6	144.2
1917	[4]3.7	[4]3.4	[1]5.0	19.4	46.4	138.0	76.2	15.4	5.4	3.1	2.6	1.9	320.5	125.4
1918	1.4	1.9	4.9	12.9	58.4	89.3	30.1	9.9	7.1	4.1	3.4	[1]2.6	226.0	88.6
1919	[1]2.7	[1]2.8	[1]5.2	29.5	84.2	61.9	31.4	10.8	5.8	4.4	3.8	3.9	246.4	96.4
1920	[1]3.3	[1]3.1	5.1	9.4	115.0	188.0	67.0	20.7	6.4	5.1	3.9	3.2	430.2	168.3
1921	2.9	3.2	7.1	10.9	63.3	106.0	31.3	19.3	6.6	3.9	3.1	2.5	260.1	101.8
1922	[1]3.5	[1]3.5	[1]5.5	11.4	104.0	128.0	32.5	11.3	3.5	2.9	3.7	3.4	311.2	121.8
1923	3.0	2.2	4.9	22.0	121.0	127.0	42.2	23.4	19.7	17.5	6.2	5.3	394.4	154.3
1924	4.4	3.7	4.9	34.0	108.0	81.5	27.2	6.6	3.2	3.9	3.5	3.2	284.1	111.2
1925	3.0	3.0	5.4	29.2	71.9	54.7	20.7	14.9	8.5	11.2	6.8	3.9	233.2	91.2
1926	3.8	3.1	4.4	18.9	76.9	92.8	27.1	9.2	2.7	3.8	3.0	3.0	248.7	97.3
1927	2.7	1.9	3.9	24.2	95.9	99.4	43.5	16.6	28.8	14.6	8.4	4.4	344.3	134.7
1928	3.4	2.4	4.0	13.7	67.6	61.9	15.6	8.6	4.9	3.5	3.0	3.0	191.6	75.0
1929	2.8	2.7	5.5	23.3	101.0	97.0	30.6	32.8	27.1	10.1	4.5	2.5	339.9	133.0
1930	2.2	2.8	3.4	33.3	54.0	63.7	20.5	14.0	3.4	3.8	1.8	2.2	205.1	80.2
1931	1.8	1.8	3.1	11.7	38.1	40.8	9.6	9.2	12.7	13.2	4.3	4.3	150.6	58.9
1932	3.2	3.1	5.1	30.1	108.0	118.0	54.6	18.6	6.5	4.5	2.9	2.6	357.2	139.7
1933	2.8	2.2	4.4	9.7	44.4	93.4	27.2	11.3	8.3	7.1	3.9	2.5	217.2	85.0
1934	2.2	2.5	5.4	30.5	36.1	7.0	4.3	4.0	4.4	3.3	2.6	1.9	104.2	40.8
1935	1.9	2.4	4.3	15.1	45.3	135.0	56.8	17.9	8.6	5.8	3.6	2.4	299.1	117.0
Mean	2.7	2.5	5.2	21.7	71.1	84.3	30.7	13.2	8.4	8.5	4.2	3.1	255.6	....
Percent of annual	1.06	.98	2.03	8.49	27.82	32.98	12.01	5.16	3.29	3.33	1.64	1.21	100.0	....

[1] Estimated by reference to Rio Grande near Del Norte from monthly relation curves.
[2] Estimated by reference to Rio Grande near Lobatos from monthly relation curves.
[3] Partial record extended by reference to Rio Grande near Del Norte or Lobatos.
[4] Estimate based upon relation of missing months to remaining months of the year as indicated by means for all complete years.

All records previous to October 1913 as published in U. S. Geological Survey Water Supply Paper no. 358 except as noted.
Records from October 1913 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 146.—*Run-off of Conejos River near La Sauses, Colo.*

[Drainage area, 887 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1911 [1]	5.0	4.8	7.0	6.0	71.0	100.0	56.0	8.5	9.0	60.0	6.2	5.6	339.1
1912 [1]	7.0	6.3	9.0	2.0	125.0	70.0	10.0	1.5	.8	1.1	5.5	3.1	241.3
1913 [1]	3.8	4.5	3.0	[illegible]	25.0	10.0	.2	.2	.3	3.0	[illegible]	[illegible]	[illegible]
1914 [1]	4.3	3.3	[illegible]	[illegible]	26.0	59.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1915 [1]	3.3	5.5	4.0	3.4	11.0	55.0	14.0	3.0	1.3	1.6	3.9	3.5	109.5
1916 [1]	3.5	6.0	8.0	5.5	80.0	109.0	24.0	11.0	3.5	20.0	7.5	4.0	282.0
1917 [1]	5.5	7.0	7.0	4.0	13.0	113.0	65.0	4.5	1.2	.9	2.5	3.1	226.7
1918 [1]	2.4	3.4	7.0	2.0	38.0	50.0	3.5	1.5	1.7	1.3	3.7	3.6	118.1
1919 [1]	4.0	5.7	7.0	19.0	72.0	20.0	4.0	2.0	1.3	1.4	4.2	4.1	144.7
1920 [1]	4.8	6.3	7.0	1.5	126.0	200.0	51.0	9.0	1.4	1.7	4.3	4.1	417.1
1921	[1]4.3	[1]6.5	[2]12.0	3.5	40.9	72.0	3.7	6.5	4.2	3.1	3.6	3.7	164.0
1922	[1]5.2	[1]7.3	5.4	6.4	110.0	98.8	7.7	.9	1.6	1.6	2.1	3.6	250.6
1923	3.7	4.4	3.7	7.7	109.0	101.0	8.9	11.7	14.0	10.1	9.5	6.0	295.7
1924	6.5	7.6	8.2	70.2	162.0	35.5	1.5	1.0	1.2	2.9	3.6	3.9	304.1
1925	3.8	5.4	5.7	13.9	27.2	6.4	.7	6.3	3.4	7.3	6.6	4.6	91.3
1926	4.7	5.0	5.8	19.2	84.2	53.3	3.7	1.2	1.4	1.4	2.0	3.1	185.0
1927	2.6	3.9	3.4	6.4	84.8	74.4	21.0	2.9	25.3	14.6	6.4	5.0	251.6
1928	5.0	5.4	6.0	6.0	52.3	26.6	.2	.3	.7	1.1	2.6	3.4	109.6
1929	3.3	4.6	5.1	6.8	94.7	45.7	1.4	18.8	18.2	2.5	6.2	4.9	212.1
1930	3.8	4.7	5.0	33.3	28.5	27.1	2.9	4.2	1.1	2.0	3.3	3.6	119.5
1931	3.5	5.3	6.8	4.0	3.6	.4	.1	.3	1.4	2.7	2.7	3.4	34.2
1932	3.6	6.7	8.6	11.8	123.0	101.0	38.9	.7	2.0	3.6	4.3	3.8	308.0
1933	3.9	4.2	4.8	1.2	24.8	58.8	1.6	.5	1.6	2.5	3.0	4.0	110.9
1934	4.6	4.3	3.4	1.2	.8	.1	.1	0	.5	1.1	1.9	2.9	20.8
1935	3.0	2.7	2.3	.8	42.8	110.0	26.4	1.7	2.3	3.3	3.7	4.0	203.0
Mean	4.2	5.3	6.3	9.6	63.5	63.1	14.0	4.2	4.4	6.6	4.3	4.0	189.5
Percent of annual	2.22	2.80	3.32	5.07	33.51	33.30	7.39	2.22	2.32	3.48	2.27	2.10	100.0

[1] Estimated by reference to run-off of Conejos River at Mogote and San Antonio River at mouth, from monthly relation curves.
[2] Partial record extended.

Records from March 1921 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

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TABLE 147.—*Run-off of San Antonio River at Ortiz, Colo.*

[Drainage area, 110 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1915		0	0.2	4.5	5.0	1.5	0.5	0.6	0.3	0.3			
1916													
1917													
1918													
1919				[1]3.7	10.6	1.1	1.7	.3	.6	.4			
1920			1.8	12.4	34.0	5.0	.6	8	.4	.5			
1921													
1922													
1923													
1924										.1	0.2		
1925			(²)	5.0	2.1	.6	.2	.3	.1	.1	.1		
1926				8.2	14.4	.9	.2	.2	.1	.1	.2		
1927				7.7	14.0	1.7	.6	.2	.1	.4			
1928			(²)	4.2	8.2	.6	.3	.4	.2	.1	[3].2		
1929				10.0	12.5	.8	.6	.7	.1	.4			
1930				(²)	6.6	.6	.7	.5	.1	.2			
1931					5.0	.1	0	.1	0				
1932				(²)	18.8	1.9	.4	.3	.1	.3	(²)		
1933				[3]3.6	9.9	2.7	.5	.1	.1	.2	[3].1		
1934				2.0	.3	0	0	.1	.1	.1			
1935				4.8	13.3	2.0	.3	.3	.2	.2	.1		

[1] Estimated.
[2] Partial record.
[3] Partially estimated.

Records from February 1915 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to November 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 148.—*Run-off of San Antonio River at mouth, near Manassa, Colo.*

[Drainage area 348 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1911 [1]	0.8	0.7	2.0	8.0	40.0	27.0	11.0	1.0	1.7	11.0	1.4	1.5	[illegible]
1912 [1]	1.6	1.6	2.5	3.0	64.0	20.0	2.5	.2	0	.3	1.1	0	
1913 [1]	.3	.6	.8	2.0	16.0	4.0	.3	0	0	.8	.5	1.4	
1914 [1]	.5	1.0	4.0	4.5	18.0	13.0	1.0	.7	1.7	2.2	.9	.2	
1915 [1]	.1	1.1	1.0	5.0	9.0	17.0	3.0	.3	.1	.3	.6	.2	
1916 [1]	.2	1.4	2.1	7.0	44.0	29.0	5.0	1.6	.5	4.0	1.9	1.0	97.7
1917 [1]	1.0	2.0	2.0	5.5	10.0	32.0	13.0	.4	.1	0	.2	0	66.2
1918 [1]	0	0	1.9	3.0	18.0	16.0	1.0	.2	.2	.2	.5	.3	41.3
1919 [1]	.4	1.3	2.1	14.0	39.0	7.0	1.1	.2	.1	.3	.7	.9	67.1
1920 [1]	.7	1.6	2.0	2.2	65.0	48.0	10.0	1.0	.1	.4	.7	.6	132.3
1921 [1]	.5	1.7	4.0	2.6	22.0	21.0	1.1	.7	.2	.1	.4	.2	54.5
1922 [1]	.3	2.1	2.2	2.7	56.0	28.0	1.3	.2	0	0	.5	.7	94.7
1923	[illegible]	[illegible]	1.9	[illegible]	45.9	19.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1924	[illegible]	2.3	3.4	12.3	[illegible]	3.5	.5	[illegible]	[illegible]	[illegible]	.3	.6	134.3
1925	.5	[1]1.4	[1]2.2	12.5	15.6	3.2	.6	1.8	.7	2.3	1.3	.7	42.8
1926	.7	1.1	2.0	16.6	46.2	16.8	1.3	.2	0	.1	.3	.2	85.5
1927	.3	.4	.4	7.0	52.2	26.2	5.4	.4	4.5	2.3	1.9	1.5	102.5
1928	1.4	1.1	1.5	5.5	30.1	8.6	.3	.2	0	.1	.1	.1	49.0
1929	0	.2	.5	7.4	47.4	10.9	1.9	4.1	3.4	1.9	1.5	1.0	80.2
1930	.5	1.9	1.4	24.0	22.9	9.9	1.4	1.5	.1	.3	.3	.1	64.3
1931	.1	.6	1.5	3.3	7.6	1.2	.1	0	0	0	.1	.6	15.1
1932	.6	1.4	2.1	10.9	62.7	30.0	8.7	.2	.1	.4	.5	.2	117.8
1933	.2	.2	.9	1.2	23.7	18.8	.6	.1	0	0	.2	.2	46.1
1934	.2	.3	.3	2.3	2.1	.2	0	.0	0	0	0	0	8.4
1935	0	.1	.1	2.6	36.6	32.3	4.1	.6	.4	.5	.4	.3	78.0
Mean	.5	1.1	1.8	8.0	34.7	18.0	3.0	.7	.7	1.3	.7	.6	71.1
Percent of annual	.71	1.55	2.53	11.25	48.81	25.32	4.22	.96	.96	1.83	.98	.84	100.0

[1] Estimated by reference to Conejos River at Mogote from monthly relation curves.

Records from April 1923 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 149.—*Run-off of Los Pinos River near Ortiz, Colo.*

[Drainage area 167 square miles. Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1915	0.8	0.9	1.5	14.0	30.5	28.6	6.3	2.7	1.2	1.1	1.2		
1916				[1]15.2	58.2	[1]37.4	[1]9.2	3.3	1.8	6.5		1.1	
1917					32.5	45.7	12.1	2.0	1.2	.8	.8		
1918			[1]1.5	9.1	34.4	19.3	5.1	1.4	1.1	1.0	1.2		
1919				21.5	53.1	17.0	7.8	4.6	1.9	1.3	1.1		
1920			2.0	8.5	76.2	45.8	9.5	2.7	.8	.8	.9		
1921													
1922													
1923													

[1] Partially estimated.

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TABLE 149.—*Run-off of Los Pinos River near Ortiz, Colo.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1924										1.5	1.2		
1925				20.8	26.4	9.5	3.1	4.5	1.8	3.3	[2] 1.8		
1926				16.0	46.1	22.4	4.3	1.7	.9	1.0	1.1		
1927				12.0	56.9	26.4	7.0	2.6	6.0	3.7	[2] 2.1	[1] 1.1	
1928	[2] .9	[2] .7	[1] 1.8	9.3	38.6	13.2	2.8	1.5	1.0	.9	[1] 1.0		
1929				15.9	48.4	17.0	4.7	6.9	5.2	3.2	2.3		
1930			2.4	28.0	38.6	16.8	[2] 3.1	[2] 3.0	[2] 1.2	[2] 1.4			
1931			(1)	6.1	17.6	7.3	2.3	1.1	1.4	2.2	[1] .9		
1932			[2] 4.3	18.4	67.0	28.0	13.1	2.6	1.2	1.5			
1933				6.0	30.8	26.3	5.1	2.0	1.8	1.6	1.3		
1934				14.8	7.0	1.6	.8	.9	1.1	.9	.8		
1935				9.7	40.3	42.3	8.0	3.4	1.7	1.4			

[1] Estimated.
[2] Partial record.

Records from January 1915 to September 1933 from the biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 150.—*Run-off of Culebra Creek at San Luis, Colo.*

[Drainage area 220 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1909					8.7	11.5	7.6	7.9	8.5	5.0	3.0	1.8	
1910	2.4	2.1	6.1	7.7	11.8	6.7	1.8	3.3	2.2	2.2	2.3	1.8	50.4
1911	2.2	1.9	2.4	2.3	4.7	3.5	4.6	3.6	2.0	4.4	2.5	3.0	37.1
1912	2.6	2.7	2.3	2.7	10.0	11.6	9.6	4.0	2.3	2.7	2.4	2.5	55.4
1913	2.2	2.0	2.5	2.4	8.6	10.0	9.1	4.2	1.3	2.5	2.4	1.8	49.0
1914	1.7	1.6	2.2	1.7	4.2	15.8	8.8	4.6	2.5	2.9	2.9	2.6	51.5
1915	2.5	2.3	2.3	2.6	8.9	19.9	14.2	5.0	2.4	2.5	2.6	2.6	67.8
1916	2.4	2.5	3.4	3.3	10.6	18.4	7.5	5.1	2.8	2.6	2.3	2.2	63.1
1917	2.2	2.0	2.4	2.2	3.5	20.4	15.8	7.5	2.2	2.3	2.2	2.1	64.8
1918	2.1	1.9	2.2	1.9	8.9	7.1	11.3	5.6	3.4	3.0	2.0	2.1	51.5
1919	(1)	(1)	(1)	2.1	4.5	18.8	11.1	7.9	(1)				
1927				1.1	6.6	8.9	8.1	4.0	2.4	1.8	[2] 1.4	[2] 1.4	
1928	[3] 1.4	[3] 1.3	1.3	1.2	4.8	15.5	9.1	4.2	1.0	1.4	[2] 1.3	[2] 1.2	43.7
[illegible]	[3] 1.1	[3] 1.1	[2] 1.2	.7	2.1	12.1	5.6	3.3	1.5	1.8	2.1	[2] 1.5	34.1
[illegible]	[2] 1.2	[3] 1.1	1.3	1.2	8.4	11.3	6.0	5.5	2.7	1.8	[2] 1.6	[3] 1.5	42.6
[illegible]	[2] 1.5	[3] 1.4	[2] 1.5	[2] 1.5	3.6	11.7	6.2	3.0	1.5	1.6	1.5	[2] 1.5	36.5
[illegible]	[2] 1.5	[2] 1.4	[2] 1.4	1.4	2.4	8.4	7.6	5.5	2.2	1.8	1.7	1.7	37.0
1[illegible]	[3] 1.4	[2] 1.1	[2] 1.2	1.1	3.1	10.8	9.4	6.2	2.4	1.7	1.7	1.5	41.6
1934	1.5	1.2	1.1	1.1	6.8	6.2	5.8	2.8	1.2	1.4	1.1	[2] 1.2	31.4
1935	1.2	.8	.9	.6	1.6	9.1	7.5	6.5	1.8	2.0	2.0	1.7	35.7

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records from January 1910 to December 1911 and October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from May to December 1909 and from January 1912 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 151.—*Run-off of San Luis Creek near Villa Grove, Colo.*

[Drainage area 255 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1922				0.9	1.2	0.6	0.3	0.4	0.3	0.4			
1923				1.2	.7	2.0	.6	2.0	2.0	2.0	1.4	[1] 0.7	
1924				9.3	13.1	5.0	.7	.6	.5	.5	.6		
1925				.9	.9	.5	.3	.6	.5	.5	.3		
1926				1.6	3.6	3.1	.8	.7	.4				

[1] Partially estimated.

Records from biennial reports of the Colorado State engineer.

TABLE 152.—*Run-off of Kerber Creek near Villa Grove, Colo.*

[Drainage area 39.5 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1922				0.4	0.5	0.2	0	0	0				
1923						1.9	1.1	2.0	1.0	0.7	[1] 0.5		
1924				2.6	6.8	5.0	1.0	.4	.3				
1925				1.1	2.0	.9	.5	.4	.3	[2] .3			
19[illegible]				1.5	4.3	3.4	1.0	.3	.2				

[1] Partially estimated. [2] Estimated.

Records from biennial reports of the Colorado State engineer.

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TABLE 153.—*Run-off of Saguache Creek near Saguache, Colo.*

[Drainage area 490 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	A
1910								(1)	2.6	2.6			
1911			[2]3.7	4.1	8.8	12.9	18.8	8.0	3.8	6.6	2.9		
1912				4.5	16.6	14.0	8.2	7.3	(1)				
1913													
1914						16.5	10.9	6.8	3.6	8.1	1.9	1.0	
1915	1.4	1.5	2.6	7.1	13.6	14.0	5.7	3.7	3.0	2.8	2.2	2.0	59.3
1916	1.6	2.1	3.1	3.4	11.3	11.5	6.6	9.9	4.2	4.1	2.8		
1917			2.2	4.6	11.5	20.5	11.1	4.5	2.8	2.6	2.2	1.6	
1918	1.6	1.7	2.5	2.8	8.4	9.2	6.0	4.5	4.7	2.9	2.7		
1919				6.4	22.2	15.6	11.3	6.2	3.3	2.3	3.2		
1920			3.6	3.4	17.3	19.8	7.1	4.6	3.1	3.2	3.0		
1921			(1)	3.1	13.5	26.4	10.1	7.4	4.6	3.4	2.9		
1922				3.4	11.2	13.2	7.0	5.0	2.8	2.3	2.1	[2]1.5	
1923	[2]1.1	[2]1.1	[2]2.2	3.5	9.4	12.5	8.7	10.0	6.8	5.8	3.1		
1924				15.3	26.9	16.7	6.8	3.3	2.3	2.6	[3]1.9		
1925				5.6	8.1	6.6	6.5	6.1	4.5	4.1	[3]2.3	[2]1.8	
1926	[2]1.5	[2]1.2	[2]1.8	7.7	14.8	12.6	6.2	3.7	2.3	3.7			
1927				5.2	8.7	8.6	7.0	7.6	7.1	6.0	3.3		
1928				6.7	21.4	17.5	6.1	4.2	3.1	2.7	2.7		
1929				4.3	10.5	11.3	6.6	12.2	11.5	5.2	[3]3.6		
1930				(1)	5.3	4.9	4.4	7.9	3.3	2.9			
1931				[3]3.3	6.3	4.5	2.4	1.9	1.8	1.9	[3]1.5		
1932				[3]3.0	16.3	10.8	7.3	5.2	2.9	2.5	[3]2.5		
1933				2.2	5.0	8.3	4.4	4.6	2.1	2.1	(1)		
1934				3.1	3.8	1.7	1.4	2.2	1.9	1.4	1.4		
1935			1.7	2.3	4.9	13.2	7.3	4.8	2.6	2.5			

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records previous to September 1912 as published in U. S. Geological Survey Water Supply Paper No. 358.
Records from June 1914 to September 1934 from biennial reports of the Colorado State engineer.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 154.—*Run-off of Carnero Creek near La Garita, Colo.*

[Drainage area, 117 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919				3.0	7.9	2.7	1.9	1.0	0.6	0.5			
1920			1.0	.8	4.1	2.8	.8	.8	.4	.4			
1921				1.2	3.2	4.5	1.9	1.8	1.1	.6			
1922				(1)	2.8	1.4	.5	2.1	.7	.6			
1923				1.8	2.8	1.1	.8	2.3	2.0	1.8			
1924				7.9	10.6	3.5	1.2	.5	.2	.3	0.3		
1925			1.0	.9	1.0	.5	.9	1.3	.8	.6	.5	[2]0.3	
1926	[2]0.2	[2]0.2	[3].6	2.0	3.0	1.9	1.2	.7	.2	.4	[3].2		
1927			.7	.7	.7	.4	.5	.6	.6	.7			
1928				2.3	7.4	2.9	.6	.6	.5	.4			
1929				(1)	1.2	.7	.6	5.1	1.7	.9			
1930				.8	.6	.4	.8	2.8	.9	.5			
1931				[3].9	.9	.5	.4	.1	.1	.2			
1932				[illegible]	1.3	.3	[illegible]	[illegible]	[illegible]	[illegible]			
1933	[illegible]			[illegible]	.3	.5	[illegible]	[illegible]	[illegible]	[illegible]			
1934				[illegible]	.6	.2	.1	[illegible]	.2	[illegible]			
1935				.7	2.2	2.2	1.3	.7	.3	.3			

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records from April 1919 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to October 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 155.—*Run-off of La Garita Creek near La Garita, Colo.*

[Drainage area, 61 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919				2.3	9.3	2.7	3.0	2.2	0.6	0.4			
1920			0.4	.5	5.0	3.8	1.1	1.3	.6	.3			
1921			(1)	.6	3.2	7.5	4.0	2.8	1.7	.5			
1922				.9	4.3	1.9	.7	1.3	.6				
1923					3.4	2.3	2.0	2.9	3.1	2.6			
1924				7.5	13.0	3.8	1.1	.5	.3	.4	0.4		
1925				1.1	1.5	.7	1.8	2.8	1.2	.8	.5	[2]0.4	
1926	[2]0.3	[2]0.3	[3].4	2.3	7.2	3.0	1.2	.7	.2	.2	[3].4		
1927				.9	1.2	.7	.7	.7	.7				
1928				.9	2.6	1.5	.9	.9	.6	.5	.5		
1929				(1)	2.4	1.4	.8	3.6	1.5				
1930				1.0	.9	.7	1.0	2.5	.8	.6			
1931				.7	1.0	.7	.4	.3	.2	.3			
1932				.7	2.2	1.2	.9	.6	.3	[3].7			
1933				[3].4	.9	1.1	1.0	.7	.3	.3			
1934				.7	.6	.3	.3	.3	.2	.2			
1935				.7	1.9	2.9	1.2	.6	.5	.4	.2		

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records from April 1919 to September 1933 from biennial reports of the Colorado State engineer.
Records from October 1933 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to November 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 156.—*Run-off of Rio Grande below Taos Junction Bridge near Taos, N. Mex.*

[Drainage area, 6,550 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1925							(2)	27.1	43.3	48.3	50.8	39.7	
1926	31.4	31.8	49.2	63.5	175.0	168.0	38.2	17.7	15.9	16.9	27.8	32.8	658.3
1927	[3] 33.0	[3] 37.1	[3] 45.3	51.4	[3] 142.0	[3] 150.0	[3] 156.0	26.9	124.0	[4] 107.0	[3] 55.2	[3] 42.7	960.6
1928	39.5	37.9	47.4	32.8	[3] 126.0	[3] 83.7	14.9	[3] 13.0	[3] 12.0	14.0	24.3	24.5	470.0
1929	26.0	27.3	39.7	42.5	[3] 141.0	[3] 115.0	[3] 23.6	[3] 94.5	[3] 85.8	63.6	[3] 50.1	39.4	748.5
1930	30.1	[3] 39.8	39.6	[3] 64.0	53.3	[3] 49.7	[3] 27.6	41.2	[3] 19.3	24.5	24.6	30.2	443.9
1931	23.8	28.8	44.4	30.0	27.1	17.0	13.8	11.2	20.1	23.0	19.1	30.3	288.6
1932	30.8	34.9	50.4	66.8	222.0	205.0	107.0	22.4	24.8	21.8	31.6	30.3	847.8
1933	29.1	24.0	36.9	22.5	[3] 45.6	104.0	[3] 25.9	[3] 15.5	16.8	19.1	23.4	30.5	393.3
1934	30.5	35.0	30.2	20.8	23.0	14.3	12.2	12.9	14.4	14.9	14.5	22.2	244.9
1935	25.1	20.8	19.5	15.7	82.1	210.0	70.3	25.1	22.5	24.8	27.8	30.9	574.6

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Partial record.
[3] Partially estimated.
[4] Estimated.

Records from July 1925 to September 1930 from reports of New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 157.—*Run-off of Rio Grande at Embudo, N. Mex.*

[Drainage area, 7,327 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890	26.9	30.7	41.9	124.0	305.0	244.0	98.0	50.1	32.4	34.6	36.6	40.0	1,064.2	123.7
1891	36.0	34.2	56.4	141.0	367.0	300.0	145.0	57.4	27.9	103.0	46.3	34.0	1,348.2	156.7
1892	30.6	34.3	64.6	177.0	301.0	187.0	33.1	11.7	9.0	12.4	18.9	19.9	899.5	104.6
1893	20.4	23.0	30.8	85.4	192.0	151.0	13.9	14.1	17.1	22.3	19.6	19.7	609.3	70.8
1894	19.6	18.3	[3] 37.0	[3] 90.0	[3] 167.0	[3] 50.0	[3] 14.0	[3] 16.0	[3] 19.0	41.8	17.8	20.8	511.3	59.4
1895	29.2	27.9	46.5	151.0	165.0	180.0	82.1	66.4	37.8	80.4	36.4	32.8	885.5	103.0
1896	32.7	31.7	58.8	107.0	98.3	21.8	18.4	15.3	13.6	21.5	23.5	25.5	468.1	54.4
1897	24.2	22.7	34.5	101.0	335.0	275.0	78.3	20.8	20.5	94.6	67.7	33.9	1,108.2	128.8
1898	30.0	26.2	42.7	133.0	132.0	207.0	158.0	29.4	20.1	17.4	21.2	20.8	837.8	97.4
1899	28.9	26.7	46.8	64.9	56.8	14.8	18.3	14.5	18.4	21.9	31.8	29.4	375.2	43.6
1900	27.9	26.4	38.6	27.8	148.0	145.0	17.3	10.6	14.8	15.5	19.3	21.8	513.0	59.6
1901	21.1	25.9	31.9	38.8	192.0	102.0	24.8	27.7	21.4	20.4	21.2	26.1	553.3	64.3
1902	26.4	25.7	32.7	39.4	49.1	28.2	9.7	15.2	13.6	14.2	13.7	16.2	282.1	32.8
1903	19.5	20.8	48.4	58.7	158.0	534.0	92.6	20.5	20.7	19.9	25.8	17.4	1,036.3	120.5
[illegible]	[3] 20.0	[3] 21.0	[3] 16.0	[3] 22.0	[3] 16.0	[3] 15.0	[4] 6.0	[4] 42.0	[4] 61.0	[3] 122.0	[3] 31.0	[3] 30.0	406.0	47.2
[illegible]	[3] 33.0	[3] 31.0	[3] 78.0	[3] 78.0	[3] 515.0	[4] 511.0	[3] 34.0	[3] 28.0	[3] 17.0	[3] 21.0	[3] 28.0	[3] 27.0	1,401.0	162.9
[illegible] [5]	30.0	29.0	34.0	76.0	307.0	360.0	181.0	53.0	41.0	77.0	56.0	43.0	1,237.0	143.8
[illegible] [5]	40.0	40.0	68.0	180.0	302.0	562.0	425.0	144.0	89.0	53.0	40.0	34.0	1,977.0	229.9
1908	[4] 21.0	[3] 21.0	[3] 60.0	[3] 64.0	[3] 80.0	[3] 68.0	[3] 37.0	[3] 62.0	[3] 34.0	[3] 34.0	[3] 29.0	[4] 26.0	536.0	62.3
1909	[3] 31.0	[3] 32.0	[3] 45.0	[3] 103.0	[3] 320.0	[3] 371.0	[3] 61.0	[3] 50.0	[3] 156.0	[3] 73.0	[3] 31.0	[4] 39.0	1,312.0	152.5
1910	[3] 35.0	[3] 31.0	[3] 103.0	[3] 186.0	[3] 310.0	[3] 95.0	[4] 11.0	[3] 20.0	[3] 15.0	[3] 22.0	[4] 28.0	[4] 30.0	886.0	103.0
1911	[3] 34.0	[3] 33.0	[3] 36.0	[3] 80.0	[3] 199.0	295.0	[3] 303.0	[3] 58.0	[3] 57.0	[3] 228.0	[4] 58.0	[4] 43.0	1,394.0	162.1
1912	[3] 40.0	[3] 39.0	[3] 53.0	[3] 83.0	[3] 390.0	422.0	[3] 77.0	[3] 36.0	[7] 22.0	29.8	33.6	27.1	1,252.5	145.7
1913	23.8	25.0	40.6	80.3	87.3	78.0	17.8	17.0	18.3	44.1	41.6	25.7	499.5	58.1
1914	29.1	30.7	46.9	76.2	196.0	228.0	72.8	73.2	58.4	37.0	[illegible]	20.6	980.0	113.7
1915	28.4	31.0	48.[illegible]	116.0	139.0	356.0	[illegible]	50.0	29.[illegible]	31.2	32.2	22.7	970.[illegible]	112.3
1916	14.4	19.5	70.3	98.4	310.0	198.0	35.2	17.0	44.0	74.4	79.4	45.0	1,176.1	136.7
1917	37.6	33.9	46.4	73.4	153.0	298.0	190.0	34.0	23.1	25.7	35.6	35.1	985.8	114.6
1918	27.5	27.9	45.1	32.9	74.2	90.2	42.8	14.8	37.8	26.8	32.1	35.7	487.8	56.7
1919	34.3	31.4	55.9	149.0	297.0	128.0	75.6	45.7	20.5	36.5	44.8	43.8	962.5	111.9
1920	32.6	41.9	47.2	62.2	455.0	570.0	174.0	36.9	82.6	87.0	46.6	35.4	1,578.4	183.5
1921	35.9	36.1	65.9	43.0	140.0	493.0	127.0	100.0	48.2	34.2	43.0	41.8	1,211.1	140.8
1922	37.6	36.2	53.4	50.1	242.0	225.0	68.6	16.9	16.5	18.1	28.4	31.1	923.9	107.4
1923	32.7	28.7	32.8	39.7	179.0	196.0	42.5	60.3	76.0	108.0	72.5	41.8	912.0	106.0
1924	34.4	42.7	59.2	213.0	404.0	147.0	87.4	24.1	22.6	23.6	28.6	39.8	1,076.4	125.2
1925	[7] 29.2	31.7	56.4	56.3	49.0	29.6	22.0	33.0	40.7	46.3	46.2	48.8	489.2	56.9
1926	45.9	42.6	70.6	96.3	241.0	230.0	[7] 40.3	19.5	16.3	18.5	29.8	[7] 36.6	887.4	103.2
1927	34.8	[7] 34.3	46.9	52.8	162.0	148.0	[7] 174.0	33.5	134.0	104.0	52.4	[7] 40.4	1,017.1	118.3
1928	[7] 41.1	37.2	50.1	42.7	159.0	102.0	15.8	17.4	15.5	16.6	28.2	25.3	550.9	64.1
1929	[7] 25.3	26.4	40.3	49.8	162.0	124.0	[7] 28.7	101.0	96.0	75.9	54.4	44.5	828.3	96.3
1930	35.6	[7] 42.0	41.6	75.3	61.5	56.8	31.8	42.9	21.9	26.0	29.3	30.5	495.2	57.6
1931	28.7	32.5	51.0	37.9	36.4	25.9	16.2	14.3	25.0	26.5	22.9	33.4	360.7	41.9
1932	29.9	34.3	54.9	77.8	253.0	210.0	109.0	25.0	24.3	23.2	32.4	33.0	906.8	105.4
1933	29.5	26.0	41.8	22.9	51.8	118.0	27.8	16.7	19.7	20.6	23.4	32.0	430.2	50.0
1934	33.0	39.0	31.8	22.8	23.4	14.8	12.8	13.6	15.0	15.7	15.4	23.1	260.4	30.3
1935	27.3	23.0	20.4	22.9	111.0	249.0	71.1	34.0	30.5	29.2	30.0	34.6	683.0	79.4
Mean	30.6	31.0	48.3	82.0	200.1	205.7	72.8	39.2	36.0	46.9	35.3	32.2	860.1	
Percent of annual	3.56	3.60	5.62	9.53	23.27	23.92	8.46	4.56	4.19	5.45	4.10	3.74	100.0	

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Estimated by reference to Rio Grande near Del Norte from monthly relation curves.
[3] Estimated by reference to Rio Grande near Lobatos from monthly relation curves.
[4] Mean of estimates by reference to Rio Grande near Lobatos and to Rio Grande at Otowi Bridge from monthly relation curves.
[5] Mean of measured run-off of Rio Grande near Lobatos and at Otowi Bridge.
[6] Estimate based upon relation of missing months to remaining months of the year as indicated by monthly means for all complete years.
[7] Partial record extended.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358, except as noted; October 1930 to September 1934.
Records from October 1913 to September 1930 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 158.—*Run-off of Rio Grande at Otowi Bridge, N. Mex.*

[Drainage area 11,303 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Ann. run-off in percent of mean
1890 [2]	30.0	40.0	58.0	298.0	600.0	325.0	120.0	77.0	46.0	47.0	47.0	51.0	1,739.0	128.3
1891 [2]	46.0	47.0	97.0	340.0	720.0	400.0	170.0	89.0	39.0	145.0	60.0	43.0	2,196.0	162.0
1892 [2]	37.0	47.0	120.0	420.0	592.0	254.0	48.0	14.0	8.0	15.0	24.0	21.0	1,600.0	118.1
1893 [2]	18.0	26.0	28.0	200.0	380.0	208.0	27.0	18.0	21.0	29.0	22.0	23.0	1,000.0	74.0
1894	[3] 17.0	[3] 17.0	[3] 50.0	[3] 135.0	[3] 240.0	[3] 43.0	[3] 17.0	[3] 22.0	[3] 20.0	[3] 26.0	[3] 26.0	[3] 40.0	656.0	48.5
1895	[3] 34.0	32.8	84.3	338.0	264.0	276.0	109.0	91.1	43.0	42.1	49.6	43.8	1,427.7	105.3
1896	36.9	34.5	81.2	207.0	166.0	31.8	25.3	14.9	17.8	28.3	29.6	30.0	703.3	51.9
1897	28.7	30.1	60.8	303.0	702.0	366.0	97.3	27.4	40.5	136.0	71.9	32.2	1,895.9	140.1
1898	21.7	24.9	33.4	266.0	200.0	224.0	162.0	39.2	19.3	21.9	35.6	39.2	1,087.2	80.4
1899	26.0	35.6	81.2	176.0	118.0	23.7	36.6	22.2	53.1	26.6	45.0	38.2	682.2	50.5
1900	36.8	32.3	52.8	51.5	212.0	173.0	18.3	10.1	42.6	23.8	25.3	29.0	707.5	52.3
1901	34.4	36.5	45.6	83.4	319.0	131.0	44.8	50.8	34.5	30.2	27.5	28.5	856.2	63.4
1902	29.6	27.2	33.7	97.6	73.6	28.2	16.7	34.2	28.8	17.2	18.4	19.2	424.4	31.4
1903	23.1	24.7	75.2	172.0	407.0	709.0	137.0	26.6	22.3	21.8	25.2	23.6	1,667.5	123.2
1904	20.9	24.2	21.3	27.3	24.2	17.0	15.1	92.0	148.0	253.0	49.4	35.4	727.8	53.8
1905	43.5	51.6	158.0	219.0	785.0	573.0	53.7	38.7	23.2	26.0	38.0	37.9	2,047.6	151.1
1906	[4] 36.0	[4] 35.0	[4] 46.0	[4] 175.0	[5] 655.0	[4] 445.0	[4] 155.0	[5] 83.0	[4] 54.0	[4] 101.0	[4] 78.0	[4] 54.0	1,917.0	141.6
1907	[4] 57.0	[4] 52.0	[5] 104.0	[4] 385.0	[4] 488.0	[4] 570.0	[4] 485.0	[5] 228.0	[4] 119.0	[4] 69.0	[4] 54.0	[4] 41.0	2,752.0	203.0
1908	[4] 43.0	[4] 48.0	[4] 108.0	[4] 150.0	[4] 210.0	[4] 152.0	[4] 60.0	[5] 97.0	[4] 45.0	[4] 42.0	[4] 35.0	[4] 31.0	1,021.0	75.6
1909	[4] 39.0	[4] 40.0	[4] 61.0	[4] 235.0	[5] 570.0	[5] 456.0	94.7	89.8	203.0	81.2	29.1	35.5	1,934.3	143.0
1910	37.4	31.3	200.0	305.0	426.0	130.0	11.0	22.1	[6] 20.0	[6] 21.0	33.8	32.3	1,269.9	93.9
1911	47.7	41.5	91.6	150.0	408.0	340.0	350.0	69.5	64.3	336.0	132.0	77.5	2,108.1	156.0
1912	46.6	42.8	94.7	139.0	701.0	[5] 566.0	[6] 117.0	53.0	38.3	38.2	38.3	32.5	1,909.4	141.0
1913	33.8	35.9	48.9	146.0	180.0	112.0	37.8	16.8	25.8	49.9	49.3	35.2	771.4	57.0
1914	40.9	42.8	90.4	170.0	373.0	259.0	140.0	117.0	83.3	87.3	56.0	36.4	1,496.1	110.4
1915	[7] 37.0	[7] 40.0	[7] 73.0	[7] 234.0	[7] 460.0	[7] 483.0	91.5	71.2	43.4	39.9	35.5	38.7	1,647.2	121.7
1916	44.1	49.6	194.0	286.0	551.0	325.0	98.5	132.0	50.7	[5] 165.0	94.8	55.6	2,026.3	151.1
1917	42.1	41.5	64.8	163.0	312.0	455.0	196.0	37.6	27.8	24.8	37.4	35.2	1,437.2	106.2
1918	32.7	32.6	67.8	71.4	185.0	186.0	65.5	26.4	[5] 41.0	[5] 31.0	[5] 40.0	44.5	773.9	57.3
1919	35.7	33.6	86.2	315.0	570.0	301.0	138.0	88.9	36.1	53.3	53.6	54.1	1,665.5	123.1
1920	48.5	77.7	85.8	142.0	860.0	705.0	184.0	59.7	37.3	46.7	62.5	48.4	2,357.6	174.0
1921	45.1	47.1	102.0	72.3	259.0	672.0	108.0	192.0	94.7	47.4	49.8	53.5	1,742.9	128.7
1922	53.5	50.2	76.1	107.0	401.0	369.0	82.0	20.7	13.5	15.9	34.9	42.2	1,266.[illegible]	93.6
1923	44.3	46.9	56.8	95.4	397.0	261.0	58.2	82.0	118.0	138.0	97.5	70.0	1,465.1	108.3
1924	44.6	60.5	60.5	368.0	684.0	204.0	55.4	31.2	23.6	28.5	41.5	49.4	1,651.2	122.2
1925	46.1	50.1	79.6	151.0	119.0	48.0	48.7	74.8	42.6	66.1	68.7	57.6	845.3	62.5
1926	49.8	45.6	75.6	175.0	446.0	335.0	49.0	20.1	22.6	24.9	34.5	38.3	1,316.4	97.3
1927	35.1	40.1	66.7	177.0	436.0	224.0	186.0	53.3	157.0	131.0	72.1	58.1	1,631.4	120.3
1928	50.7	49.1	75.1	96.4	348.0	135.0	18.7	24.6	15.3	18.1	32.6	30.7	893.3	66.0
1929	33.7	38.3	63.5	120.0	347.0	184.0	51.6	162.0	148.0	104.0	66.0	56.4	1,377.5	101.7
1930	48.2	59.1	61.6	223.0	155.0	96.6	65.6	67.3	28.9	40.7	41.1	40.1	925.2	68.[illegible]
1931	36.6	46.4	64.1	71.3	124.0	38.5	21.6	22.6	58.0	63.0	36.7	46.5	629.3	
1932	39.2	62.6	130.0	327.0	537.0	296.0	143.0	41.5	31.3	35.1	45.2	40.6	1,728.5	
1933	42.2	38.5	59.5	59.0	177.0	195.0	46.5	30.2	31.3	30.2	30.7	40.7	780.8	
1934	41.2	46.5	43.9	70.1	43.4	16.3	13.5	14.5	22.9	19.4	20.4	28.3	380.4	
1935	34.2	31.3	29.1	55.8	201.0	363.0	88.3	84.1	63.8	54.6	55.1	40.6	1,100.9	82.0
Mean	37.9	41.0	77.0	185.8	379.3	275.1	94.7	60.4	51.4	62.9	46.7	40.8	1,353.0	....
Percent of annual	2.80	3.03	5.69	13.73	28.03	20.33	7.00	4.47	3.80	4.65	3.45	3.02	100.0	....

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Estimated by reference to Rio Grande at Embudo from monthly relation curves.
[3] Estimated by reference to Rio Grande near Del Norte from monthly relation curves for period 1895–1905.
[4] Estimated by reference to Rio Grande near Lobatos from monthly relation curves.
[5] Estimated by reference to Rio Grande at San Marcial from monthly relation curves. (Where there was a choice between methods (4) and (5), (4) was used unless an unusual condition due to the influence of the Rio Chama was indicated, in which case (5) was preferred.)
[6] Partial record extended.
[7] Estimated by reference to sum of Rio Grande at Embudo and Rio Chama near Chamita from monthly relation curves.

Records as published by U. S. Geological Survey; previous to October 1913 from Water Supply Paper No. 358 except as noted; October 1930 to September 1934.
Records from October 1913 to September 1930 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 159.—*Run-off of Rio Grande at Cochiti, N. Mex.*

[Drainage area 11,661 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1925	33.6	59.5	93.7	158.0	135.0	46.1	43.3	54.4	48.8	70.2	61.3	54.7	858.6
1926	[3] 62.0	[3] 71.0	[3] 118.0	[3] 242.0	[3] 532.0	[3] 230.0	[3] 62.8	[3] 18.5	[3] 18.0	21.0	30.1	39.9	1,435.3
1927	40.9	42.7	63.8	182.0	427.0	218.0	207.0	55.2	[3] 172.0	130.0	76.2	[3] 62.5	1,677.3
1928	[3] 53.5	52.5	76.0	84.6	300.0	136.0	15.0	[3] 29.1	14.3	[3] 14.3	[3] 39.9	39.2	854.4
1929	[2] 40.1	37.2	[3] 60.5	113.0	344.0	183.0	45.8	157.0	133.0	108.0	[3] 83.0	[3] 61.5	1,366.1
1930	[2] 48.3	[2] 56.2	60.1	214.0	156.0	101.0	55.0	61.1	23.0	22.2	32.1	35.4	874.4
1931	36.6	40.4	57.8	68.1	126.0	40.0	18.5	20.7	52.1	50.9	34.2	47.7	593.0
1932	42.2	80.0	121.0	303.0	488.0	256.0	167.0	36.0	30.2	32.8	46.3	[3] 42.8	1,645.3
1933	[3] 43.9	39.8	63.2	51.6	154.0	168.0	46.1	31.8	26.5	22.6	25.2	33.6	706.3
1934	40.8	42.5	37.9	61.7	31.7	8.8	4.4	5.0	15.4	10.7	15.1	29.5	303.5
1935	33.7	30.8	23.2	62.6	182.0	366.0	73.5	69.9	50.4	38.1	51.1	40.5	1,021.8

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Partially estimated.
[3] Estimated.

Records from January 1925 to September 1930 from reports of the New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 160.—*Run-off of Rio Grande at San Felipe, N. Mex.*

[Drainage area, 13,066 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1926	64.6	76.7	125.0	247.0	549.0	236.0	66.2	22.3	21.5	24.9	53.9	48.5	1,535.6
1927	43.3	47.9	74.6	174.0	460.0	251.0	317.0	89.9	204.0	137.0	82.7	62.2	1,943.6
1928	[3] 53.5	53.6	95.4	[2] 98.8	[2] 344.0	149.0	24.1	77.0	16.0	21.3	35.3	[2] 34.5	1,002.5
1929	32.1	[2] 36.9	56.1	107.0	340.0	164.0	[3] 77.2	[3] 169.0	180.0	111.0	84.8	74.5	1,432.6
1930	53.5	55.7	66.3	218.0	153.0	106.0	82.8	58.1	22.2	38.6	34.2	36.2	924.6
1931	35.4	47.1	60.5	66.0	139.0	36.8	24.4	23.4	61.2	42.2	35.4	[2] 49.3	620.7
1932	[2] 40.1	64.2	118.0	299.0	564.0	291.0	[2] 160.0	[3] 42.7	[2] 27.2	33.9	[2] 47.4	[3] 44.3	1,731.8
1933	[3] 44.3	[2] 42.7	[3] 78.8	[2] 58.5	[3] 166.0	216.0	51.7	[2] 34.9	[3] 28.5	27.1	39.4	60.3	848.2
1934	51.4	53.4	42.7	[2] 67.8	48.7	12.6	5.9	8.0	18.6	18.1	19.5	32.4	379.1
1935	32.8	30.7	29.3	58.1	209.0	385.0	93.1	120.0	75.2	43.5	66.6	44.1	1,187.4

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Partially estimated.
[3] Estimated.

Records from January 1926 to September 1930 from reports of the New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 161.—*Run-off of Rio Grande at San Marcial, N. Mex.*

[Drainage area, 24,176 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890 [2]	27.0	33.0	61.0	190.0	500.0	290.0	54.0	61.0	37.0	6.0	27.0	41.0	1,317.0	116.8
1891 [2]	40.0	66.0	152.0	328.0	1,000.0	430.0	128.0	56.0	92.0	135.0	32.0	31.0	2,488.0	220.6
1892 [2]	34.0	46.0	72.0	253.0	605.0	200.0	44.0	1.0	2.0	0	2.0	10.0	1,269.0	112.5
1893	[3] 23.0	[3] 24.0	[2] 17.0	[2] 100.0	[2] 330.0	[2] 25.0	[3] 0	[3] 0	[3] 0	[3] 4.0	[3] 0	[3] 18.0	541.0	48.0
1894	[3] 13.0	[3] 18.0	[3] 38.0	[3] 125.0	[4] 190.0	[4] 33.0	[4] 16.0	[4] 0	[4] 3.2	[3] 55.0	[3] 0	[3] 19.0	510.2	45.2
1895	[3] 33.0	53.8	129.0	279.0	223.0	233.0	149.0	179.0	[5] 25.0	[3] 23.0	[3] 26.0	[3] 38.0	1,390.8	123.4
1896	[6] 40.0	39.1	41.8	187.0	124.0	9.8	28.7	7.3	7.7	45.6	12.4	38.1	581.5	51.6
1897	19.5	24.3	40.8	213.0	755.0	366.0	66.0	6.1	114.0	282.0	176.0	153.0	2,215.7	196.5
1898	57.7	59.4	62.2	271.0	166.0	126.0	167.0	13.8	3.7	0	10.2	23.4	960.4	85.2
1899	27.9	24.6	27.5	54.1	35.0	1.0	28.4	6.4	2.9	.7	9.5	21.8	239.8	21.3
1900	40.6	35.1	33.2	5.3	124.0	160.0	.1	0	56.1	.1	2.4	10.1	467.0	41.4
1901	21.0	25.5	15.1	23.7	256.0	96.2	59.3	65.5	37.6	17.0	20.1	19.2	656.2	58.2
1902	22.7	17.4	8.0	40.1	26.8	6.4	0	49.2	13.3	.8	4.6	11.3	200.6	17.8
1903	17.2	21.9	46.8	100.0	318.0	660.0	77.8	3.1	1.4	.5	5.5	18.9	1,271.1	112.7
1904	16.8	18.9	6.1	0	0	0	10.5	56.0	44.7	463.0	51.8	41.8	709.6	62.9
1905	39.1	63.9	218.0	279.0	962.0	714.0	35.8	20.1	5.3	7.3	42.4	34.3	2,421.2	214.7
1906	36.5	39.7	56.9	163.0	501.0	345.0	118.0	43.2	25.5	70.8	77.8	86.1	1,563.5	138.6
1907	60.6	67.7	92.5	223.0	369.0	524.0	329.0	166.0	161.0	64.5	56.5	44.7	2,158.5	191.4
1908	43.6	48.0	77.4	124.0	165.0	90.5	49.0	95.7	9.7	2.8	29.9	38.4	774.0	68.6
1909	41.6	34.3	52.6	104.0	336.0	290.0	48.1	52.7	179.0	59.7	39.6	41.8	1,279.4	113.5
1910	61.3	42.0	144.0	190.0	309.0	63.1	1.1	7.3	3.0	.6	8.9	23.2	853.5	75.7
1911	30.2	35.7	87.1	92.5	304.0	270.0	392.0	63.2	39.2	313.0	116.0	57.0	1,799.9	159.6
1912	50.3	44.4	77.4	118.0	502.0	502.0	114.0	22.8	7.6	9.0	27.6	25.0	1,500.1	133.0
1913	22.4	38.1	35.3	99.1	129.0	96.1	6.9	.2	4.9	33.1	35.2	24.9	525.2	46.6
1914	38.1	40.1	35.9	116.0	267.0	312.0	160.0	[illegible]	33.1	[illegible]	43.2	40.0	[illegible]	104.6
1915	[illegible]	[illegible]	[illegible]	[illegible]	394.0	309.0	[illegible]	[illegible]	[illegible]	13.0	22.7	35.4	[illegible]	[illegible]
1916	47.8	47.1	54.0	234.0	488.0	306.0	45.7	97.8	19.4	162.0	88.1	48.9	1,648.8	146.2
1917	45.6	37.9	38.8	94.6	239.0	367.0	174.0	6.1	7.7	1.0	14.5	28.4	1,054.6	93.5
1918	28.0	22.8	45.6	30.5	117.0	67.2	22.4	1.7	0	11.0	24.3	40.7	411.2	36.5
1919	34.4	35.4	75.6	315.0	487.0	167.0	248.0	81.8	6.8	33.3	40.0	55.1	1,579.4	140.1
1920	51.3	87.4	84.2	139.0	676.0	863.0	176.0	38.9	5.9	14.7	46.1	39.9	2,222.4	197.1
1921	45.0	44.5	81.8	44.4	216.0	649.0	206.0	158.0	61.9	25.9	37.7	55.2	1,625.4	144.1
1922	58.5	48.8	56.9	81.5	344.0	311.0	49.6	0	0	0	0	12.7	963.0	85.4
1923	40.9	40.1	52.0	64.9	305.0	221.0	28.8	78.1	121.0	99.6	104.0	68.2	1,223.6	108.5
1924	56.0	77.1	76.9	407.0	608.0	134.0	30.0	7.2	2.9	0	3.8	15.1	1,438.0	127.5
1925	17.4	37.8	41.4	98.2	53.9	2.6	1.3	21.3	27.0	32.0	40.3	44.6	418.8	37.1
1926	45.2	37.1	59.0	118.0	440.0	272.0	27.2	1.6	3.9	3.2	8.9	31.4	1,047.5	92.9
1927	38.7	32.9	35.4	134.0	317.0	168.0	154.0	65.8	189.0	105.0	61.3	47.9	1,349.0	119.6
1928	49.6	47.0	49.7	40.2	251.0	106.0	.6	9.4	5.0	0	4.3	27.8	590.6	52.4
1929	26.5	29.6	43.0	78.8	276.0	132.0	38.1	275.0	308.0	123.0	76.2	58.4	1,464.6	129.9
1930	44.8	52.9	65.2	186.0	124.0	62.5	79.3	53.1	4.8	4.3	18.0	36.1	731.0	64.8
1931	39.2	45.8	49.6	53.1	92.8	5.1	8.0	6.9	59.0	55.6	26.8	47.9	489.8	43.4
1932	43.7	64.0	98.2	235.0	431.0	212.0	157.0	60.7	12.2	16.8	31.6	37.3	1,399.5	124.1
1933	45.1	38.6	47.5	16.8	94.5	253.0	55.2	37.9	42.3	15.0	23.0	46.2	716.0	63.5
1934	48.9	46.3	26.7	29.5	4.4	.2	0	31.7	25.5	.9	2.6	27.8	244.5	21.7
1935	44.9	39.1	23.4	21.5	182.0	368.0	36.0	108.0	64.6	37.2	51.2	53.6	1,029.5	91.3
Mean	37.9	41.6	63.4	138.5	318.2	230.8	81.7	48.9	41.2	52.7	34.4	38.4	1,127.7	
Percent of annual	3.36	3.69	5.62	12.28	28.22	20.47	7.24	4.34	3.65	4.67	3.05	3.41	100.0	

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Estimated by reference to Rio Grande at El Paso from monthly relation curves for period 1897-1913.
[3] Estimated by reference to Rio Grande at Embudo from monthly relation curves.
[4] Estimated by reference to Rio Grande near Del Norte from monthly relation curves for period 1895-1913.
[5] Estimated by reference to Rio Grande at Otowi Bridge from monthly relation curves.
[6] Partial record extended.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358 except as noted; October 1913 to December 1930. Records from January 1931 to December 1935 from water bulletins of the International Boundary Commission.

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TABLE 162.—*Run-off of Costilla River near Costilla, N. Mex.*

[Drainage area 229 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	A:
1911	[1]1.0	[1]1.0	2.3	[1]3.5	7.0	5.0	4.9	3.2	2.0	5.2	2.1	[1]1.0	38.2
1912	[1]1.0	[1]1.0	1.9	4.8	20.2	20.7	7.6	3.2	2.2	2.0	[1]2.0	[1]1.0	67.6
1913	[1]1.0	[1]1.0	[1]1.8	6.0	6.5	4.4	1.8	1.6	.9	1.1	1.3	1.1	28.5
1914	1.3	1.2	2.7	4.1	13.7	7.8	7.3	6.1	[1]1.6	[1]1.4	[1]1.0	[1]1.0	49.2
1915	1.2	1.1	1.7	7.7	17.7	24.0	5.8	4.7	1.6	1.6	1.5	[1]1.3	69.9
1916	1.2	1.1	2.0	5.6	14.8	9.0	4.8	4.0	1.5	1.4	[1]1.2	1.2	47.8
1917	1.1	.9	1.6	4.5	13.4	17.1	6.4	3.5	1.7	1.7	[1]1.2	1.2	54.3
1918													
1919													
1920	1.2	1.1	1.7	3.5	16.4	14.4	6.9	3.5	1.6	[1]1.7	[1]1.2	[1]1.1	54.3

[1] Partial record extended.

Records from 1920 report by George M. Neel to Costilla Estates.

TABLE 163.—*Run-off of Rio Colorado near Questa, N. Mex.*

[Drainage area 112 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912										(1)	1.5	1.2	
1913	[3]1.2	[3]1.1	[3]1.4	2.7	6.3	6.1	3.1	1.8	1.6	1.7	1.4	[3].7	29.1
1914													
1915	[3]1.1	1.2	1.3	3.7	13.0	15.8	7.9	4.4	2.6	2.0	1.0	[3]1.3	55.9
1916	1.9	1.6	2.4	4.8	25.8	20.2	6.8	5.0	2.7	2.5	2.0	1.2	76.9
1917	1.7	1.2	1.3	1.8	8.3	17.5	8.0	2.6	1.7	1.3	.9	.8	47.1
1918	1.2	1.3	1.2	2.2	10.2	11.7	5.8	2.6	2.0	1.5	1.0	.5	41.2
1919	.6	1.1	.6	2.4	18.7	12.6	12.3	4.5	2.1	1.7	1.3	1.8	54.7
1920	1.7	1.4	1.7	3.4	19.0	5.8	3.6	3.7	1.8	1.7	1.5	1.4	46.7
1921	1.5	1.5	2.2	2.8	42.7	29.2	8.7	6.4	4.0	2.1	1.6	1.8	104.5
1922	1.9	1.7	2.7	2.9	8.0	5.4	3.0	2.3	1.3	1.3	1.2	1.2	32.9
1923	1.5	1.7	2.4	2.8	11.9	10.2	5.0	3.2	3.2	3.2	2.1	2.5	49.7
1924	2.7	2.0	4.4	11.2	21.7	19.6	18.2	1.9	1.8	1.9	1.7	1.5	88.6
1925	1.2	1.4	1.8	3.0	5.1	3.3	2.5	2.4	2.1	2.0	1.5	1.5	27.8
1926	1.3	[3]1.4	[3]2.0					[3].7	[3]2.0	[3]1.8	[3]1.4	[3]1.0	
1927	1.1	.6	1.6	3.9	10.3	9.2	4.2	2.5	2.6	[3]2.0	[3]1.3	1.1	41.0
1928	[3]1.4	[3]1.3	[3]1.3	[3]2.0	9.3	7.8	[3]4.0	[3]2.5	1.9	1.3	1.3	1.1	35.2
1929	1.2	1.0	1.2	2.5	[3]8.6	[3]9.5	[3]4.3	5.1	4.5	2.6	1.8	[3]1.4	43.7
1930	1.3	1.1	[3]1.3	5.9	7.0	6.5	4.7	7.4	3.1	2.3	1.5	1.5	[illegible]
1931	1.4	1.2	1.2	2.1	6.0	5.3	2.5	1.3	2.5	3.1	1.4	1.1	
1932	[3]1.5	1.4	1.8	8.5	18.5	[3]12.0	5.7	3.0	2.0	[3]1.8	1.8	1.1	
1933	1.3	[3]1.1	1.2	1.5	4.0	8.2	4.2	1.9	1.5	1.4	1.1	1.0	
1934	1.0	1.0	1.2	2.1	3.8	2.3	1.8	[3]1.6	[3]1.7	1.3	.9	.9	
1935	[3]1.1	[3]1.0	[3]1.1	[3]2.2	7.0	19.0	4.9	2.9	2.0	1.9	1.2	1.1	[illegible]

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey: Previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358; October 1930 to September 1934.
Records from October 1913 to September 1930 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 164.—*Run-off of Rio Colorado below Questa, N. Mex.*

[Drainage area 167 square miles. Unit, 1,000 acre-feet.]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912	2.8	2.1	2.4	3.5		(1)	2.5	2.6	2.9	2.5	1.6	1.5	
1913	1.6	1.3	1.5	3.5	7.2	6.1	2.6	1.5	1.3	1.7	1.3	1.1	30.7
1914	1.3	1.1	1.1	5.9	19.1	10.3	5.0	4.4	3.0	2.6	1.8	1.2	56.8
1915	1.6	1.5	1.7	4.8	17.0	25.4	10.3	4.4	3.0	2.6	2.1	1.8	76.2
1916	1.9	2.1	3.3	5.5	18.0	19.3	12.4	6.5	3.2	3.7	2.8	2.2	80.9
1917	2.0	1.9	1.8	3.2	12.1	18.1	8.6	3.3	2.5	1.9	1.7	1.3	58.4
1918	1.3	1.3	1.8	2.7	10.5	11.1	7.4	2.8	2.5	2.1	1.9	1.9	47.3
1919	2.0	1.8	2.0	6.0	16.7	12.7	8.5	3.8	2.7	2.6	2.2	1.9	62.9
1920	2.0	1.8	2.0	3.3	21.5	32.3	11.7	4.5	4.5	3.1	2.0	1.5	90.2
1921	1.4	1.5	2.2	3.1	20.5	26.7	8.7	7.1	3.7	3.0	2.2	2.1	82.2
1922	1.9	1.9	2.3	3.1	8.7	5.8	1.4	2.3	1.4	1.5	1.4	1.3	33.0
1923	1.4	1.1	1.4	1.8	12.7	9.2	5.3	3.6	2.7	2.1	1.7	1.0	44.0
1924	.6	.7	1.8	2.5	20.5	24.2	12.8	3.6	2.3	2.1	2.0	1.9	75.0
1925	1.3	1.4	2.3	5.2	7.7	5.4	1.9	2.0	1.8	1.7	1.6	1.6	33.9
1926	.9	1.3	1.7	7.2	9.3			.3	8.8	3.2	1.9	1.1	
1927	1.1	1.7	2.2	5.3	18.0	10.3	7.9	1.7	4.5	8.8	2.2	1.0	61.7
1928	[2].9	[3]1.2	[3]1.7	3.4	18.2	19.9	4.5	4.0	2.6	1.7	[3]1.2	[3].9	60.2

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Record previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to December 1928 from reports of New Mexico State engineer.

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TABLE 165.—*Run-off of Rio Hondo at Valdez, N. Mex.*

[Drainage area 38 square miles. Unit, 1,000 acre-feet.]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1915	------	------	------	------	------	------	------	------	------	------	------	(1)	------
1916	0.8	0.9	1.4	2.7	10.8	12.6	(1)	(1)	------	(1)	1.4	0.9	------
1917	1.0	.8	.8	1.0	3.3	(1)	3.8	0.8	0.7	0.2	.3	.6	------
1918	.4	.5	.8	.9	3.2	5.2	2.7	.6	.5	.2	.7	1.0	16.7
1919	.9	.8	.7	1.6	3.7	4.6	2.4	.7	.3	.6	.9	1.0	18.2
1920	1.2	1.1	.7	1.4	7.0	7.4	2.3	.7	.6	.4	.4	1.8	25.0
1921	.7	.6	.7	1.0	5.8	9.7	2.4	3.9	1.9	.8	.7	.7	28.9
1922	.7	.6	.7	1.0	2.7	2.0	.3	.3	.2	.1	.2	.4	9.2
1923	.6	.5	.5	1.1	6.1	5.0	.5	.6	.7	1.2	1.0	.9	18.7
1924	.8	.6	.7	2.5	9.4	8.3	3.1	1.2	1.1	1.1	.8	.8	30.4
1925	.9	.9	.9	2.2	1.2	.7	.3	.4	.2	.2	.7	.8	9.4
1926	.6	[2].6	[2].6	2.0	9.0	10.9	[3]1.9	[2].6	.7	.5	.6	[3].7	28.6
1927	.8	.7	1.3	3.4	6.2	6.3	1.2	.5	1.4	1.4	.8	.8	24.8
1928	[3].7	[3].8	.8	1.0	6.7	3.4	.3	.4	.2	.1	.4	[3].7	15.5
1929	[2].6	[2].6	.7	1.4	4.7	5.2	.6	1.4	2.4	2.1	1.1	[3].8	21.6
1930	.7	.6	.9	3.1	2.4	3.2	1.6	2.6	.5	.5	.6	.9	17.6
1931	.6	.6	.5	.7	1.3	.9	.2	.3	1.4	2.1	[2].9	[3].9	10.4
1932	1.1	.9	1.4	4.5	9.7	6.4	1.7	.8	.5	.2	.4	.6	28.2
1933	[3].6	[3].6	.6	.5	1.6	5.1	1.0	.5	.3	0	.1	.8	11.7
1934	.6	.5	.5	.7	1.8	.4	.2	.2	.3	------	------	------	------

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records from December 1915 to September 1930 from reports of New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.

TABLE 166.—*Run-off of Rio Hondo at Arroyo Hondo, N. Mex.*

[Drainage area, 71 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912	------	------	------	------	------	------	2.3	1.8	1.6	0.5	0.8	1.6	------
1913	0.7	0.7	0.8	1.2	2.8	2.6	1.4	.5	.5	.6	.8	.7	13.3
1914	.8	[1].8	1.0	1.1	3.9	3.1	1.6	.8	.5	.7	.8	.8	15.9
1915	[1]1.0	.9	1.0	2.5	10.7	15.5	3.9	.8	.6	.6	.7	[1]1.8	39.5
1916	1.6	1.6	2.5	4.8	15.0	13.0	2.8	1.7	1.6	1.7	1.6	1.7	49.6
1917	1.5	1.3	1.3	1.4	4.9	9.5	2.8	.0	.2	.6	.5	1.1	25.1
1918	.8	.9	1.1	1.5	4.1	4.4	1.3	.5	.7	.7	.6	.8	17.4
1919	1.1	.7	1.0	2.3	7.0	6.4	3.5	.8	.5	1.3	1.5	1.6	27.7
1920	1.9	1.4	.8	1.3	11.4	15.1	3.2	1.0	.8	.5	.7	1.1	39.2
1921	.9	.9	.8	.9	7.1	10.4	4.1	3.8	2.0	.8	1.1	1.3	34.1
1922	1.3	1.0	1.0	1.3	3.0	1.8	.3	.4	.3	.4	.4	.5	11.7
1923	.6	.7	.9	1.8	7.2	5.3	1.3	1.5	2.0	2.3	2.0	1.5	27.1
1924	1.0	.9	1.3	2.9	10.3	7.0	2.7	.6	.9	.8	.8	.8	30.0
1925	.7	.8	1.1	1.9	1.2	.4	.4	.3	.3	.9	1.0	1.1	9.8
1926	[2]1.0	[1].9	[1]1.0	[2]2.1	5.7	[2]6.3	1.7	[1].5	[2].6	.5	.7	.8	21.8
1927	.9	.7	1.0	2.6	7.5	6.6	[illegible]	.7	[illegible]	[illegible]	[illegible]	1.4	[illegible]
1928	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.9	.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1932	(3)	[illegible]	[illegible]	1.0	10.7	4.0	[illegible]	.3	1.1	.9	.9	[1].9	------
1933	[2].9	[1].8	[2].8	.7	1.7	[2]5.0	1.2	.6	.6	.6	.6	.9	14.4
1934	1.0	.8	.8	.6	1.3	.5	1.3	.4	.7	.7	[2].6	[2]1.0	9.7
1935	[2]1.0	[2].9	.9	1.0	4.0	7.8	1.6	1.0	1.1	1.2	.9	1.2	22.6

[1] Estimated.
[2] Partially estimated.
[3] Partial record.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; January 1932 to September 1934.
Records from October 1913 to December 1928 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 167.—*Run-off of Rio Pueblo de Taos near Taos, N. Mex.*

[Drainage area, 67 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1911	[1]0.4	0.7	1.3	3.3	9.0	3.6	1.5	1.2	1.0	2.8	1.5	[1]1.2	27.5
1912	------	------	(2)	2.8	[3]10.9	(2)	.8	.6	.6	[1].6	[1].5	.5	------
1913	[1].6	[1].7	[1].8	1.8	3.5	1.9	.9	.5	.5	.6	.5	.5	12.8
1914	.4	.4	1.0	------	(2)	2.6	1.4	1.3	.6	.6	.5	.5	------
1915	.5	.4	.8	4.1	8.7	3.1	1.9	1.1	.7	.7	.5	.6	28.1
1916	.6	.6	2.0	4.8	------	------	------	------	------	------	------	------	------

[1] Estimated.
[2] Partial record.
[3] 24 days.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to April 1916 from reports of the New Mexico State engineer.

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TABLE 168.—*Run-off of Rio Taos at Los Cordovas, N. Mex.*

[Drainage area 359 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1910	----	----	----	(1)	9.3	0.7	0.1	0.2	0.3	0.6	0.9	1.2	----
1911	[3] 1.3	1.3	3.2	5.2	13.3	5.1	3.5	1.4	1.5	8.4	3.9	[3] 1.2	49.3
1912	1.6	2.2	4.3	8.1	27.2	13.9	1.3	.5	.7	1.5	1.9	2.3	65.5
1913	[3] 1.5	1.6	2.6	5.0	4.5	2.8	.4	.5	.7	1.5	1.6	1.2	23.9
1914	1.9	1.5	2.4	6.8	25.0	6.7	2.4	1.7	1.1	1.5	1.5	1.3	53.8
1915	1.8	2.5	3.1	13.7	30.3	22.3	1.5	1.0	1.0	1.2	1.7	2.1	82.2
1916	2.8	3.3	5.5	9.1	17.6	8.1	1.7	1.9	1.4	2.9	2.0	2.3	58.6
1917	2.4	2.0	2.3	2.1	6.4	7.2	2.1	.7	.6	.8	1.4	1.1	29.1
1918	1.4	1.5	3.4	4.3	9.5	6.8	1.3	1.0	1.0	1.1	1.3	1.5	34.1
1919	1.8	2.2	3.2	10.3	21.5	11.3	6.9	3.2	1.8	3.2	2.8	2.7	70.9
1920	2.7	3.2	3.1	7.2	29.4	13.2	.9	1.1	1.2	.2	.4	.5	63.1
1921	.5	.5	1.0	.6	4.6	8.9	3.4	5.1	2.3	1.2	.4	.3	28.8
1922	.3	.4	1.2	1.0	.8	.1	.0	.3	.0	.6	1.2	1.7	7.6
1923	2.1	.0	1.7	1.7	6.8	2.6	.5	1.2	1.3	2.0	2.6	2.4	26.9
1924	2.7	2.8	2.6	11.4	19.3	5.6	1.1	1.1	.7	1.2	1.6	1.6	51.7
1925	1.5	2.0	3.1	2.5	.9	.3	.3	.2	.6	.8	1.7	1.5	15.4
1926	[3] 1.6	----	----	----	----	----	----	.1	.9	1.1	[3] 1.3	[3] 1.9	----
1927	[3] 1.7	[3] 1.6	2.7	6.9	[3] 10.1	5.1	.8	.7	1.4	[3] 1.9	[3] 1.5	[3] 1.5	36.9
1928	[3] 2.2	[3] 2.8	[3] 2.4	2.1	14.4	4.1	.3	[2] .4	[2] .4	[2] .6	1.3	[3] 1.6	32.6
1929	1.7	1.7	3.1	4.6	12.7	6.8	.8	3.5	4.3	3.3	2.6	2.4	47.5
1930	2.2	2.5	2.7	7.5	5.1	2.5	2.5	2.3	1.1	1.6	1.9	1.9	33.8
1931	1.7	2.1	2.7	2.2	2.2	.6	.3	.5	2.2	2.5	[3] 2.0	2.3	21.3
1932	[3] 2.3	4.2	5.0	14.2	21.9	5.5	2.2	1.7	1.3	1.6	2.0	[3] 1.7	63.6
1933	[3] 1.7	[3] 1.8	2.5	1.2	3.5	6.4	1.6	.8	1.0	.9	1.3	1.5	24.2
1934	[3] 1.6	[3] 1.7	1.4	.9	.9	.5	.3	[3] .3	.6	.7	1.1	1.0	11.0
1935	1.9	1.4	1.4	1.6	13.6	13.0	.7	1.1	1.4	1.4	1.6	1.6	40.7

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; October 1930 to September 1934.
Records from October 1913 to September 1930 from reports of the New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 169.—*Run-off of Rio Lucero near Arroyo Seco, N. Mex.*

[Drainage area 17 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1910	----	----	----	----	----	----	----	----	----	----	----	(1)	---
1911	0.4	0.4	0.7	1.5	4.4	4.7	3.6	2.4	1.6	2.7	1.4	[2] 0.9	
1912	----	----	(1)	1.0	4.7	5.7	2.5	1.1	.7	.5	.4	.4	----
1913	[2] .4	[2] .4	[3] .4	1.3	2.9	2.6	1.3	.9	.8	1.2	.8	.7	
1914	.5	.3	.8	[3] 1.7	4.7	5.4	2.0	1.6	.9	1.0	.6	.5	20.0
1915	.4	.3	.6	2.0	3.1	6.9	3.2	1.6	.7	.5	.9	.7	20.9
1933	----	----	----	----	----	----	----	----	----	----	(1)	[3] .4	----
1934	[3] .3	[3] .2	.6	1.3	2.6	1.3	.7	.7	.7	.6	[3] .4	[3] .4	9.8
1935	[3] .4	[3] .5	.6	1.2	2.6	6.2	2.1	1.2	.9	[3] .7	[3] .5	[3] .4	17.3

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Record as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; November 1933 to September 1934.
Records from October 1913 to December 1915 from reports of New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 170.—*Run-off of Rio Fernando de Taos near Taos, N. Mex.*

[Drainage area 64 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912	----	----	----	----	----	----	----	----	----	[1] 208	121	105	----
1913	[1] 42	49	269	1,340	922	672	218	133	111	235	177	66	5,234
1914	141	127	603	2,130	3,720	643	621	497	246	243	178	165	9,313
1915	182	160	303	2,710	5,200	2,330	639	460	260	200	182	143	12,769
1916	232	389	967	2,200	4,260	706	303	396	249	256	142	91	10,191
1917	123	125	271	434	1,100	421	112	66	44	47	28	19	2,790
1918	14	47	575	603	1,520	461	438	107	112	152	172	152	4,353
1919	123	79	169	3,590	5,500	1,200	1,110	999	372	235	220	239	13,836
1920	218	350	531	1,620	4,260	1,630	847	499	248	93	157	146	10,599
1921	248	289	380	390	1,470	1,580	640	752	271	212	174	466	6,872
1922	221	126	680	1,290	920	179	584	150	27	22	38	58	4,295
1923	67	120	330	880	1,030	190	62	38	47	580	326	41	3,731
1924	63	180	113	2,260	749	342	305	140	44	37	43	73	4,349
1925	110	116	566	316	116	53	106	58	41	88	101	87	1,758
1926	38	81	299	3,397	7,853	2,108	190	123	69	73	105	48	14,384
1927	52	123	299	803	603	292	186	99	115	73	61	38	2,744
1928	[1] 92	137	388	1,097	2,707	322	230	190	94	66	129	[1] 98	5,550

[1] Partially estimated.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to December 1928 from reports of New Mexico State engineer.

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TABLE 171.—*Run-off of Embudo Creek at Dixon, N. Mex.*

[Drainage area 305 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1923										5.3	1.6	1.6	
1924	2.4	2.7	2.3	18.0	24.0	10.7	2.0	.2	1.7	2.6	2.0	2.2	70.8
1925	2.1	2.6	2.6	5.1	2.3	1.6	6.3	5.8	4.7	5.4	2.4	1.9	42.8
1926	1.6	2.0	3.9	6.8	13.8	8.4	3.2	0.6	3.8	2.6	1.7	1.6	50.0
1927	1.5	1.7	3.1	15.3	16.3	5.3	2.0	1.0	2.6	2.6	1.8	1.6	55.4
1928	1.4	1.4	2.0	8.4	21.4	[1] 9.3	[1] .8	3.1	1.4	1.8	2.1	1.7	54.8
1929	1.6	1.2	1.9	5.7	19.5	8.5	[1] 3.8	[1] 9.8	11.3	5.2	3.5	3.2	75.2
1930	2.0	1.6	1.7	[1] 11.4	8.6	[1] 6.8	[1] 5.7	6.2	2.0	2.0	1.6	1.7	51.3
1931	1.5	1.3	2.0	6.6	18.1	7.7	2.2	1.9	5.4	[1] 6.9	[1] 2.7	[1] 2.7	59.0
1932	2.2	4.2	6.7	21.9	[1] 26.3	[1] 11.2	[1] 3.0	4.8	3.1	3.6	2.1	1.5	90.5
1933	1.7	1.3	1.2	2.0	[1] 6.3	[1] 14.1	[1] 3.1	[1] 1.9	1.1	1.7	1.7	2.0	38.1
1934	1.7	1.2	1.4	2.2	1.9	.7	.3	.5	1.2	1.3	1.1	1.5	15.0
1935	2.1	1.5	2.3	9.1	30.0	29.5	5.3	9.0	6.1	4.0	1.9	2.0	102.8

[1] Partially estimated.

Records from October 1923 to September 1930 from reports of the New Mexico State engineer.
Records from October 1930 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 172.—*Run-off of Rio Chama at Chama, N. Mex.*

[Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912									(1)	1.8	1.5	0.9	
1913	[2] 0.8	[2] 0.6	1.1	13.9	25.5	12.4	3.0	1.6	1.4	2.1	1.6	1.3	65.3
1914	[2] .7	[2] .9	3.8	18.7	47.7	23.0	6.7	3.9	4.0	7.0	3.2	1.8	121.4
1915	[2] 1.5	[2] 1.2	[2] 2.8	22.6	38.2	35.8	10.9	3.4	2.0	1.3	(1)		
1916			(1)	29.2	62.1	34.3	11.5	5.5	3.2				

[1] Partial record.
[2] Estimated.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 355.
Records from October 1913 to September 1916 from reports of New Mexico State engineer.

TABLE 173.—*Run-off of Rio Chama at Park View, N. Mex.*

[Drainage area 405 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912											(1)	2.0	
1913	[2] 1.8	[2] 2.5	4.3	45.6	86.1	26.1	4.5	2.1	2.4	4.6	2.9	3.3	189.2
1914	[2] 3.1	[2] 3.0	9.1	50.8	133.0	48.6	12.9	7.3	7.0	12.2	6.4	4.1	297.5
1915	[2] 3.5	[2] 2.8	[2] 6.2	41.8	101.0	94.0	20.7	8.3	3.7	2.7	.8		
1925	[2] 3.7	[2] 2.5	[3] 18.4	[3] 107.0	61.9	[3] 16.9	[illegible]	[illegible]	[illegible]	10.7	[3] 15.9	[3] 4.0	251.[illegible]
1926	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[3] 3.3	[3] 3.[illegible]	336.3
1927	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59.0	21.7	8.4	28.7	16.7	[3] 9.0	[3] 6.5	431.9
1928	[2] 4.3	[2] 4.9	[3] 13.3	[3] 42.8	[3] 119.0	[3] 26.8	[3] 5.0	[3] 3.8	[3] 2.1	[3] 1.5	[3] 1.6	[3] 1.5	226.6
1929	[2] 1.8	[2] 2.2	[3] 6.0	[3] 55.2	119.0	33.0	[3] 8.8	20.5	[3] 20.0	10.3	[3] 6.2	[3] 4.3	287.3
1930	[2] 4.0	[2] 4.3	[3] 8.9	[3] 92.2	[3] 73.4	[3] 32.5	12.1	9.1	[3] 2.7	4.2	[3] 2.5	[2] 2.3	249.2
1931	[2] 2.1	[2] 3.1	[2] 4.3	18.3	54.4	12.6	1.9	2.0	4.8	7.0	[3] 4.4	[2] 5.6	120.5
1932	[2] 6.1	[2] 8.3	11.9	94.9	235.0	[3] 73.9	20.9	6.6	3.2	3.1	2.4	[3] 2.6	458.9
1933	[2] 2.8	[2] 2.5	[3] 5.0	[3] 21.5	[3] 92.2	60.4	[3] 11.2	[3] 4.7	[3] 5.7	[3] 5.4	3.1	[3] 3.4	217.9
1934	[2] 2.0	2.9	8.6	42.2	17.6	[3] 2.8	0.9	0.0	2.2	1.5	1.6	1.4	85.2
1935	2.0	2.5	4.8	39.7	133.0	114.0	17.6	8.9	6.6	5.2	3.1	2.8	340.2

[1] Partial Record
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; October 1930 to September 1934.
Records from October 1913 to September 1930 from reports of New Mexico State engineer.
Records from October 1934 to December 1934 are provisional records furnished by U. S. Geological Survey.

TABLE 174.—*Estimated run-off of Rio Chama above El Vado Reservoir, N. Mex.*

[Drainage area 873 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in per-cent of mean
1890 [1]	2.1	2.8	6.0	126.0	185.0	70.0	14.0	13.0	7.0	7.0	4.1	3.9	440.9	133.8
1891 [1]	4.3	4.4	20.0	144.0	214.0	80.0	16.0	14.0	6.0	24.0	5.0	3.8	535.5	162.5
1892 [1]	3.2	4.4	20.0	176.0	184.0	62.0	10.0	2.0	0	1.9	2.9	1.6	468.0	142.0
1893 [1]	.4	0	0	83.0	137.0	58.0	9.0	3.2	3.5	4.2	1.9	2.8	303.0	91.9
1894	[1] .2	[1] 0	[2] 5.0	[2] 80.0	[2] 120.0	[2] 28.0	[2] 8.0	[2] 2.0	[2] 2.0	[1] 0	[2] 4.3	[1] 4.3	253.8	77.0
1895	[3] 2.6	[3] .9	[3] 19.0	[3] 109.0	[3] 101.0	[3] 78.0	[3] 18.0	[3] 12.0	[3] 4.3	[3] 7.0	[3] 4.8	[3] 3.9	360.5	109.4
1896 [2]	2.4	0	10.0	72.0	63.0	14.0	7.0	0	3.7	4.3	3.1	3.2	182.7	55.4
1897 [2]	2.5	2.0	12.0	146.0	220.0	76.0	13.0	5.0	8.0	23.0	2.6	0	510.1	154.8
1898 [2]	0	0	0	97.0	63.0	23.0	3.0	7.0	0	2.9	5.0	4.3	205.2	62.3
1899 [2]	.1	2.6	17.0	79.0	55.0	13.0	12.0	6.0	12.0	3.0	4.8	3.8	208.3	63.2
1900	3.9	1.3	4.6	17.0	60.0	37.0	1.0	0	10.0	5.0	4.0	3.7	147.5	44.7

S   es at end of table.

TABLE 174.—*Estimated run-off of Rio Chama above El Vado Reservoir, N. Mex.*—Continued

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	of mean
1901 [1]	2.1	3.4	4.3	31.0	106.0	38.0	13.0	12.0	7.0	1.0	3.2	2.6	223.5	67.8
1902 [2]	2.1	0	0	42.0	24.0	2.0	5.0	10.0	7.0	2.0	2.8	2.8	99.7	30.2
1903 [3]	2.2	.4	12.0	82.0	165.0	117.0	28.0	4.8	1.6	1.5	0	3.6	418.1	126.9
1904	[4] 2.5	[4] 4.4	[4] 3.0	[4] 15.0	[4] 8.0	[4] 3.0	[4] 6.0	[4] 18.0	[4] 24.0	[4] 52.0	[4] 6.0	[4] 1.9	143.8	43.6
1905 [4]	6.0	11.0	42.0	91.0	182.0	66.0	10.0	6.0	3.5	4.2	5.0	2.9	429.6	130.4
1906	[5] 5.0	[5] 5.0	[5] 8.0	[5] 70.0	[5] 186.0	[5] 78.0	[5] 16.0	[5] 11.0	[5] 7.0	[5] 13.0	[5] 7.0	[5] 3.0	409.0	124.1
1907 [4]	8.0	7.0	21.0	141.0	145.0	101.0	35.0	26.0	8.0	9.0	5.0	2.3	508.3	154.3
1908	[7] 5.0	[7] 4.0	[6] 26.0	[6] 62.0	[6] 108.0	[6] 48.0	[6] 11.0	[6] 12.0	[6] 4.8	[6] 6.0	[6] 3.6	[6] 1.8	292.2	88.7
1909	[6] 6.0	[6] 6.0	[6] 10.0	[6] 91.0	[6] 163.0	[6] 79.0	[6] 15.0	[6] 13.0	[6] 11.0	[6] 7.0	[6] 0	[6] .3	401.3	121.8
1910	[4] 2.5	[4] 1.7	[4] 51.0	[4] 97.0	[4] 128.0	[4] 44.0	[4] 0	[4] 3.5	[4] 1.7	[4] 0	[4] 3.6	[4] 1.4	334.4	101.5
1911	[4] 7.0	[4] 6.0	[4] 27.0	[4] 67.0	[4] 144.0	[4] 52.0	[4] 30.0	[4] 7.0	[4] 4.1	[4] 47.0	[7] 4.7	[7] 5.0	400.8	121.6
1912	[4] 4.5	[4] 7.0	[4] 22.0	[4] 50.0	[4] 184.0	[6] 101.0	[4] 7.0	[4] 8.0	[4] 4.8	[3] 5.0	[3] 2.8	[3] 3.4	399.5	121.2
1913	[8] 2.0	[8] 2.7	[8] 5.0	[8] 52.0	[8] 88.0	[8] 28.0	[8] 5.0	[8] 2.5	[8] 3.5	5.1	3.3	3.6	200.7	60.9
1914	3.4	3.6	9.4	54.7	132.0	53.6	14.2	7.5	7.6	14.6	6.4	4.4	311.4	94.5
1915	4.0	3.3	10.9	78.0	123.0	94.6	18.2	8.0	4.0	2.7	1.3	[9] 4.1	352.1	106.8
1916	[9] 8.0	[9] 4.5	[9] 85.0	[10] 78.0	170.0	86.9	21.7	15.9	6.1	[9] 31.0	[9] 8.0	[9] 4.5	519.5	157.7
1917 [9]	7.0	4.0	14.0	47.0	125.0	99.0	21.0	4.7	1.5	1.0	2.8	3.2	330.2	100.2
1918 [9]	1.9	3.1	15.0	20.0	114.0	35.0	10.0	2.8	2.5	2.8	3.3	3.9	214.3	65.0
1919 [9]	4.8	3.1	25.0	80.0	147.0	46.0	38.0	12.0	1.8	8.0	6.0	5.0	376.7	114.3
1920	[9] 8.0	[10] 10.0	32.6	59.4	183.0	127.0	56.7	18.0	4.0	4.4	4.5	2.4	510.0	154.8
1921	3.1	4.2	13.0	21.9	119.0	68.3	11.7	19.7	7.8	5.8	3.6	2.8	280.9	85.2
1922	3.0	4.8	31.4	59.3	197.0	60.5	7.2	4.2	2.9	3.0	4.2	6.1	383.6	116.4
1923	7.3	7.8	10.5	36.7	149.0	61.5	12.6	13.7	23.8	15.2	8.5	4.9	351.5	106.6
1924	6.8	9.6	36.0	105.0	178.0	47.3	12.4	4.1	2.0	4.2	3.3	3.4	412.1	125.1
1925 [8]	4.4	3.0	15.0	76.0	57.0	19.0	7.0	11.0	6.0	13.0	9.0	7.0	227.4	69.0
1926 [8]	4.4	3.5	6.0	55.0	198.0	73.0	11.0	3.7	1.7	3.8	3.8	4.1	368.0	111.7
1927 [8]	4.0	4.5	14.0	102.0	186.0	65.0	24.0	10.0	33.0	17.0	10.0	6.0	475.5	144.2
1928 [8]	5.0	5.0	14.0	43.0	128.0	28.0	4.8	4.2	1.9	1.5	1.9	1.8	239.1	72.6
1929 [8]	2.1	2.8	9.0	67.0	127.0	33.0	10.0	28.0	22.0	10.0	7.0	4.7	322.6	97.9
1930 [8]	4.4	5.0	10.0	101.0	77.0	83.0	13.0	10.0	2.6	4.4	2.6	2.2	265.2	80.5
1931 [8]	2.3	3.6	6.0	22.0	58.0	13.0	2.1	2.1	7.0	12.0	5.0	4.8	137.9	41.8
1932 [8]	6.0	10.0	20.0	109.0	246.0	75.0	21.0	8.0	3.3	3.5	2.8	2.8	507.4	154.0
1933 [8]	3.0	2.8	6.0	23.0	98.0	64.0	13.0	6.0	7.0	6.0	3.2	3.7	235.7	71.5
1934 [8]	3.4	3.5	9.0	43.0	18.0	3.0	1.0	.6	10.0	1.5	1.6	1.6	96.2	29.2
1935	[8] 2.7	[8] 3.0	[8] 7.0	[8] 45.0	[8] 141.0	[8] 117.0	[8] 17.0	[8] 11.0	[8] 8.0	[8] 8.0	2.5	2.4	364.6	110.6
Mean	3.8	4.0	16.2	72.7	130.5	56.5	13.9	8.8	6.7	8.9	4.1	3.4	329.5	....
Percent of annual	1.15	1.21	4.92	22.06	39.61	17.15	4.22	2.67	2.03	2.70	1.25	1.03	100.0	....

[1] [2] [3] Estimated by reference to Rio Grande gain, Embudo to Otowi Bridge, from monthly relation curves: [1] Otowi Bridge, estimated; [2] actual records; [3] Embudo estimated.
[4] Estimated by reference to Rio Grande near Del Norte from monthly relation curves.
[5] [6] Estimated by reference to Rio Grande gain, Lobatos to Otowi Bridge, from monthly relation curves: [5] actual records; [6] Otowi Bridge estimated.
[7] Estimate based upon relation of missing months to remaining months of the year as indicated by means for all complete years.
[8] Estimated by adding to Park View run-off, 15 percent of Rio Chama gain, Park View to Chamita. Chamita flow corrected for storage regulation beginning Jant
[9] Estimated by reference to Rio Chama near Chamita from monthly relation curves.
[10] Partial record extended by reference to Rio Chama near Chamita.

Records from October 1913 to December 1924 for station "near Tierra Amarilla" from reports of New Mexico State engineer.
Records for November and December 1935 are provisional records furnished by U. S. Geological Survey for new station "below El Vado Dam, near Tierra Amarilla", corrected for storage.

TABLE 175.—*Run-off of Rio Chama near Chamita, N. Mex.*

[Drainage area 3,202 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912	....	....	....	....	....	....	....	....	....	....	(1)	2.6	....
1913	[2] 2.8	[2] 3.9	9.2	73.2	100.0	42.0	10.7	4.8	9.9	9.3	7.9	5.4	279.1
1914	7.1	10.5	38.5	94.6	175.0	44.7	43.5	18.5	12.6	21.2	11.1	5.8	483.1
1915	[2] 4.2	[2] 5.9	24.4	134.0	213.0	219.0	30.4	14.0	7.1	2.0	3.6	7.7	665.3
1916	10.3	13.4	129.0	208.0	322.0	86.1	26.7	35.7	9.1	43.4	14.7	8.8	907.2
1917	9.0	10.1	23.1	87.2	146.0	141.0	40.4	8.1	3.8	2.4	3.5	5.0	479.6
1918	(1)	(1)	23.7	39.9	106.0	37.2	(1)	4.1	5.3	4.7	4.5	7.1	....
1919	6.8	5.4	38.8	150.0	220.0	55.6	80.5	24.4	4.3	12.1	9.7	11.3	618.9
1920	10.0	37.1	53.9	120.0	313.0	141.0	61.5	19.4	8.3	9.2	7.7	5.2	786.4
1921	8.2	10.0	33.1	36.2	118.0	87.7	57.9	37.0	15.0	10.6	7.6	8.1	429.4
1922	7.2	15.6	29.4	48.6	126.0	82.9	12.1	4.5	.3	1.6	5.2	8.0	341.4
1923	7.7	25.8	31.8	85.2	159.0	69.5	34.5	27.0	20.6	20.0	14.4	10.3	505.8
1924	6.5	45.0	24.3	202.0	346.0	78.6	14.2	6.8	3.8	8.6	2.2	6.0	744.0
1925	5.9	10.4	23.6	122.0	91.4	16.1	12.1	16.9	4.7	13.8	8.9	8.0	333.8
1926	7.6	5.6	13.4	105.0	255.0	[2] 142.0	[2] 2.0	[2] 1.2	1.5	4.5	6.4	5.3	549.5
1927	4.8	6.1	29.7	138.0	301.0	96.0	34.5	12.9	55.5	19.4	[2] 12.7	[2] 11.4	722.0
1928	[2] 9.2	8.1	21.4	46.9	[2] 179.0	[2] 33.0	[2] 3.6	6.6	[2] .6	[2] 1.1	[2] 3.7	[2] 3.6	316.8
1929	[2] 4.0	[2] 6.0	23.4	131.0	170.0	32.1	[2] 15.1	[2] 70.4	35.9	11.6	[2] 11.0	[2] 7.1	517.6
1930	[2] 6.9	9.8	[2] 18.2	150.0	96.8	34.0	[2] 19.8	14.1	2.2	[2] 5.5	3.5	[2] 1.7	362.5
1931	[2] 3.5	[2] 6.2	13.2	44.2	77.0	13.8	3.5	3.0	20.2	40.1	[2] 8.3	[2] 8.0	241.0
1932	[2] 8.0	[2] 20.9	63.9	246.0	306.0	81.3	20.7	13.7	3.6	5.5	4.9	[2] 4.1	778.6
1933	[2] 4.3	4.8	14.2	31.2	[2] 128.0	[2] 84.7	[2] 22.0	[2] 11.9	[2] 11.9	7.1	3.7	5.5	329.3
1934	6.0	6.6	11.2	47.9	18.3	[2] 4.2	[2] 1.5	[2] 0.6	7.4	1.4	1.8	2.8	109.7
1935	4.6	5.6	6.9	33.5	89.4	120.0	13.3	37.3	31.6	31.9	21.8	10.0	411.9

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey. Previous to October 1913 in Water Supply Paper No. 358; October 1913 to June 1915; October 1930 to September 1934.
Records from July 1915 to September 1930 from reports of the New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

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TABLE 176.—*Run-off of El Rito Creek near El Rito, N. Mex.*

[Drainage area 52 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1931	...	...	...	...	(1)	250	90	155	174	210	[2] 244	[2] 91	...
1932	61	169	1,550	7,720	8,110	1,060	266	179	81	136	[2] 101	[2] 107	19,540
1933	[2] 97	[2] 98	[2] 276	1,210	3,780	992	250	113	80	89	73	[3] 123	7,181
1934	[3] 123	[2] 139	423	878	338	81	61	58	73	52	65	85	2,376
1935	127	129	304	4,100	7,340	1,430	186	146	102	102	80	62	14,108

[1] Partial record.
[2] Partially estimated.
[3] Estimated.

Records from May 1931 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 177.—*Run-off of Rio Ojo Caliente at La Madera, N. Mex.*

[Drainage area 344 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1932	...	...	...	[1] 30.5	33.6	[1] 3.8	1.0	1.3	[1] 0.3	[1] 0.6	[2] 0.6	[2] 0.7	...
1933	[1] 0.8	[2] 1.1	[1] 1.2	[1] 4.9	[1] 20.1	[1] 6.1	[1] 1.2	[1] .7	.4	.6	.8	[1] .9	38.8
1934	[1] .9	1.0	2.3	3.2	1.2	.4	.4	.2	.3	.6	.5	.8	11.8
1935	1.4	1.1	1.9	14.1	21.4	7.1	.9	1.1	.7	.6	.9	.9	52.1

[1] Partially estimated.
[2] Estimated.

Records from April 1932 to September 1933 from reports of U. S. Geological Survey.
Records from October 1933 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 178.—*Run-off of Rio Vallecitos at Vallecitos, N. Mex.*

[Drainage area 115 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1911	...	...	...	...	...	(1)	2.3	0.5	0.5	2.1	1.3	(1)	...
1912	...	...	...	6.3	32.9	4.9	.7	.3	.2	.3	.2	[2] 0.3	...
19..	...	...	0.6	13.0	10.4	1.7	.4	.7	.4	.6	.5	[2] .4	...
	[2] 0.4	[2] 0.4	1.3	11.5	18.8	2.3	1.0	2.2	.2	1.7	1.1	[2] .6	41.5

. artial record.
[2] Estimated.

Records previous to October 1913 from U. S. Geological Survey. Water Supply Paper No. 358.
Records from October 1913 to December 1914 from reports of the New Mexico State engineer.

TABLE 179.—*Run-off of Rio Santa Cruz at Cundiyo, N. Mex.*

[Drainage area 86 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1928	...	...	...	...	...	2,154	518	767	323	295	316	395	...
1929	385	310	441	1,755	4,539	2,913	...	...	...	...	...	...	...
1930	...	...	...	...	...	...	...	...	[1] 936	[1] 928	[1] 900	[1] 964	...
1931	[1] 736	[1] 621	[1] 1,120	3,260	4,630	3,430	1,440	[1] 1,110	5,030	2,230	[1] 1,060	[2] 1,420	26,067
1932	[2] 1,100	889	2,530	7,760	10,400	4,650	2,080	1,990	1,260	1,010	695	[1] 607	34,971
1933	[2] 490	[2] 530	[1] 680	986	2,470	3,370	2,090	[1] 1,560	[1] 956	690	574	[1] 496	14,832
1934	[1] 525	421	678	1,160	1,450	607	498	695	985	800	460	474	8,553
1935	[1] 450	461	1,050	2,550	8,440	9,500	2,160	2,950	2,100	1,100	829	837	32,427

[1] Partially estimated.
[2] Estimated.

Records from June 1928 to September 1931 from reports of the New Mexico State engineer.
Records from October 1931 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 180.—*Run-off of Nambe Creek near Nambe, N. Mex.*[1]

[Drainage area 37 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1932	...	...	...	...	...	...	...	...	...	415	[2] 328	[2] 157	...
1933	[2] 186	[2] 169	[2] 261	346	[2] 1,143	1,413	571	438	525	463	347	[2] 192	5,956
1934	152	130	187	400	551	[2] 232	[2] 133	[2] 392	679	99	264	[2] 501	3,720
1935	[2] 396	[2] 197	292	616	1,985	4,019	1,028	1,350	1,251	574	375	307	12,890

[1] Includes the diversion by Nambe canal above the station.
[2] Partially estimated.

-rds from U. S. Geological Survey; those from October 1934 to December 1935 are provisional.

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TABLE 181.—*Run-off of Santa Fe Creek near Sante Fe, N. Mex.*

[Drainage area 22 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1913	[1] 0.1	[1] 0.1	0.1	0.6	1.0	1.4	0.7	0.4	0.3	0.3	0.2	0.3	5.5
1914	.2	.2	.5	1.1	1.8	1.0	1.6	1.0	.4	.4	.4	.2	8.8
1915	.2	.2	.7	4.1	2.6	2.2	1.2	.6	.2	.2	.2	.1	12.5
1916	.4	.8	1.8	2.4	3.4	1.8	.8	.5	.3	.6	.3	.2	13.3
1917	.2	.2	.1	.2	.6	.6	.2	.1	.1	.1	.1	.1	2.6
1918	.1	.1	.5	.6	1.2	1.0	.5	.4	.2	.1	.1	.1	4.9
1919	.1	.1	.6	2.6	(1)	(1)	3.5	1.7	.7	.7	.3	.3	------
1920	.2	.3	.4	.9	2.8	1.3	.3	.2	.1	.1	.2	.2	7.0
1921	.2	.2	.3	.5	1.9	4.5	3.1	6.1	1.0	.2	.2	.2	18.3
1922	.1	.1	.3	.9	1.0	.5	.2	.1	.1	.0	.1	.1	3.5
1923	.1	.1	.3	.7	1.7	.9	.2	.3	.2	.2	.3	.2	5.2
1924	.1	.1	.5	4.2	3.9	1.2	.3	.2	.1	.1	.1	.1	10.9
1925	.1	.1	.2	.3	.2	.1	.1	.2	.2	.2	.3	.1	2.1
1926	[2] .1	[2] .1	.4	[2] 1.2	4.3	[2] 2.3	[2] .4	.2	.2	.1	.1	.2	9.6
1927	[2] .1	.0	.3	.7	1.6	.4	.2	[2] .3	.3	[2] .5	------	------	------
1928	[2] .1	[2] .1	.1	.1	1.8	.6	.2	.4	.5	.2	.2	[2] .1	4.4
1929	.2	.2	.2	.3	1.9	1.1	[2] .4	1.3	2.1	.6	.3	[2] .2	8.8
1930	.2	.2	.3	1.0	.8	.5	.7	1.0	.3	.2	[2] .1	[2] .1	5.4
1931	[2] .2	[2] .2	[2] .2	.7	2.1	1.0	.3	.2	1.7	.9	[2] .2	.1	7.8
1932	.2	.3	.7	1.3	2.0	.8	.4	.4	.5	.1	.1	.1	6.9
1933	.1	.1	.1	.2	.4	.7	.4	.3	.1	.1	.1	.1	2.7
1934	.1	.1	.1	.2	.3	.2	.2	.2	.2	.1	.1	.1	1.9
1935	.1	.1	.2	.3	1.7	1.6	.4	.5	.7	.5	.3	.1	6.5

[1] Estimated.
[2] Partially estimated.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; October 1913 to December 1914; October 1930 to September 1934.
Records from January 1915 to September 1930 from reports of the New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 182.—*Run-off of Arroyo Hondo near Santa Fe, N. Mex.*

[Drainage area 13 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1913	------	(1)	48	84	14	39	46	12	4	12	3	0	------
1914	27	27	45	24	36	126	159	56	[2] 30	23	28	11	592
1915	0	34	161	892	331	139	474	102	55	11	44	6	2,7
1916	[2] 12	(1)	584	486	45	8	129	(1)	9	260	74	15	------
1917	9	10	16	12	5	1	1	1	0	0	0	0	
1918	0	14	69	59	23	0	1	0	0	2	3	4	1.
1919	11	17	222	507	126	23	293	28	57	42	55	37	1,418
1920	15	38	19	12	17	1	0	0	0	4	6	12	124
1921	13	17	18	69	47	62	122	121	74	42	9	4	596
1922	12	11	19	26	21	4	0	0	0	------	------	------	------

[1] Partial record.
[2] Estimated.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358.
Records from October 1913 to September 1922 from reports of New Mexico State engineer.

TABLE 183.—*Run-off of Rio Puerco at Rio Puerco, N. Mex.*

[Drainage area 4,795 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1913	0	0	0.1	1.0	0	4.3	0.3	4.4	3.6	6.1	1.9	0.3	22.0
1914	1.9	16.2	4.6	3.6	3.8	.9	52.0	18.8	3.2	11.9	.2	1.7	118.8
1915	.9	2.8	19.7	76.0	9.2	3.3	[1] 87.1	11.8	15.5	.1	.2	.7	229.3
1916	4.3	6.8	21.4	6.4	4.9	0	19.6	48.3	.8	27.8	.2	1.4	141.9
1917	2.1	.2	.3	0	0	0	1.3	3.0	15.3	0	.1	.1	22.4
1918	1.4	1.4	1.6	0	.1	1.9	9.1	2.5	.2	3.0	.9	.9	23.0
1919	.8	3.5	18.1	31.3	11.2	.7	76.1	24.7	3.7	4.1	1.6	10.2	180.0
1920	5.3	9.2	4.5	8.4	9.0	1.7	.2	1.7	.6	.2	.5	0	41.3
1921	0	0	0	0	0	(2)	19.9	27.6	3.7	1.0	1.1	.1	------
1922	.1	.1	.2	0	0	0	0	1.5	.9	.1	.2	.2	3.8
1923	0	0	0	0	0	0	.2	3.2	2.3	.1	2.2	.2	8.2
1924	.2	.3	2.1	14.6	5.4	0	3.8	0	7.4	0	.1	1.0	34.9
1925	2.3	1.5	.1	.1	0	1.5	(2)	------	(2)	6.6	.6	.5	------
1926	------	------	------	------	------	------	------	------	6.8	1.1	[1] .2	.9	------
1927	2.0	[1] .4	14.3	23.8	3.6	4.5	[1] 15.2	[1] 35.7	[1] 49.6	.2	.4	.2	149.9
1934	------	------	0	0	1.3	.7	.9	[1] 12.3	[1] 28.4	.2	.1	.1	------
1935	2.6	1.1	[1] 1.9	.4	5.8	[1] 3.1	0	71.4	24.3	.2	.2	0	110.5

[1] Partially estimated.
[2] Partial record.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; October 1913 to December 1914; March to September 1934.
Records from January 1916 to December 1927 from reports of the New Mexico State engineer.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 184.—*Run-off of Bluewater Creek near Bluewater, N. Mex.*

[Drainage area 235 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912	...	...	...	...	...	...	(1)	340	71	96	40	15	...
1913	0	0	513	4,780	69	46	58	49	365	307	101	6	6,294
1914	0	694	6,040	1,990	177	30	904	389	192	189	84	[3] 61	10,750
1915	[3] 190	[2] 227	8,150	10,800	3,540	2,900	721	453	159	237	600	[3] 398	28,375
1916	(1)	...	(1)	7,620	144	107	943	1,700	694	[3] 2,970	591	246	...
1917	216	229	898	1,040	800	60	109	41	53	14	20	8	3,488
1918	6	1,230	2,410	149	39	468	177	195	36	37	35	24	4,806
1919	12	86	3,200	8,670	280	(1)							
1921	...	...	...	(1)	37	37	2,280	1,650	296	131	82	61	...
1922	129	440	319	267	36	6	8	52	15	21	67	180	1,640
1923	170	600	2,960	2,460	332	43	210	480	1,310	101	696	1,015	10,377
1924	1,620	2,610	947	1,015	601	46	43	57	35	44	23	68	7,109
1925	238	1,040	944	66	20	20	32	94	152	218	148	171	3,143
1926	[3] 145	[3] 189	[3] 12,128	[3] 8,767	[3] 1,672	[3] 141	[3] 87	[3] 305	[3] 54	[3] 652	[3] 48	[3] 274	24,462
1927	[3] 381	[3] 143	[3] 8,848	10,744	1,408	[3] 1,057	[3] 797	[3] 79	[3] 121	[3] 117	45	[3] 30	23,770
1928	C	[3] 40	[3] 48	[3] 88	[3] 137	1,550	518	[3] 84	[3] 45	93	[3] 125	[3] 166	2,894
1929	[3] 60	[3] 22	[3] 37	198	1,368	866	287	438	219	311	[3] 280	[3] 306	4,390
1930	[3] 307	[3] 247	269	371	2,300	1,160	1,770	848	577	107	[3] 132	[3] 160	8,248
1931	[3] 114	[3] 22	52	348	792	1,350	508	211	355	27	[3] 29	[3] 33	3,841
1932	[3] 15	[3] 54	[3] 424	942	1,980	3,160	1,990	1,470	[3] 691	[3] 713	[3] 510	[3] 292	12,241
1933	[3] 405	[3] 451	390	1,370	2,130	1,930	2,500	1,760	[3] 309	272	290	[3] 139	11,955
1934	[3] 147	117	126	713	2,280	788	54	29	24	25	[3] 42	[3] 28	4,373
1935	[3] 28	[3] 13	64	[3] 464	[3] 1,200	3,450	2,860	823	[3] 320	[3] 264	193	[3] 118	9,797

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358; October 1913 to December 1914; October 1920 to September 1934. Records from January 1915 to September 1930 from reports of the New Mexico State engineer. Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 185.—*Run-off of Bluewater Creek at Grants, N. Mex.*

[Unit acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
[illegible]	0	0	41	1,950	0	0	19	0	22	310	4	0	2,346
[illegible]	...	...	...	...	...	...	...	...	...	...	...	...	...
[illegible]	...	(1)	(1)	(1)	1,380	110	282	187	132	2	0	0	...
[illegible]	(1)	1,290	12,600	5,750	56	6	138	574	65	639	52	5	...
1917	0	11	40	13	136	21	12	13	12	12	9	5	284
1918	0	202	497	4	7	26	26	10	9	19	15	7	822
1919	1	4	680	4,100	8	4	5,740	1,280	651	14	11	228	12,721
1920	860	5,100	4,160	7,920	260	91	18	18	12	12	9	6	18,466
1921	11	11	12	12	(1)	...	...	(1)	70	19	18	16	...
1922	12	90	12	18	9	53	0	0	0	7	13	24	238
1923	[illegible]	3	358	362	[illegible]	[illegible]	102	2,390	1,000	27	318	41	7,732
1924	[illegible]	19	365	2,310	56	[illegible]	[illegible]	132	31	[illegible]	3	36	3,409
1925	22	6	6	6	1	1	28	10	153	1	0	0	234
1926	0	0	0	357	183	...	...	...	0	0	0	0	...

[1] Partial record.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358. Records from October 1913 to December 1926 from reports of the New Mexico State engineer.

TABLE 186.—*Run-off of San Jose River near Suwanee, N. Mex.*

[Drainage area 2,765 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1910	...	...	...	...	...	...	...	...	(1)	0.4	0.2	(1)	...
1911	...	...	...	...	...	...	...	...	...	...	...	...	...
1912	0.5	0.2	0.9	...	...	(1)	(1)	(1)	(1)	1.1	.4	0.1	...
1913	[2] .2	[3] .3	.5	1.9	0.2	1.8	0.3	0.6	0.7	1.2	.4	.3	8.4
1914	.5	.2	2.5	1.0	1.2	[2] .4	[3] 5.8	3.3	1.6	3.3	.5	.8	21.1
1915	.6	1.1	3.1	9.5	[3] 2.6	.3	[3] 11.4	2.1	2.0	.2	.2	.2	33.3
1916	2.7	4.3	12.0	8.1	1.4	.7	2.7	(1)	.3	6.0	.6	.5	...
1917	1.4	.9	.3	.2	.2	.2	.6	1.3	(1)	...	...	...	...

[1] Partial record.
[2] Estimated.
[3] Partially estimated.

Records previous to October 1913 from U. S. Geological Survey Water Supply Paper No. 358. Records from October 1913 to September 1917 from records of the New Mexico State engineer.

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TABLE 187.—*Discharge of Rio Grande below Elephant Butte Dam, N. Mex.*

[Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1915	0	0	12.2	72.8	199.0	241.0	118.0	117.0	77.1	21.2	14.1	23.5	895.9	104.2
1916	1.6	42.6	89.6	107.0	165.0	192.0	117.0	82.7	67.3	110.0	85.6	115.0	1,125.4	130.8
1917	95.3	107.0	109.0	102.0	124.0	138.0	191.0	114.0	110.0	109.0	51.9	52.7	1,303.9	151.6
1918	0	51.6	75.6	89.8	94.1	95.2	90.4	77.5	66.6	33.6	19.9	.9	695.2	80.8
1919	.9	22.2	53.7	75.0	124.0	112.0	94.7	91.0	67.8	11.3	18.0	3.8	674.4	78.4
1920	12.9	22.7	64.0	89.3	133.0	114.0	120.0	112.0	103.0	54.6	36.3	36.6	898.4	104.5
1921	2.9	36.5	86.7	81.5	109.0	121.0	123.0	125.0	124.0	83.0	60.7	26.7	980.0	113.9
1922	14.9	54.8	73.2	106.0	125.0	124.0	127.0	136.0	112.0	59.3	30.6	35.8	998.6	116.1
1923	12.1	36.4	54.0	103.0	123.0	132.0	130.0	105.0	79.1	45.0	12.8	12.7	845.1	98.3
1924	1.0	57.5	65.2	124.0	155.0	146.0	121.0	162.0	93.4	34.7	21.4	22.3	1,003.5	116.7
1925	4.6	42.5	88.5	136.0	121.0	124.0	124.0	95.9	49.4	10.3	10.3	11.5	818.0	95.1
1926	1.8	19.3	61.3	108.0	108.0	129.0	97.8	117.0	78.6	13.3	16.8	10.8	761.7	88.6
1927	5.7	34.7	62.7	115.0	128.0	127.0	137.0	122.0	86.3	33.1	17.4	13.2	882.1	102.6
1928	11.0	33.9	71.3	123.0	89.8	125.0	130.0	119.0	90.4	26.8	8.5	6.4	835.1	97.1
1929	8.8	28.7	64.0	121.0	97.8	117.0	102.0	78.7	65.5	6.8	4.8	5.8	700.9	81.5
1930	.2	31.0	73.2	116.0	101.0	114.0	117.0	125.0	77.9	17.5	10.7	10.1	793.6	92.3
1931	.4	17.6	73.0	93.9	99.8	124.0	128.0	103.0	69.5	19.9	16.7	4.8	750.6	87.3
1932	.3	26.0	64.1	113.0	105.0	126.0	134.0	132.0	87.1	12.9	18.9	12.5	831.8	96.7
1933	.9	32.1	71.8	111.0	108.0	101.0	127.0	133.0	90.0	17.8	13.9	20.3	826.8	96.1
1934	1.5	54.1	71.3	108.0	102.0	130.0	132.0	134.0	72.5	.5	6.5	1.5	803.9	93.4
1935	.4	8.3	43.2	84.4	78.5	110.0	128.0	117.0	45.9	9.2	5.9	5.8	636.6	74.0
Mean	8.4	36.2	67.0	103.8	118.6	130.1	123.3	114.2	81.6	34.8	21.5	20.6	860.1	100.0
Percent of annual	.98	4.21	7.79	12.07	13.79	15.12	14.33	13.28	9.49	4.05	2.50	2.39	100.0	....

Records previous to October 1916 from U. S. Bureau of Reclamation.
Records from October 1916 to September 1934 as published by U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Bureau of Reclamation.

TABLE 188.—*Run-off of Rio Grande at El Paso, Tex.*

[Drainage area 29,413 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Annual run-off in percent of mean
1890	12.0	16.1	26.1	130.0	355.0	262.0	52.5	45.1	10.5	4.0	16.9	32.9	963.1	129.4
1891	27.7	44.9	115.0	254.0	727.0	399.0	140.0	40.7	45.7	91.5	20.3	21.2	1,927.0	258.8
1892	20.1	27.4	46.2	187.0	436.0	175.0	41.1	.8	0	0	0	0	933.6	[illegible]
1893	8.2	8.0	2.1	48.1	231.0	13.4	[2] 0	[2] 0	[2] 0	[2] 3	[2] 0	[2] 6	319.8	[illegible]
1894 [2]	0	3	15.0	72.0	127.0	19.0	10.0	0	1.0	37.0	0	6.0	290.0	[illegible]
1895	[3] 19.0	[3] 34.0	[3] 95.0	[3] 210.0	[3] 150.0	[3] 205.0	[3] 168.0	[3] 131.0	[3] 5.0	[3] 15.0	[3] 16.0	[3] 29.0	1,077.0	[illegible]
1896 [2]	27.0	21.0	17.0	127.0	75.0	5.0	23.0	5.0	2.0	30.0	8.0	30.0	370.0	[illegible]
1897	18.7	10.8	4.4	104.0	511.0	303.0	81.8	8.1	41.9	106.0	67.4	41.8	1,360.9	182.9
1898	30.1	33.7	20.0	97.9	140.0	112.0	196.0	31.2	2.3	.2	.1	5.7	669.2	89.9
1899	12.9	11.3	7.1	8.8	10.3	0	19.6	.4	0	.1	.1	2.8	73.4	9.9
1900	8.1	5.7	.5	.3	44.8	93.1	.1	0	16.5	0	0	.7	169.8	22.8
1901	.3	4.5	3.7	0	158.0	77.0	12.6	60.7	21.0	5.3	12.8	8.0	363.9	48.9
1902	8.3	5.8	.6	7.9	.5	.3	0	14.5	9.3	1.4	.3	1.8	50.7	6.8
1903	[illegible]	[illegible]	22.6	49.5	204.0	387.0	158.0	4.3	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]
1904	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	366.0	48.4	[illegible]	[illegible]	[illegible]
1905	35.9	43.3	188.0	198.0	[illegible]	351.0	58.8	19.8	3.3	4.2	25.5	37.5	2,011.3	270.2
1906	27.0	31.7	25.3	88.0	349.0	271.0	96.6	49.2	2.8	36.2	59.3	76.3	1,114.4	149.7
1907	60.4	46.6	60.0	176.0	269.0	443.0	837.0	135.0	167.0	50.0	54.9	37.6	1,836.5	246.7
1908	33.0	31.2	47.8	90.1	117.0	40.2	16.3	56.6	14.3	0	5.1	23.4	467.0	62.7
1909	22.3	17.2	28.8	61.5	270.0	234.0	24.8	19.0	118.0	35.3	20.3	22.8	874.0	117.4
1910	43.5	19.7	92.9	117.0	274.0	83.1	.1	0	.1	0	0	.6	581.0	78.0
1911	9.3	11.9	43.5	31.9	248.0	229.0	435.0	53.6	11.6	294.0	119.0	62.4	1,549.2	208.1
1912	48.6	32.3	60.4	96.0	382.0	514.0	126.0	30.8	20.3	1.2	18.4	27.0	1,357.0	182.3
1913	18.8	35.0	15.6	50.7	88.6	43.0	5.7	0	0	6.7	17.1	21.1	302.3	40.6
1914	21.9	23.2	36.8	[4] 64.0	[4] 185.0	[4] 185.0	[4] 180.0	70.1	8.2	66.1	51.0	67.5	962.8	129.3
1915	39.3	32.0	22.2	37.8	143.0	184.0	76.7	88.3	59.9	19.5	1.9	[4] 30.0	734.6	98.7
1916	3.4	16.3	36.5	52.8	98.8	112.0	53.7	55.3	25.9	39.9	.6	64.6	555.8	74.6
1917	64.8	55.7	58.8	54.2	73.3	76.2	141.0	81.1	77.9	85.1	43.8	65.9	887.8	119.2
1918	2.3	82.0	48.7	48.6	46.6	28.6	28.3	33.9	19.5	83.9	20.3	6.4	349.1	46.9
1919	3.5	17.1	42.9	56.4	90.2	71.1	67.2	62.0	50.9	26.9	16.5	7.3	512.0	68.8
1920	24.2	13.1	49.5	70.4	72.5	82.6	84.1	107.0	74.8	79.7	28.2	41.1	707.2	95.0
1921	6.6	24.8	67.0	58.9	76.6	93.6	105.0	114.0	118.0	100.0	69.2	43.9	870.6	116.9
1922	17.8	47.9	67.5	85.5	74.9	79.0	83.2	112.0	82.3	54.1	36.7	37.8	778.7	104.6
1923	16.5	23.7	47.2	72.2	87.3	90.3	90.9	123.0	60.4	51.6	23.3	32.3	728.7	97.9
1924	17.5	48.5	56.8	91.0	122.0	98.2	111.0	107.0	77.4	32.0	21.1	27.7	810.2	108.8
1925	11.6	29.2	56.7	75.1	78.2	88.4	79.8	96.9	87.4	25.3	15.3	14.9	633.8	85.1
1926	12.2	15.4	41.3	65.4	69.4	75.2	88.9	63.1	65.0	21.1	21.0	18.8	556.8	74.8
1927	13.9	24.6	38.1	59.0	71.7	73.8	86.8	90.7	80.6	30.3	29.5	20.6	619.6	83.2
1928	12.7	26.6	43.5	80.3	68.9	72.6	86.1	97.8	67.2	31.7	22.3	14.3	624.0	83.8
1929	12.2	18.0	37.1	62.5	70.7	46.2	83.0	107.0	51.5	25.9	14.3	12.7	552.1	74.2
1930	8.2	16.3	42.9	62.5	58.8	67.8	82.4	83.0	51.9	25.8	16.7	16.1	532.4	71.5
1931	9.1	13.9	40.5	56.6	53.7	63.1	76.4	88.6	52.5	26.7	22.2	14.1	517.6	69.[illegible]
1932	9.1	16.9	34.5	57.2	62.5	73.6	78.5	85.7	67.4	34.9	34.4	22.5	567.2	[illegible]
1933	11.8	24.9	39.6	66.5	63.5	79.1	82.6	95.6	66.7	33.6	30.5	24.8	609.2	81.8
1934	11.2	33.1	43.5	56.7	60.7	62.0	73.8	80.2	48.0	18.3	11.4	9.6	508.5	68.3
1935	8.5	8.8	18.4	44.9	47.6	56.7	69.9	95.9	65.8	20.2	11.5	11.7	459.9	61.8
Mean	18.1	23.4	41.5	77.2	162.6	148.1	85.2	57.7	40.5	43.0	22.4	24.8	744.5	....
Percent of annual	2.43	3.14	5.58	10.37	21.85	19.88	11.43	7.75	5.44	5.78	3.02	3.33	100.0	....

[1] Exclusive of closed basin area, San Luis Valley, Colo.
[2] Estimated same as [3] except that San Marcial values to enter curves were estimates, not records.
[3] Estimated by reference to Rio Grande at San Marcial from monthly relation curves for period 1895–1913.
[4] Estimated by reference to Rio Grande below Elephant Butte Reservoir from monthly relation curves.

Records as published by U. S. Geological Survey: Previous to October 1913 from Water Supply Paper No. 358 except as noted; October 1913 to December 1930. Records from January 1931 to December 1935 from water bulletins of the International Boundary Commission.

TABLE 189.—*Run-off of Rio Grande at Tornillo Bridge, Tex.*

[Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1927										12.2	17.9	16.1	
1928	8.2	10.4	8.1	28.0	26.7	13.6	22.1	59.2	27.6	13.9	16.8	10.7	245.3
1929	8.2	3.5	4.7	10.2	25.8	5.1	21.3	59.6	10.3	12.7	9.6	7.4	178.1
1930	8.6	4.4	9.2	10.1	9.8	19.8	24.5	2.75	10.6	10.3	7.7	11.1	153.6
1931	8.3	6.8	8.9	20.1	12.2	8.7	20.3	40.8	17.8	10.4	12.4	9.5	176.2
1932	7.1	10.5	7.1	7.0	12.5	14.5	17.6	27.1	23.3	33.4	12.9	15.5	188.5
1933	10.6	12.2	5.5	15.5	11.8	31.0	24.5	28.1	22.6	17.4	9.3	14.3	202.8
1934	10.1	20.4	13.6	3.5	6.1	2.6	9.2	7.0	8.0	6.7	3.1	4.0	94.3
1935	6.8	2.1	.5	.6	.6	1.5	1.6	21.7	44.1	7.0	5.2	8.0	99.7

Records from October 1927 to December 1930 from reports of U. S. Geological Survey.
Records from January 1931 to December 1935 from water bulletins of the International Boundary Commission.

TABLE 190.—*Run-off of Rio Grande at Fort Quitman, Tex.*

[Drainage area 31,044 square miles.[1] Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1923										38.1	18.9	23.4	
1924	19.2	30.4	28.5	31.6	50.7	31.0	61.5	29.2	41.9	17.6	12.9	19.0	373.5
1925	13.8	15.8	18.3	13.5	14.7	18.7	8.9	58.1	59.5	20.8	13.2	12.6	267.9
1926	13.9	8.7	11.3	22.8	31.1	27.3	48.3	19.7	26.4	30.0	17.4	19.4	276.3
1927	13.5	14.1	7.7	11.3	13.5	19.5	14.0	45.3	42.2	21.2	20.2	18.4	240.9
1928	12.5	13.1	7.4	21.0	25.4	9.6	12.3	66.4	36.7	24.0	20.9	14.4	263.7
1929	10.6	8.7	9.2	7.6	22.0	7.1	14.4	62.1	15.6	24.4	17.1	13.0	211.8
1930	11.5	9.3	10.8	11.5	11.6	25.5	22.0	25.5	10.0	22.9	12.3	15.1	188.0
1931	9.4	10.2	10.1	34.7	21.7	8.8	17.2	36.6	17.6	14.3	16.5	14.6	211.7
1932	8.1	12.1	11.6	7.1	9.2	9.4	13.9	24.9	27.4	45.7	20.6	21.0	211.0
1933	12.8	15.6	12.2	12.6	10.8	29.0	20.5	19.1	28.9	22.0	13.0	17.3	213.8
1934	12.5	20.5	16.6	7.8	7.3	4.5	4.6	4.4	9.1	4.5	5.0	5.6	102.4
1935	5.4	3.5	1.1	1.2	[2] .9	3.6	4.3	24.3	57.2	20.7	10.5	12.7	145.4

[1] Exclusive of Closed Basin Area, San Luis Valley, Colorado.
[2] Partially estimated.

Records from October 1923 to December 1930 as published by U. S. Geological Survey.
Records from January 1931 to December 1935 from water bulletins of the International Boundary Commission.

TABLE 191.—*Run-off of Alamosa River near Monticello, N. Mex.*

[Drainage area 385 square miles. Unit, acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1929										[1] 133	[2] 554	[2] 553	
1930													
1931					435	506	660	1,750	878	746	540	491	
1932	466	543	323	457	578	530	536	553	560	527	522	509	6,504
1933	479	495	449	426	447	740	303	749	591	439	438	481	5,247
1934	479	400	430	492	345	418	415	1,070	430	448	433	468	5,428
1935	378	366	412	408	458	415	410	1,250	699	454	458	442	6,150

[1] Partially estimated.
[2] Estimated.

Records from October 1929 to December 1931 from reports of the New Mexico State engineer.
Records from January 1932 to September 1934 from reports of U. S. Geological Survey.
Records from October 1934 to December 1935 are provisional records furnished by U. S. Geological Survey.

TABLE 192.—*Run-off of Navajo River at Edith, Colo.*

[Drainage area 165 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1912									(1)	3.2	2.9	2.6	
1913	[2] 2.1	[2] 1.7	[2] 3.7	16.1	10.2	14.9	5.3	2.8	2.5	3.9	2.7	2.6	68.5
1914	[2] 2.3	[2] 1.9	9.9	20.7	32.8	(1)				8.7	3.7	[2] 2.5	
1915	[2] 2.2	[2] 2.7	6.8	25.2	34.7	38.4	20.7	8.2	3.1	2.6	2.4	[2] 2.4	147.4
1916	2.5	3.8	21.2	32.2	36.3	33.4	20.2	12.8	4.6	12.1	3.3	3.2	185.6
1917	3.8	2.8	3.2	20.5	32.2	54.5	(1)	(1)	3.4	2.8	2.0	2.3	
1918	1.9	2.2	5.3	9.3	18.7	21.8	8.5	4.4	3.3	2.2	1.9	2.0	81.5
1919	2.3	2.9	8.7	22.5	45.3	24.1	17.0	6.9	4.6	4.8	4.8	4.8	148.7
1920	2.9	4.0	21.8	42.1	78.3	46.5	17.8	9.3	3.4	2.7	2.7	2.6	234.1
1921	2.2	1.9	4.2	9.7	32.2	46.5	15.2	14.4	5.3	3.6	2.6	2.7	140.5
1922	2.4	3.1	7.2	26.6	56.5	35.7	9.4	3.5	2.1	1.9	2.0	2.0	152.4
1923	3.3	4.5	6.3	14.2	33.2	29.2	11.2	7.9	6.3	5.7	3.3	2.9	128.0
1924	3.5	3.8	4.3	26.3	23.4	20.1	13.0	4.2	2.3	1.9	1.8	1.7	106.3
1925	1.1	2.6	7.9	19.5	23.0	17.6	8.5	5.3	4.7	7.0	3.2	2.8	103.2
1926	[3] 2.8	[3] 3.0	[3] 6.5	22.3	34.2	30.6	14.8	5.0	2.5	2.8	[3] 2.1	[3] 2.2	128.8
1927	[3] 2.3	[3] 2.8	6.3	27.0	40.5	34.4	15.7	6.5	16.8	6.5	5.7	[3] 3.9	158.4
1928	[3] 3.4	[3] 3.7	[3] 6.7	9.4	27.4	13.5	5.4	3.8	1.6	1.5	[3] 2.1	[3] 1.8	80.3
1935						51.0	21.4	8.7	5.8	4.5	[3] 2.6	[3] 2.0	

[1] Partial record.
stimated.
tially estimated.

Records previous to October 1913 as published by U. S. Geological Survey in Water Supply Paper No. 358.
Records from October 1913 to December 1928 from reports of the New Mexico State engineer.
Records from June to December 1935 are provisional records furnished by U. S. Geological Survey.

PART I

APPENDIX B.—ESTIMATES OF WATER PRODUCTION IN T' UPPER RIO GRANDE BASIN, 1890-1935

Drainage Areas

Since the run-off from many tributary drainages has never been measured it was required to estimate their run-off by comparison with that of drainages which have been measured. One of the first requirements for estimating was therefore a detailed compilation of the drainage areas for all streams. Detail topographic maps are available for only a very limited portion of the upper Rio Grande drainage and the determination of drainage areas was required to be based in the main on general maps of the Geological Survey, Forest Service, and State agencies. Using these maps, the various drainages were measured by planimeter and the results are given in table 193. In this table the drainage areas are arranged as nearly as possible in consecutive downstream cumulative order with subtotals at gaging stations and at the confluence of tributaries with the main stream.

Water Production, San Luis Section, Colorado

In accordance with natural divisions of this section, the estimates of water production were segregated to the closed basin, the southwest and the southeast areas and the production derived is the run-off from the mountainous regions at the rim of the valley floor or approximately at the 8,500-foot contour. No account is taken of production due to precipitation on the floor of the valley. Although this is a factor in the total water production it is very small in proportion to the mountain run-off production. Of the three areas, the southwest is the most important with respect to contribution of water to the Rio Grande. Knowledge of water production in the closed basin becomes of importance in investigations looking to drainage of this basin to the Rio Grande. The production of the southeast area has for many years and is at present practically all used in irrigation so that its contribution to the Rio Grande is very small.

TABLE 193.—*Drainage areas in upper Rio Grande Basin*

SAN LUIS SECTION, COLORADO

Closed basin	*Drainage Area in Square Miles*	
Kerber Creek near Villa Grove (gage)	39.5	
San Luis Creek near Villa Grove (gage)		255.0
Villa Grove to Isabel Creek, inclusive:		
Above foothill line—Group A	72.0	
Foothill line to San Luis Creek	142.4	
		214.4

TABLE 193.—*Drainage areas in upper Rio Grande Basin*—Contd.

SAN LUIS SECTION, COLORADO—Continued

Closed basin—Continued	*Drainage Area in Square Miles*	
Crestone Creek to Deadman Creek inclusive:		
Above foothill line—Group B	42.6	
Foothill line to San Luis Creek	130.0	
		172.6
Villa Grove to Saguache Creek—West side		100.0
Saguache Creek near Saguache (gage)	490.0	
Gage to San Luis Creek	396.0	
Saguache Creek		886.0
Carnero Creek near La Garita (gage)	117.0	
La Garita Creek near La Garita (gage)	61.0	
Carnero and La Garita gages to San Luis Creek	162.0	
Carnero and La Garita Creeks		340.0
San Luis Creek above sump		1,968.0
Pole, Sand, Medano and Zapato Creeks to southern boundary closed basin:		
Above foothill line—Group C	102.0	
Foothill line to sump	362.0	
		[illegible]
Direct to sump—west side		508.0
Sump		972.0
Closed basin		2,940

Live area

Rio Grande at Thirty-Mile Bridge (gage)		163
Direct—left bank to Clear Creek		36.5
Clear Creek below Continental Reservoir (gage)	43.0	
Clear Creek		141.0
Direct—left bank to Wason		135.0
Direct—right bank to Wason		224.5
Rio Grande at Wason (gage)		700
Direct—right bank to Goose Creek		13.0
Goose Creek		87.0
Direct—right bank to South Fork		28.0
South Fork Rio Grande near South Fork (gage)		216.0
Direct—right bank to Del Norte gage		46.0
Direct—Left bank to Embargo Creek		162.0
Embargo Creek		62.4
Direct—left bank to Del Norte gage		5.6
Rio Grande near Del Norte (gage)		1,320
Direct—left bank to Monte Vista gage		103.5
Direct—right bank to Pinos Creek		[illegible]
Pinos Creek near Del Norte (gage)	62.0	
Pinos Creek		[illegible]

TABLE 193.—*Drainage areas in upper Rio Grande Basin*—Contd.

SAN LUIS SECTION, COLORADO—Continued

Live area—Continued		Drainage Area in Square Miles
Direct—right bank to San Francisco Creek		11. 1
San Francisco Creek		24. 0
Direct—right bank to Monte Vista gage		19. 0
Rio Grande near Monte Vista (gage)		1, 590
Direct—left bank to Alamosa		38. 6
Raton Creek near Monte Vista	13. 0	
Raton Creek and direct—right bank to Alamosa		83. 4
Rio Grande at Alamosa (gage)		1, 712
Dry Creek near Monte Vista	6. 6	
Rock Creek near Monte Vista (gage)	38. 0	
Gato Creek at Tipton's Ranch (gage)	31. 5	
Dry, Rock and Gato Creeks and direct—right bank to Alamosa Creek		457. 7
Alamosa Creek below Terrace Reservoir (gage)	120. 0	
Alamosa Creek		190. 0
Direct—right bank to La Jara Creek		6. 0
La Jara Creek near Capulin (gage)	73. 0	
La Jara Creek		240. 0
Direct—left bank to Trinchera Creek		193. 4
Trinchera Creek above Mountain Home Reservoir (gage)	61. 0	
Direct to Sangre de Cristo Creek	97. 4	
Sangre de Cristo Creek near Fort Garland (gage)	176. 0	
Direct to Mouth	6. 0	
Ute Creek near Fort Garland (gage)	32. 0	
Direct to mouth	8. 6	
Cottonwood Creek	15. 0	
Sangre de Cristo Creek	237. 6	
Direct to mouth	20. 6	
Trinchera Creek		416. 6
Direct—right bank to Conjeos River		59. 3
Conejos River near Mogote (gage)	282. 0	
Direct—left bank to mouth	153. 5	
Direct—right bank to Manassa	86. 0	
Los Pinos River near Ortiz (gage)	[1] 167. 0	
San Antonio River at Ortiz (gage)	[1] 110. 0	
Direct to mouth (Manassa)	[1] 71. 0	
San Antonio River	348. 0	
Direct—right bank to mouth	17. 5	
Conejos River		887. 0
Direct—left bank to Culebra Creek		186. 3
Culebra Creek at San Luis (gage)	220. 0	
Rito Seco	53. 7	
Direct to mouth	59. 0	
Culebra Creek		332. 7
Direct—left bank to Lobatos (gage)		70. 0
Direct—right bank to Lobatos (gage)		49. 0
Rio Grande near Lobatos (gage)		4, 800
Direct—right bank to Colorado-New Mexico line		84. 4

[1] 17 square miles of Los Pinos and 128 of San Antonio River drainage areas .e shown are in New Mexico.

TABLE 193.—*Drainage areas in upper Rio Grande Basin*—Contd.

SAN LUIS SECTION, COLORADO—Continued

Live area—Continued		Drainage Area in Square Miles
Direct—left bank to Costilla River		65. 6
Costilla River in Colorado (included in New Mexico figures)	50. 0	
Rio Grande at Colorado-New Mexico State line		4, 950
MIDDLE SECTION, NEW MEXICO [2]		
Costilla River (includes Colorado area)		287. 0
Direct—left bank, to Latir Creek		133. 5
Latir Creek		22. 5
Direct—left bank to Rio Colorado		51. 5
Rio Colorado near Questa (gage)	112. 0	
Direct to mouth	77. 0	
Rio Colorado (Red River)		189. 0
Direct—left bank to Rio Hondo		36. 0
Rio Hondo at Valdez (gage)	38. 0	
Direct to Arroyo Hondo (gage)	33. 0	
Rio Hondo		71. 0
Direct—left bank to Rio Taos		37. 5
Rio Lucero near Arroyo Seco (gage)	17. 0	
Rio Taos at Los Cordovas (gage)	359. 0	
Direct to mouth	37. 0	
Rio Taos		396. 0
Direct—right bank to Taos Junction Bridge		376. 0
Rio Grande below Taos Junction Bridge (gage)		6, 550
Direct—left bank to Embudo Creek		55. 0
Embudo Creek at Dixon (gage)	305. 0	
Direct to mouth	1. 0	
Embudo Creek		306. 0
Direct—right bank to Arroyo Aguaje de Petaca		136. 5
Arroyo Aguaje de Petaca		223. 0
Direct—Right bank to Embudo		56. 5
Rio Grande at Embudo (gage)		7, 327
Direct—left bank to Truchas River		6. 4
Truchas River		63. 0
Direct—left bank to Rio Santa Cruz		74. 6
Direct—right bank to Rio Chama		25. 0
Rio Chama at Parkview (gage)	[3] 405. 0	
Nutritas Creek near Tierra Amarilla (gage)	51. 5	
Direct to mouth	12. 5	
Nutrias Creek	64. 0	
Willow and Horse Lake Creeks	211. 5	
Burford and Rock Lake Creeks	166. 5	
Direct—left bank to El Vado Dam	26. 0	
Rio Chama below El Vado Dam (gage)	873. 0	
Direct—left bank to Nutrias Creek	14. 3	
Nutrias Creek near Cebolla (gage)	22. 0	
Direct to mouth	81. 1	

[2] Total for Rio Grande stations do not include the closed basin area in Colorado.
[3] Includes 204 square miles in Colorado.

TABLE 193.—*Drainage areas in upper Rio Grande Basin*—Contd.

MIDDLE SECTION, NEW MEXICO—Continued

			Drainage Area in Square Miles
Nutrias Creek		103.1	
Direct—left bank to Cebolla Creek		14.8	
Cebolla Creek		128.0	
Direct—left bank to Arroyo Seco		44.3	
Direct—right bank to Rio Gallina		70.0	
Rio Gallina		322.0	
Direct—right bank to Ojitos Canyon		12.5	
Ojitos Canyon		20.0	
Direct—right bank to Rio Puerco		28.2	
Rio Puerco		216.0	
Direct—right bank to Canones Creek		12.3	
Canones Creek		95.0	
Arroyo Seco (Horn River) near Canjilon (gage)	16.0		
Direct to mouth	156.0		
Arroyo Seco		172.0	
Direct—left bank to El Rito Creek		135.5	
El Rito Creek near El Rito (gage)	52.0		
Direct to mouth	69.0		
El Rito Creek		121.0	
Direct—right bank to Abiquiu Creek		31.4	
Abiquiu Creek		40.0	
Direct—right bank to Bear Creek		56.5	
Bear Creek		47.4	
Direct—left bank to Rio Ojo Caliente		34.5	
Rio Vallecitos at Vallecitos (gage)	114.5		
Rio Ojo Caliente at La Madera (gage)	344.0		
Direct to mouth	171.0		
Rio Ojo Caliente		515.0	
Direct—left bank to Chamita		75.0	
Direct—right bank to Chamita		20.2	
Rio Chama near Chamita (gage)		3,202.0	
Rio Chama			3,202.0
Direct—right bank to Otowi Bridge			181.0
Rio Santa Cruz at Cundiyo (gage)		85.7	
Direct to mouth		102.8	
Rio Santa Cruz			188.5
Direct—left bank to Pojoaque Creek			43.7
Nambe Creek near Nambe (gage)		37.0	
Pojoaque Creek			185.0
Direct—left bank to Otowi Bridge			6.8
Rio Grande at Otowi Bridge (gage)			11,303
Direct to Cochiti			358.0
Rio Grande at Cochiti (gage)			11,661
Direct—left bank to Santa Fe Creek			11.2
Santa Fe Creek near Santa Fe (gage)		22.0	
Arroyo Hondo near Santa Fe (gage)		14.0	
Direct—below Santa Fe and Arroyo Hondo gages		192.0	
Santa Fe Creek			228.0
Direct—left bank to Galisteo Creek			13.5
Galisteo Creek			697.0
Direct—left bank to San Felipe			254.0
Direct—right bank to San Felipe			221.3

TABLE 193.—*Drainage areas in upper Rio Grande Basin*—Contd.

MIDDLE SECTION, NEW MEXICO—Continued

		Drainage Area in Square Miles
Rio Grande at San Felipe (gage)		13,086
Direct—left bank to Tijeras Arroyo		305.0
Tijeras Arroyo		144.6
Direct—right bank to Jemez Creek		54.3
Jemez Creek near San Ysidro (gage)	854.0	
Direct to mouth	155.0	
Jemez Creek at mouth near Bernalillo (gage)		1,009.0
Direct—right bank to Isleta		371.0
Direct—left bank to Isleta		32.1
Rio Grande at Isleta (gage)		15,002
Direct—right bank to Rio Puerco		511.0
Bluewater Creek near Bluewater (gage)	235.0	
Rio Puerco at Rio Puerco (gage)	4,795.0	
Direct to mouth	242.0	
Rio Puerco		5,037.0
Direct—right bank to Rio Salado		77.0
Rio Salado		1,434.0
Direct—right bank to San Acacia		5.0
Direct—left bank to San Acacia		1,131.0
Rio Grande at San Acacia (gage)		23,197
Direct—left bank to San Marcial		363.0
Direct—right bank to San Marcial		616.0
Rio Grande at San Marcial (gage)		24,176

ELEPHANT BUTTE-FORT QUITMAN SECTION, NEW MEX. AND TEXAS[4]

Direct—left bank to Elephant Butte Dam		140.7
Direct—right bank to Alamosa River		815.6
Alamosa River near Monticello (gage)	385.0	
Direct to mouth	326.0	
Alamosa River		711.0
Direct—right bank to Rio Cuchillo		79.7
Rio Grande below Elephant Butte Dam (gage)		25,923
Rio Cuchillo		352.9
Direct—right bank to Palomas River		38.8
Palomas River		234.0
Direct—right bank to Percha Dam		549.0
Direct—left bank to Percha Dam		120.3
Rio Grande at Percha Dam (gage)		27,218
Direct—left bank to Leasburg Dam		225.0
Direct—right bank to Leasburg Dam		643.0
Rio Grande at Leasburg Dam (gage)		28,086
Direct—left bank to El Paso		842.0
Direct—right bank to El Paso		485.0
Rio Grande at El Paso (gage)		29,413
Direct to Fort Quitman in Texas		797.0
Direct to Fort Quitman in Mexico		834.0
Rio Grande at Fort Quitman (gage)		31,044

[4] Totals for Rio Grande stations do not include the closed basin area in Colo.

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MAGNETOTELLURIC INVESTIGATION IN THE SAN LUIS VALLEY, COLORADO

by

Chisengu L. Mdala

In the southwest area the Rio Grande is the principal stream and the main tributaries from north to south are Alamosa Creek, La Jara Creek, Conejos River, and San Antonio River. No tributaries of consequence enter the river from the north after it enters the valley floor. The estimates of water production for this area are based on the stream-flow records for Rio Grande near Del Norte, Pinos Creek near Del Norte, and Rock Creek near Monte Vista as a northern group, and Alamosa Creek below Terrace Reservoir, La Jara Creek near Capulin, Conejos River near Mogote, Los Pinos River near Ortiz, and San Antonio River at Ortiz as a southern group. The Rio Grande record begins with July 1889, that for the Conejos River with May 1903, and the others at later dates and covering considerably shorter periods. As the principal basis for the estimates, the monthly record for Rio Grande near Del Norte was completed for the period 1890–1935 by supplying missing months from curves of monthly run-off relations to other Rio Grande stations or from mean monthly distribution relations. The record was then corrected for regulation above the station by storage and the diversions of Del Norte Irrigation District to give natural flow or the flow which would have occurred at the station without any upstream regulation. There is a small amount of irrigation in the mountain valleys above the station which was neglected in deriving the natural-flow figures. Similarly, the monthly record for Conejos River near Mogote was extended and missing months estimated to cover the 1890–1935 period. As there is no storage on the Conejos this record was taken to represent the natural flow. Corrections to the Alamosa and La Jara Creek records were made for storage regulation on those streams.

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*

[Estimated natural run-off at rim of valley. Drainage area 2,392 square miles. Unit, 1,000 acre-feet]

Year and month	Northern group		Southern group		Total
	Rio Grande near Del Norte, 1,320 square miles	Unmeasured, 189 square miles	Conejos River near Mogote, 282 square miles	Unmeasured, 601 square miles	
1890					
January	13.5	1.1	2.4	2.4	19.4
February	11.1	1.1	2.1	2.0	16.3
March	27.5	2.8	6.2	9.0	45.5
April	54.4	8.0	23.0	38.0	123.4
May	266.2	25.0	110.0	145.0	546.2
June	227.0	17.0	93.0	59.0	396.0
July	92.9	6.0	35.0	21.0	154.9
August	37.5	2.6	11.0	7.5	58.6
September	22.8	1.3	5.0	4.0	33.1
October	28.9	1.6	6.0	4.8	41.3
November	20.2	1.2	4.3	3.3	29.0
December	18.4	1.2	3.5	3.0	26.1
Year	820.4	68.9	301.5	299.0	1,489.8
1891					
January	16.9	1.5	3.0	2.9	24.3
February	13.9	1.2	2.6	3.0	20.7
March	26.8	2.7	6.1	9.0	44.6
April	84.0	17.0	35.0	59.0	195.0
May	202.2	13.0	84.0	108.0	407.2
June	247.0	20.0	101.0	65.0	433.0
July	103.7	7.0	39.0	23.0	172.7
August	40.7	2.7	12.0	8.0	63.4
September	31.4	1.9	7.5	5.2	46.0
October	51.9	3.0	13.0	9.0	76.9
November	22.3	1.4	4.6	3.8	32.1
December	19.1	1.2	3.7	3.4	27.4
Year	859.9	72.6	311.5	299.3	1,543.3
1892					
January	16.9	1.5	3.0	2.9	24.3
February	14.4	1.3	2.7	3.1	21.5
March	19.5	1.7	4.8	6.0	32.0
April	62.4	10.0	26.0	43.0	141.4
May	180.2	7.0	66.0	62.0	315.2
June	130.0	7.0	55.0	33.0	225.0
July	45.2	2.5	16.0	9.0	72.7
August	27.2	2.0	9.0	6.3	44.5
September	15.6	.7	2.8	2.8	21.9
October	15.9	1.0	2.7	2.5	22.1
November	14.3	1.0	3.4	2.9	21.6
December	10.8	.7	2.0	2.1	15.6
Year	552.4	36.4	193.4	195.6	957.8
1893					
January	9.8	.9	1.7	2.0	14.4
February	9.7	.9	1.8	2.0	14.4
March	15.5	1.4	4.1	5.3	26.3
April	31.8	2.5	13.0	21.0	68.3
May	120.2	6.0	50.0	59.0	235.2
June	104.0	5.0	45.0	26.0	180.0
July	24.0	1.0	7.0	4.0	36.0
August	19.8	1.5	7.0	5.0	33.3
September	16.1	.8	3.0	3.0	22.9
October	16.2	1.0	2.8	2.6	22.6
November	14.3	1.0	3.4	2.9	21.6
December	10.8	.8	2.0	2.1	15.7
Year	392.2	22.8	140.8	134.9	690.7
1894					
January	10.8	.9	1.9	2.0	15.6
February	9.7	.9	1.8	2.0	14.4
March	[illegible]	[illegible]	[illegible]	5.0	30.3
April	55.0	[illegible]	23.0	38.0	124.0
May	147.2	8.0	61.0	75.0	291.2
June	63.7	3.0	29.0	15.0	110.7
July	22.1	1.0	6.5	4.0	33.6
August	23.5	1.8	8.0	5.7	39.0
September	21.1	1.2	4.2	3.6	30.1
October	22.1	1.4	4.5	3.8	31.8
November	16.8	1.1	3.8	3.1	24.8
December	13.8	.9	2.6	2.6	19.9
Year	424.3	29.9	150.9	160.8	765.9
1895					
January	12.3	1.0	2.2	2.1	17.6
February	10.6	1.0	2.0	2.0	15.6
March	26.8	2.7	6.1	9.0	44.6
April	119.1	24.0	50.0	85.0	278.1
May	141.1	8.0	58.0	71.0	278.2
June	139.0	8.0	59.0	36.0	242.0
July	64.3	4.0	23.0	14.0	105.3
August	45.1	3.1	13.0	9.0	70.2
September	26.7	1.6	6.0	4.5	38.8
October	25.8	1.5	5.9	4.7	37.9
November	20.4	1.2	4.4	3.4	29.4
December	18.5	1.2	3.6	3.3	26.6
Year	649.8	57.3	233.2	244.0	1,184.3
1896					
January	17.0	1.5	3.0	3.0	24.5
February	15.6	1.5	2.9	3.0	23.0
March	30.8	3.5	6.8	10.0	51.1
April	91.1	19.0	38.0	64.0	212.1
May	151.5	9.0	63.0	78.0	301.5
June	51.5	2.6	25.0	13.0	92.1
July	23.8	1.0	7.0	4.2	36.0
August	16.2	1.3	6.0	4.5	28.0
September	29.7	1.8	7.0	5.0	43.5
October	27.9	1.6	6.0	4.9	40.4
November	18.1	1.2	4.0	3.1	26.4
December	12.9	1.0	2.6	2.6	20.1
Year	487.1	45.0	171.3	195.3	898.7

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Unmeasured, 601 square miles	Total
1897					
January	13.9	1.2	2.5	2.5	20.1
February	11.2	1.1	2.1	2.1	16.5
March	27.2	2.7	6.2	9.0	45.1
April	63.6	11.0	27.0	45.0	146.6
May	217.5	16.0	90.0	117.0	440.5
June	201.9	14.0	83.0	52.0	350.9
July	67.6	4.3	25.0	15.0	111.9
August	28.9	2.1	9.0	6.0	46.0
September	37.5	2.3	9.0	6.0	54.8
October	90.5	4.9	25.0	17.0	137.4
November	39.6	2.3	7.0	4.6	53.5
December	24.1	1.5	4.8	4.0	34.4
Year	823.5	63.4	290.6	280.2	1,457.7
1898					
January	20.1	1.6	3.6	3.4	28.9
February	16.8	1.5	3.2	4.0	25.5
March	27.8	3.0	6.3	9.5	46.6
April	114.1	22.0	47.0	80.0	263.1
May	167.5	10.0	70.0	88.0	335.5
June	259.9	21.0	106.0	66.0	451.9
July	100.5	7.0	38.0	23.0	168.5
August	31.0	2.2	10.0	7.0	50.2
September	19.0	1.0	4.0	3.5	27.5
October	16.0	1.0	2.8	2.6	22.4
November	13.1	.9	3.2	2.9	20.1
December	11.2	.8	2.0	2.0	16.0
Year	797.0	72.2	296.1	293.9	1,459.2
1899					
January	11.2	1.0	2.0	2.0	16.2
February	10.1	1.0	1.9	2.0	15.0
March	18.5	1.7	4.6	6.0	30.8
April	36.9	3.5	16.0	26.0	82.4
May	85.2	4.3	35.0	38.0	162.5
June	64.8	3.1	30.0	16.0	113.9
July	42.7	2.2	15.0	9.0	68.9
August	36.4	2.5	11.0	7.5	57.4
September	22.0	1.2	4.8	4.0	32.0
October	29.2	1.7	6.0	4.9	41.8
November	23.8	1.5	5.0	3.6	33.9
December	12.7	.8	2.3	2.3	18.1
Year	393.5	24.5	133.6	121.3	672.9
1900					
January	9.3	.9	1.7	1.7	13.6
February	10.7	1.0	2.0	2.1	15.8
March	15.5	1.5	4.1	5.5	26.6
April	25.0	1.4	10.0	15.0	[illegible]
May	75.5	11.0	[illegible]	33.0	[illegible]
June	159.9	9.0	67.0	41.0	276.9
July	33.1	1.5	11.0	6.4	52.0
August	13.7	1.2	5.0	4.0	23.9
September	15.2	.7	2.7	2.0	21.5
October	21.0	1.3	4.4	3.6	30.3
November	14.9	1.0	3.5	3.0	22.4
December	12.4	.9	2.2	2.2	17.7
Year	506.2	31.4	196.6	180.4	904.6
1901					
January	12.4	1.2	2.2	2.2	18.0
February	9.8	.9	1.8	1.9	14.4
March	13.9	1.3	3.8	4.9	23.9
April	42.3	4.7	18.0	30.0	95.0
May	158.5	9.0	66.0	82.0	315.5
June	115.9	6.0	50.0	30.0	201.9
July	36.0	1.7	12.0	7.0	56.7
August	28.2	2.1	10.0	7.0	47.3
September	26.5	1.6	6.0	4.5	38.6
October	16.1	1.0	2.8	2.6	22.5
November	16.8	1.1	3.8	3.1	24.8
December	10.9	.8	2.0	2.0	13.7
Year	487.3	31.4	178.4	177.2	874.3
1902					
January	9.9	.9	1.8	1.8	14.4
February	8.4	.8	1.6	1.8	12.6
March	14.2	1.3	3.9	5.0	24.4
April	38.1	3.8	16.0	26.0	83.9
May	72.4	3.6	30.0	31.0	137.0
June	36.7	1.8	18.0	8.0	64.5
July	8.0	.3	2.0	1.2	12.4
August	10.8	1.0	4.0	3.1	18.9
September	12.3	.6	2.0	2.5	17.4
October	14.9	1.0	2.6	2.6	21.1
November	12.9	.9	3.2	3.0	20.0
December	9.9	.8	1.8	1.8	14.3
Year	249.4	16.8	86.9	87.8	440.9

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Unmeasured, 601 square miles	Total
1903					
January	3.6	.5	.5	1.1	5.7
February	5.1	.6	1.5	1.8	9.0
March	10.1	1.0	3.7	2.8	17.6
April	44.6	5.0	18.0	29.0	96.6
May	174.5	11.0	79.4	101.0	365.9
June	308.9	28.0	138.0	90.0	564.9
July	101.5	7.0	39.7	24.0	172.2
August	32.0	2.2	10.6	7.0	51.7
September	30.6	1.8	9.3	6.0	47.8
October	21.5	1.3	8.5	6.5	37.8
November	17.0	1.2	3.0	2.8	24.0
December	11.1	.8	1.5	1.9	15.3
Year	760.5	60.4	313.7	273.9	1,408.5
1904					
January	6.6	.7	.9	1.4	9.6
February	7.1	.7	1.8	1.9	11.5
March	12.2	1.0	4.0	3.2	20.4
April	39.0	4.0	16.8	27.0	86.8
May	71.9	3.4	31.3	32.0	138.6
June	42.3	1.7	19.0	8.0	71.0
July	20.0	.8	4.7	3.0	28.5
August	42.1	2.9	19.4	13.0	77.4
September	41.2	2.5	13.9	8.0	65.6
October	89.1	4.8	31.7	21.0	146.6
November	21.0	1.3	3.7	3.0	29.0
December	13.1	1.0	2.7	2.6	19.4
Year	405.6	24.8	149.9	124.1	704.4
1905					
January	15.1	1.4	2.9	2.8	22.2
February	12.1	1.1	2.4	2.2	17.8
March	27.2	2.8	6.2	4.4	40.6
April	45.4	5.5	17.7	29.0	97.6
May	210.7	15.0	94.9	124.0	444.6
June	361.7	35.0	132.0	86.0	614.7
July	66.4	4.1	32.5	19.0	[illegible]
August	35.2	2.5	13.1	9.0	[illegible]
September	22.4	1.2	5.2	4.0	[illegible]
October	26.4	1.6	4.4	3.3	[illegible]
November	17.6	1.2	4.1	3.2	[illegible]
December	12.4	.9	2.3	2.3	17.9
Year	852.6	72.3	317.7	289.4	1,532.0
1906					
January	11.2	1.0	2.0	2.0	16.2
February	10.1	1.0	1.9	2.0	15.0
March	[illegible]	[illegible]	[illegible]	5.6	[illegible]
April	[illegible]	[illegible]	[illegible]	38.0	[illegible]
May	236.7	20.0	82.4	106.0	445.1
June	295.7	26.0	127.0	83.0	531.7
July	115.3	8.0	44.0	26.0	193.3
August	47.4	3.2	14.0	9.4	74.0
September	42.8	2.6	11.0	7.0	63.4
October	54.8	3.0	14.0	10.0	81.8
November	32.5	1.9	6.0	4.1	44.5
December	18.5	1.2	3.6	3.3	26.6
Year	949.1	80.6	333.6	297.4	1,660.7
1907					
January	20.1	1.8	4.1	3.6	29.6
February	17.1	1.5	3.0	2.6	24.2
March	25.2	2.5	10.0	7.0	44.7
April	95.2	20.0	28.9	48.0	192.1
May	161.8	10.9	52.1	62.0	285.9
June	360.7	35.0	109.0	70.0	574.7
July	278.3	22.0	93.5	56.0	449.8
August	92.4	6.0	26.3	17.0	141.7
September	48.4	4.0	12.9	8.0	73.3
October	30.4	1.7	6.5	5.0	43.6
November	20.8	1.2	4.9	3.7	30.6
December	14.1	1.0	4.6	3.9	23.6
Year	1,164.5	100.7	355.8	286.8	1,913.8
1908					
January	11.1	1.0	2.2	2.2	16.5
February	10.1	1.0	2.1	2.1	15.3
March	21.2	2.0	7.0	5.0	35.2
April	45.2	5.5	13.0	20.0	83.7
May	104.8	5.5	34.7	37.0	182.0
June	173.7	10.0	60.6	43.0	296.3
July	65.1	4.0	26.6	16.0	111.7
August	56.8	3.7	17.7	12.0	90.2
September	20.5	1.2	7.0	5.0	33.7
October	16.7	1.1	6.3	5.0	29.1
November	12.3	.8	4.9	3.7	21.7
December	12.2	.8	2.4	2.4	[illegible]
Year	549.7	36.6	193.5	153.4	[illegible]

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TX_MSJ_000209

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Alamosa Creek at Terrace Reservoir, 115 square miles	Southern group: Unmeasured, 486 square miles	Total
1909						
January	13.2	1.2	2.4	(1)	2.4	19.2
February	13.3	1.2	2.5	(1)	2.3	19.3
March	19.4	1.7	5.0	(1)	4.0	30.1
April	49.3	7.0	19.0	9.0	29.0	113.3
May	197.5	14.0	75.0	29.2	73.0	388.7
June	283.4	23.0	119.0	37.6	40.0	503.0
July	92.5	6.0	33.7	11.2	8.0	151.4
August	52.1	3.5	19.3	(1)	13.0	87.9
September	98.5	6.0	27.7	(1)	16.0	148.2
October	40.6	2.4	9.3	3.9	4.5	60.7
November	25.0	1.6	5.0	2.9	3.0	37.5
December	24.6	1.8	4.9	6.0	5.5	42.8
Year	909.4	69.4	322.8	[2] 99.8	200.7	1,602.1
1910						
January	19.9	1.8	3.6	(1)	3.3	28.6
February	16.6	1.5	2.8	(1)	2.5	23.4
March	40.1	5.0	10.4	(1)	7.0	62.5
April	83.6	17.0	29.9	11.4	40.0	181.9
May	211.5	17.0	75.0	29.0	73.0	405.5
June	143.4	8.0	43.9	18.9	15.0	229.2
July	37.0	2.2	10.9	5.8	3.6	59.5
August	29.3	2.2	10.5	6.6	3.5	52.1
September	19.5	1.2	3.8	1.7	1.6	27.8
October	22.3	1.4	3.9	(1)	3.4	31.0
November	18.3	1.2	3.5	(1)	3.0	26.0
December	13.6	1.0	3.7	(1)	3.3	21.6
Year	655.1	59.5	201.9	[2] 73.4	159.2	1,149.1

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Alamosa Creek at Terrace Reservoir, 115 square miles	Southern group: Unmeasured, 486 square miles	Total
1911						
January	15.5	1.4	3.4	(1)	3.0	23.3
February	13.6	1.3	2.5	(1)	2.3	19.7
March	21.2	2.0	5.0	(1)	4.0	32.2
April	57.3	9.0	21.6	7.2	30.0	125.1
May	205.9	15.0	85.5	28.6	81.0	416.0
June	286.2	24.0	123.0	40.7	42.0	515.9
July	170.9	12.0	70.1	21.4	15.0	289.4
August	59.4	4.1	20.5	7.4	5.5	96.9
September	39.3	2.8	17.1	7.2	5.0	71.4
October	151.0	8.0	46.0	18.4	19.0	242.4
November	32.5	1.8	6.0	(1)	4.2	44.5
December	25.3	1.6	5.0	(1)	4.1	36.0
Year	1,078.1	83.0	405.7	[2] 130.9	215.1	1,912.8
1912						
January	21.2	1.9	4.7	(1)	4.0	31.8
February	16.1	1.5	3.1	3.1	5.5	29.3
March	17.7	1.6	5.6	3.4	10.0	38.3
April	34.8	3.0	13.2	4.1	19.0	74.1
May	230.9	20.0	114.0	33.6	107.0	505.5
June	259.0	20.0	103.0	33.4	35.0	450.4
July	106.7	8.0	38.6	21.8	10.0	185.1
August	48.8	3.7	9.5	10.5	4.0	76.5
September	26.1	2.2	3.8	3.2	2.0	37.3
October	23.7	1.5	5.0	(1)	4.0	34.2
November	16.1	1.0	5.1	(1)	3.8	26.0
December	11.3	.7	2.0	(1)	2.0	16.0
Year	812.4	65.1	307.6	[2] 113.1	206.3	1,504.5

...r and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Unmeasured, 601 square miles	Total
1913					
January	10.5	1.0	2.6	2.5	16.6
February	9.5	1.0	2.4	2.2	15.1
March	16.0	1.5	3.4	2.6	23.5
April	[illegible]	[illegible]	3.9	[illegible]	[illegible]
May	[illegible]	[illegible]	58.0	[illegible]	[illegible]
June	124.0	6.0	48.7	29.0	207.7
July	67.9	4.3	12.1	7.0	91.3
August	40.2	2.8	4.1	3.0	50.1
September	28.7	1.7	3.9	3.5	37.8
October	35.1	2.0	7.4	5.5	50.0
November	23.4	1.4	3.2	2.8	30.8
December	24.0	1.5	4.8	4.0	34.3
Year	574.9	37.2	157.5	143.1	912.7

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Unmeasured, 601 square miles	Total
1914					
January	19.3	1.5	2.9	2.8	26.5
February	17.3	1.5	2.7	2.5	24.0
March	[illegible]	[illegible]	[illegible]	5.0	33.9
April	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
May	201.6	14.0	[illegible]	71.0	345.2
June	254.9	21.0	80.3	50.0	406.2
July	117.0	8.0	28.1	17.0	170.1
August	54.0	3.6	18.9	11.0	87.5
September	33.9	2.2	17.0	12.0	65.1
October	45.3	2.6	13.1	9.0	70.0
November	17.3	1.2	4.4	3.5	26.4
December	13.0	.9	2.5	2.5	18.9
Year	819.9	59.7	253.2	215.3	1,348.1

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 189 square miles	Southern group: Conejos River, near Mogote, 282 square miles	Southern group: Alamosa Creek at Terrace Reservoir, 115 square miles	Southern group: La Jara Creek near Capulin, 73 square miles	Southern group: Los Pinos River near Ortiz, 167 square miles	Southern group: San Antonio River at Ortiz, 110 square miles	Southern group: Unmeasured, 136 square miles	Total
1915									
January	12.6	1.2	2.3	(1)	(1)	0.8	(1)	2.0	18.9
February	12.8	1.2	2.8	(1)	(1)	.9	0	1.4	20.1
March	17.8	1.5	3.7	(1)	(1)	1.5	.2	1.3	26.0
April	46.2	5.7	18.4	6.1	2.6	14.0	4.5	3.8	101.3
May	125.2	7.0	35.4	17.6	3.3	30.5	5.0	4.3	238.3
June	216.6	14.0	92.8	34.9	2.0	28.6	1.5	3.1	393.5
July	91.9	6.0	43.0	14.5	1.8	6.3	.5	.7	164.7
August	36.8	2.7	12.9	4.9	.9	2.7	.6	0	61.5
September	28.1	1.9	6.0	2.5	.4	1.2	.3	0	40.4
October	22.3	1.5	5.0	1.9	.3	1.1	.3	0	32.4
November	19.0	1.2	3.6	(1)	(1)	1.2	(1)	1.8	26.8
December	12.7	.8	2.5	(1)	(1)	(1)	(1)	2.5	18.5
Year	643.0	44.7	238.4	[2] 82.4	[2] 11.3	[2] 88.8	[2] 12.9	20.9	1,142.4

...e no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
...l year. Missing months are included in the total for the unmeasured area.

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TX_MSJ_000210

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group		Southern group						
	Rio Grande near Del Norte, 1,320 square miles	Unmeasured, 189 square miles	Conejos River, near Mogote, 282 square miles	Alamosa Creek at Terrace Reservoir, 115 square miles	La Jara Creek near Capulin, 73 square miles	Los Pinos River near Ortiz, 167 square miles	San Antonio River at Ortiz, 110 square miles	Unmeasured, 136 square miles	Total
1916									
January	19.2	1.7	2.4	(1)	(1)	(1)	(1)	2.3	25.6
February	17.5	1.5	3.0	(1)	(1)	(1)	(1)	2.7	24.7
March	35.5	4.2	5.2	(1)	(1)	(1)	(1)	4.1	49.0
April	70.1	13.0	21.7	8.6	7.0	15.2	6.3	10.2	152.1
May	182.2	13.0	90.4	32.5	7.3	58.2	14.7	7.1	405.4
June	248.2	19.0	129.0	35.5	1.2	37.4	2.2	1.8	474.3
July	110.1	8.0	50.2	13.5	1.3	9.2	7.7	.5	200.5
August	93.5	6.0	24.0	9.5	1.6	3.3	.6	.1	138.6
September	36.8	2.5	10.8	3.8	.7	1.8	.2	0	56.6
October	80.5	4.4	20.4	5.8	.6	6.5	.9	.1	119.2
November	35.5	2.0	7.5	(1)	(1)	(1)	(1)	5.0	50.0
December	18.2	1.2	4.0	1.8	(1)	(1)	(1)	3.0	28.2
Year	947.8	76.5	368.6	[2] 111.0	[2] 19.7	[2] 131.6	[2] 32.6	36.9	1,724.2
1917									
January	19.6	1.7	3.7	(1)	(1)	(1)	(1)	3.3	28.3
February	16.8	1.5	3.4	1.1	(1)	(1)	(1)	4.5	27.0
March	20.4	1.8	5.0	1.2	(1)	(1)	(1)	6.0	34.4
April	42.9	4.3	19.4	5.3	5.7	(1)	(1)	25.0	102.6
May	125.1	7.0	46.4	18.8	9.2	32.5	9.3	12.4	260.7
June	373.5	36.0	138.0	68.0	3.2	45.7	2.5	5.0	671.9
July	195.5	14.0	76.2	28.5	0	12.1	1.2	0	327.5
August	50.5	3.6	15.4	7.3	0	2.0	.3	0	79.1
September	25.8	1.7	5.4	2.9	1.1	1.2	.7	0	38.8
October	16.8	1.2	3.1	1.3	1.1	.8	.2	0	24.5
November	14.3	1.0	2.6	.8	.8	.8	.1	0	20.4
December	11.6	.7	1.9	(1)	(1)	(1)	(1)	2.0	16.2
Year	912.8	74.5	320.5	[2] 135.2	[2] 21.1	[2] 95.1	[2] 14.3	57.9	1,631.4
1918									
January	12.7	1.0	1.4	(1)	(1)	(1)	(1)	1.7	16.8
February	12.8	1.0	1.9	(1)	(1)	(1)	(1)	2.0	17.7
March	17.2	1.5	4.9	2.1	(1)	1.5	(1)	2.0	30.2
April	20.1	1.5	12.9	3.4	(1)	9.1	(1)	10.0	63.0
May	112.9	6.0	58.4	18.8	(1)	24.4	(1)	17.0	247.5
June	144.6	8.0	80.3	24.3	(1)	19.3	(1)	5.0	
July	58.3	3.9	30.1	10.2	(1)	5.1	(1)	2.0	
August	33.9	2.5	9.9	4.1	(1)	1.4	(1)	.9	
September	40.9	2.5	7.1	(1)	(1)	1.1	(1)	4.0	
October	23.0	1.4	4.1	(1)	(1)	1.0	(1)	2.6	
November	20.5	1.3	3.4	(1)	(1)	1.2	(1)	1.6	28.0
December	12.9	1.0	2.6	(1)	(1)	(1)	(1)	2.6	20.1
Year	516.8	31.6	226.0	[2] 62.9	------------	[2] 74.1	------------	52.4	963.8

Year and month	Northern group				Southern group					
	Rio Grande near Del Norte, 1,320 square miles	Pinos Creek near Del Norte, 62 square miles	Rock Creek near Monte Vista, 38 square miles	Unmeasured, 89 square miles	Conejos River near Mogote, 282 square miles	Alamosa Creek at Terrace Reservoir, 115 square miles	La Jara Creek near Capulin, 73 square miles	Los Pinos River near Ortiz, 167 square miles	San Antonio River at Ortiz, 110 square miles	Unmeasured, 130 square miles	Total
1919											
January	15.4	(1)	(1)	1.4	2.7	(1)	(1)	(1)	(1)	2.6	22.1
February	14.6	(1)	(1)	1.4	2.8	(1)	(1)	(1)	(1)	3.0	21.8
March	21.6	(1)	(1)	1.8	5.2	(1)	(1)	(1)	(1)	7.4	36.0
April	64.6	4.0	2.5	4.7	29.5	9.3	6.1	21.5	3.7	8.9	154.8
May	242.9	8.4	4.5	6.3	84.2	34.1	6.9	53.1	10.6	9.2	460.2
June	183.6	8.6	2.6	3.0	61.9	22.9	6.0	17.0	1.1	9.2	312.9
July	107.8	4.1	2.0	2.2	31.4	12.4	3.6	7.8	1.7	1.4	174.4
August	54.1	1.7	1.0	1.0	10.8	5.6	.8	4.6	.3	0	79.9
September	28.7	1.0	.4	.4	5.8	2.0	.7	1.9	.6	0	41.5
October	23.8	.7	.4	.3	4.4	1.0	.7	1.3	.4	0	33.0
November	19.9	.7	.5	.4	3.8	(1)	.8	1.1	(1)	1.5	28.7
December	18.2	(1)	(1)	1.2	3.9	(1)	(1)	(1)	(1)	2.5	26.9
Year	795.3	[2] 26.2	[2] 13.9	24.1	246.4	[2] 87.3	[2] 25.6	[2] 108.3	[2] 18.4	46.7	1,392.2

[1] Where no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
[2] Partial year. Missing months are included in the total for the unmeasured area.

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TX_MSJ_000211

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Pinos Creek near Del Norte, 62 square miles	Rock Creek near Monte Vista, 38 square miles	Unmeasured, 89 square miles	Southern group: Conejos River near Mogote, 282 square miles	Alamosa Creek at Terrace Reservoir, 115 square miles	La Jara Creek near Capulin, 73 square miles	Los Pinos River near Ortiz, 167 square miles	San Antonio River at Ortiz, 110 square miles	Unmeasured, 136 square miles	Total
1920											
January	18.1	([1])	([1])	1.5	3.3	([1])	([1])	([1])	([1])	3.1	26.0
February	16.7	([1])	([1])	1.5	3.1	([1])	([1])	([1])	([1])	3.9	25.2
March	19.2	([1])	.4	1.3	5.1	2.0	([1])	2.0	1.8	1.4	33.2
April	32.3	1.3	.8	1.5	9.4	11.5	1.4	8.5	12.4	2.0	81.1
May	270.9	14.0	5.7	9.7	115.0	38.4	10.8	76.8	34.0	14.5	589.2
June	374.2	20.2	4.7	9.2	188.0	55.5	3.4	45.8	5.0	5.3	711.3
July	140.6	5.5	1.8	2.7	67.0	23.7	3.7	9.5	.0	1.5	256.6
August	53.9	1.6	1.0	1.0	20.7	7.1	3.1	2.7	.8	.2	92.1
September	25.9	.7	.4	.3	6.4	2.7	1.0	.8	.4	0	38.6
October	25.0	.7	.4	.3	5.1	1.8	.9	.8	.5	0	35.5
November	22.2	([1])	([1])	1.4	3.9	([1])	.8	.9	([1])	1.5	30.7
December	16.4	([1])	([1])	1.1	3.2	([1])	([1])	([1])	([1])	3.0	23.7
Year	1,015.4	[2] 44.0	15.2	31.5	430.2	[2] 142.7	[2] 25.1	[2] 147.2	[2] 55.5	36.4	1,943.2
1921											
January	17.5	([1])	([1])	1.5	2.9	([1])	([1])	([1])	([1])	2.7	24.6
February	17.1	([1])	([1])	1.5	2.2	([1])	([1])	([1])	([1])	2.8	24.6
March	27.8	([1])	([1])	3.0	7.1	([1])	([1])	([1])	([1])	5.0	42.9
April	38.3	1.1	.5	1.2	10.9	([1])	([1])	([1])	([1])	7.0	59.0
May	209.6	6.5	1.8	3.6	63.3	([1])	4.0	([1])	([1])	48.0	337.7
June	378.5	8.1	2.0	3.7	106.0	([1])	1.3	([1])	([1])	67.0	566.6
July	138.3	3.4	.8	1.7	31.3	([1])	1.1	([1])	([1])	15.0	191.6
August	86.8	2.7	.8	1.2	19.3	([1])	.8	([1])	([1])	12.0	123.6
September	46.4	1.8	.4	.8	6.6	([1])	.6	([1])	([1])	4.0	60.6
October	25.2	.8	.2	.2	3.9	([1])	.8	([1])	([1])	3.0	34.1
November	22.3	([1])	([1])	1.4	3.1	([1])	([1])	([1])	([1])	2.8	29.6
December	17.7	([1])	([1])	1.2	2.5	([1])	([1])	([1])	([1])	2.5	23.9
Year	1,025.5	[2] 24.4	[2] 6.5	21.0	260.1	----------	[2] 9.5	----------	----------	171.8	1,518.8
1922											
January	19.0	([1])	([1])	1.7	3.5	([1])	([1])	([1])	([1])	3.1	27.3
February	16.3	([1])	([1])	1.6	3.5	([1])	([1])	([1])	([1])	4.6	28.0
March	22.9	([1])	([1])	2.0	5.5	([1])	([1])	([1])	([1])	8.0	38.4
April	46.8	1.5	.5	1.5	11.4	6.2	([1])	([1])	([1])	20.0	87.9
May	286.2	13.5	3.1	8.1	104.0	32.2	5.8	([1])	([1])	83.0	535.9
June	323.1	18.7	2.5	10.0	126.0	38.8	2.4	([1])	([1])	43.0	564.5
July	71.3	2.6	1.0	1.4	32.5	10.0	5.8	([1])	([1])	8.0	132.6
August	60.6	1.1	.8	.6	11.3	4.8	1.4	([1])	([1])	2.9	83.5
September	29.2	.6	.4	.3	3.5	3.2	.6	([1])	([1])	1.7	39.5
October	18.8	.7	.3	.3	2.9	1.2	([1])	([1])	([1])	1.8	26.0
November	16.2	([1])	([1])	1.2	3.7	1.3	([1])	([1])	([1])	2.0	24.4
December	16.1	([1])	([1])	1.3	3.4	1.5	([1])	([1])	([1])	2.5	24.8
Year	928.5	[2] 38.7	[2] 8.6	30.0	311.2	[2] 99.2	[2] 16.0	----------	----------	180.6	1,612.8
1923											
January	16.2	([1])	([1])	1.5	3.0	[illegible]	([1])	([1])	([1])	[illegible]	[illegible]
February	[illegible]	([1])	([1])	[illegible]	[illegible]	[illegible]	([1])	([1])	([1])	[illegible]	[illegible]
March	20.2	([1])	([1])	[illegible]	[illegible]	2.1	([1])	([1])	([1])	7.0	36.0
April	35.4	1.5	.5	1.4	22.0	4.1	([1])	([1])	([1])	28.0	92.9
May	211.1	8.4	2.8	5.5	121.0	32.7	8.9	([1])	([1])	89.0	479.4
June	251.8	8.2	2.0	3.7	127.0	31.1	1.8	([1])	([1])	40.0	465.6
July	93.3	2.9	1.3	1.7	42.2	15.0	5.1	([1])	([1])	10.0	171.5
August	63.4	2.3	.9	1.2	23.4	4.4	2.4	([1])	([1])	4.2	102.2
September	60.1	1.9	.9	1.0	19.7	6.0	1.7	([1])	([1])	5.5	96.8
October	54.2	1.6	.9	.3	17.5	3.3	1.4	([1])	([1])	4.5	83.7
November	34.9	.9	.5	.5	6.2	4.3	1.2	([1])	([1])	2.5	51.0
December	23.8	([1])	([1])	1.6	5.8	5.2	([1])	([1])	([1])	4.4	38.3
Year	878.8	[2] 27.7	[2] 9.8	21.5	304.4	109.9	[2] 22.5	----------	----------	202.4	1,667.0
1924											
January	19.9	([1])	([1])	1.7	4.4	([1])	([1])	([1])	([1])	3.8	29.8
February	17.5	([1])	([1])	1.5	3.7	([1])	([1])	([1])	([1])	3.0	25.7
March	19.8	([1])	([1])	1.7	4.9	([1])	([1])	([1])	([1])	3.4	29.3
April	72.8	4.9	2.7	5.6	34.0	7.8	([1])	([1])	([1])	41.0	168.8
May	241.7	12.9	3.8	8.2	108.0	35.9	4.6	([1])	([1])	87.0	502.1
June	219.1	7.7	1.8	4.7	81.5	24.8	2.7	([1])	([1])	51.0	393.3
July	59.0	1.8	.7	.9	27.2	6.4	4.8	([1])	([1])	6.0	108.8
August	26.2	.8	.3	.2	6.6	2.7	1.7	([1])	([1])	2.1	40.6
September	16.5	.5	.2	.3	3.2	1.4	1.0	([1])	([1])	1.4	34.5
October	18.9	([1])	([1])	1.2	3.9	.8	.9	1.3	.1	0	27.1
November	12.5	([1])	([1])	1.0	3.5	1.0	.7	1.6	.2	0	20.7
December	14.5	([1])	([1])	1.1	3.2	1.2	([1])	([1])	([1])	2.2	22.2
Year	787.9	[2] 28.6	[2] 9.5	23.1	284.1	[2] 82.0	[2] 16.4	[2] 3.1	[2] .3	200.9	1,390.9

[1] Where no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
[2] Partial year. Missing months are included in the total for the unmeasured area.

CO - 003132

TX_MSJ_000212

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group		Southern group						Total
	Rio Grande, near Del Norte, 1,320 square miles	Unmeasured, 189 square miles	Conejos River, near Mogote, 282 square miles	Alamosa Creek at Terrace Reservoir, 115 square miles	La Jara Creek, near Capulin, 73 square miles	Los Pinos River, near Ortiz, 167 square miles	San Antonio River at Ortiz, 110 square miles	Unmeasured 136 square miles	
1925									
January	14.9	1.4	3.0	(1)	(1)	(1)	(1)	2.9	22.2
February	15.4	1.5	3.0	(1)	(1)	(1)	(1)	2.7	22.6
March	26.6	2.6	5.4	(1)	1.0	(1)	(1)	3.0	38.6
April	61.2	11.0	29.2	9.9	3.9	20.8	5.1	5.6	146.7
May	163.3	11.0	71.9	27.9	3.4	26.4	2.1	4.6	310.6
June	171.8	10.0	54.7	19.9	1.0	9.5	.6	1.6	269.1
July	78.5	5.2	20.7	9.4	.9	3.1	.2	.4	118.4
August	45.2	3.2	14.9	5.4	2.0	4.5	.3	.1	75.6
September	56.3	3.7	8.5	3.5	.4	1.8	.1	0	74.3
October	54.6	3.0	11.2	3.1	.4	3.3	.1	0	75.7
November	24.6	1.6	6.8	2.1	.2	1.8	.1	0	37.2
December	27.8	1.8	3.9	(1)	(1)	(1)	(1)	3.3	36.8
Year	740.2	56.0	233.2	[2] 81.2	[2] 13.2	[2] 71.2	[2] 8.6	24.2	1,227.8
1926									
January	19.9	1.7	3.8	(1)	(1)	(1)	(1)	3.2	28.6
February	15.5	1.4	3.1	(1)	(1)	(1)	(1)	2.7	22.7
March	17.7	1.6	4.4	(1)	(1)	(1)	(1)	3.2	26.9
April	36.2	3.5	18.9	4.3	2.9	15.0	8.2	4.2	94.2
May	160.7	10.0	76.9	23.1	6.7	46.1	14.4	9.0	346.9
June	195.2	1.4	92.8	27.3	2.0	22.4	.9	3.0	345.0
July	76.6	5.0	27.1	8.9	2.2	4.3	.2	.9	125.2
August	42.5	3.0	9.2	4.2	.6	1.7	.2	0	61.4
September	20.9	1.4	2.7	1.5	.4	.9	.1	0	27.9
October	20.4	1.3	3.8	.9	.4	1.0	.1	0	27.9
November	16.9	1.1	3.0	.4	.3	1.1	.2	0	23.0
December	17.0	1.2	3.0	.6	(1)	(1)	(1)	1.9	23.7
Year	639.5	32.6	248.7	[2] 71.2	[2] 15.5	[2] 93.5	[2] 24.3	28.1	1,153.4
1927									
January	14.9	1.4	2.7	.9	(1)	(1)	(1)	2.5	22.4
February	15.0	1.4	1.9	1.2	(1)	(1)	(1)	3.0	22.5
March	18.8	1.7	3.9	2.5	(1)	(1)	(1)	6.0	32.9
April	57.8	9.0	24.2	7.0	3.3	12.0	7.7	4.7	125.7
May	218.4	18.0	95.9	32.3	4.6	56.9	14.0	6.1	[illegible]
June	229.2	15.0	99.4	31.0	.9	26.4	1.7	1.4	[illegible]
July	139.1	10.0	43.5	14.5	1.2	7.0	.6	.5	[illegible]
August	55.8	3.8	16.6	5.7	.9	2.6	.2	0	[illegible]
September	146.2	10.0	28.8	8.3	1.2	6.0	.7	0	[illegible]
October	70.9	3.9	14.6	4.2	.9	3.7	.4	.1	98.7
November	31.5	2.0	8.4	3.3	(1)	2.1	(1)	.8	48.1
December	22.0	1.3	4.4	(1)	(1)	1.1	(1)	2.5	31.3
Year	1,019.6	77.5	344.3	[2] 110.9	[2] 13.0	[2] 117.8	[2] 25.3	27.6	1,736.0
1928									
January	19.9	[illegible]	[illegible]	(1)	(1)	[illegible]	(1)	2.0	25.0
February	18.6	1.7	2.4	(1)	(1)	.7	(1)	1.5	24.9
March	24.1	2.4	4.0	(1)	(1)	1.8	(1)	2.0	34.3
April	41.5	3.5	13.7	3.5	2.4	9.3	4.2	3.5	81.6
May	196.3	13.0	67.6	23.6	3.3	38.6	8.2	4.3	354.9
June	153.8	9.0	61.9	15.2	.5	13.2	.6	.8	255.0
July	66.0	4.0	15.6	4.4	1.4	2.8	.3	.6	95.1
August	32.8	2.4	8.6	4.0	.5	1.5	.4	0	50.2
September	23.0	1.5	4.9	1.6	.7	1.0	.2	0	32.9
October	22.5	1.5	3.5	.9	.2	.9	.1	0	30.6
November	21.8	1.4	3.0	.7	.4	1.0	.2	0	28.5
December	17.6	1.2	3.0	.4	(1)	(1)	(1)	1.8	24.0
Year	638.9	43.4	191.6	[2] 54.3	[2] 9.4	[2] 71.7	[2] 14.2	16.5	1,040.0
1929									
January	16.6	1.5	2.8	0.7	(1)	(1)	(1)	2.5	24.1
February	14.6	1.3	2.7	.9	(1)	(1)	(1)	3.5	23.0
March	20.4	1.8	5.5	4.0	(1)	(1)	(1)	10.0	41.7
April	53.1	6.0	23.3	9.3	4.1	15.9	10.0	6.0	129.7
May	222.6	19.0	110.0	23.8	5.9	48.4	12.5	7.9	451.1
June	248.4	18.0	97.0	29.5	1.5	17.0	.8	2.3	414.5
July	94.9	8.0	30.6	11.1	1.0	4.7	.6	.4	149.3
August	108.3	7.0	32.6	11.7	.3	6.9	.7	0	167.5
September	85.2	6.0	27.1	9.1	1.0	5.2	.1	0	133.7
October	59.8	3.3	10.1	3.1	.6	3.2	.4	.1	80.6
November	25.9	1.7	4.5	3.1	(1)	2.3	(1)	.5	38.0
December	15.4	1.1	2.5	1.0	(1)	(1)	(1)	1.8	21.8
Year	965.2	74.7	339.7	117.3	[2] 14.4	[2] 103.6	[2] 25.1	35.0	1,675.0

[1] Where no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
[2] Partial year. Missing months are included in the total for the unmeasured area.

CO - 003133

TX_MSJ_000213

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Unmeasured, 180 square miles	Southern group: Conejos River, near Mogote, 282 square miles	Southern group: Alamosa Creek at Terrace Reservoir, 115 square miles	Southern group: La Jara Creek, near Capulin, 73 square miles	Southern group: Los Pinos River, near Ortiz, 167 square miles	Southern group: San Antonio River at Ortiz, 110 square miles	Southern group: Unmeasured 136 square miles	Total
1930									
January	13.5	1.2	2.2	3.1	(1)	(1)	(1)	3.6	23.6
February	18.9	1.3	2.8	2.3	(1)	(1)	(1)	4.8	25.1
March	17.8	1.6	3.4	2.3	(1)	2.4	(1)	3.0	30.5
April	56.1	8.0	33.3	9.2	(1)	28.0	(1)	28.0	162.6
May	98.3	7.0	54.0	15.5	3.7	38.6	6.0	5.0	228.7
June	120.5	4.0	63.7	17.8	2.0	16.8	.6	1.9	227.3
July	57.8	3.5	20.5	6.9	1.1	3.1	.7	.4	94.0
August	50.7	3.5	14.0	6.4	1.0	3.0	.5	.1	79.2
September	23.6	2.5	3.4	1.9	.6	1.2	.1	0	33.3
October	22.9	1.5	3.8	1.6	.3	1.4	.2	0	31.7
November	16.7	1.2	1.8	1.8	(1)	(1)	(1)	1.7	23.2
December	14.6	1.0	2.2	1.0	(1)	(1)	(1)	1.7	20.5
Year	506.4	36.3	205.1	69.8	[2] 8.7	[2] 94.5	[2] 8.7	50.2	979.7
1931									
January	9.2	.9	1.8	1.1	(1)	(1)	(1)	2.0	15.0
February	10.3	1.0	1.8	.9	(1)	(1)	(1)	2.6	16.6
March	14.1	1.3	3.1	1.1	(1)	(1)	(1)	3.8	23.4
April	28.0	1.5	11.7	2.9	(1)	6.1	(1)	8.0	58.2
May	74.2	7.0	38.1	12.8	2.4	17.6	5.0	3.3	160.4
June	87.7	4.0	40.8	11.9	.7	7.3	.1	1.1	153.6
July	29.7	1.7	9.6	3.0	.4	2.3	0	.2	46.9
August	18.0	1.5	9.2	2.8	.5	1.1	.1	0	33.2
September	23.1	1.7	12.7	4.8	.7	1.4	0	0	44.4
October	30.4	2.0	13.2	5.3	(1)	2.2	(1)	1.8	54.4
November	14.7	1.0	4.3	1.4	(1)	(1)	(1)	2.2	23.6
December	13.6	1.0	4.3	1.5	(1)	(1)	(1)	3.0	23.4
Year	353.0	24.6	150.6	49.5	[2] 4.7	[2] 38.0	[2] 5.2	27.5	653.1
1932									
January	13.9	1.2	3.2	1.3	(1)	(1)	(1)	3.2	22.8
February	14.2	1.3	3.1	1.6	(1)	(1)	(1)	4.3	24.5
March	19.0	1.7	5.1	1.5	(1)	4.3	(1)	4.0	35.6
April	60.4	6.0	30.1	8.9	3.8	18.4	12.0	4.0	143.6
May	275.3	27.0	108.0	35.1	9.1	67.0	18.8	12.2	552.5
June	264.1	21.0	118.0	37.6	.9	38.0	1.9	1.3	482.8
July	127.0	9.0	54.5	20.8	0	13.1	.4	0	225.8
…ust	65.3	4.2	18.6	3.9	.1	2.6	.3	0	95.0
…ember	27.6	1.8	6.5	2.0	.4	1.2	.1	0	39.6
…ber	20.7	1.4	4.5	1.4	0	1.5	.3	0	29.8
…ember	13.6	1.0	2.9	1.1	(1)	(1)	(1)	1.8	20.7
…ecember	12.7	1.0	2.6	1.1	(1)	(1)	(1)	2.0	19.4
Year	915.0	76.6	357.2	116.3	[2] 14.3	[2] 146.1	[2] 33.8	33.8	1,602.1
1933									
January	12.8	1.2	2.8	.9	(1)	(1)	(1)	2.6	20.3
February	10.4	1.0	2.2	1.1	(1)	(1)	(1)	3.1	17.8
March	[illegible]	[illegible]	4.4	1.1	(1)	(1)	(1)	[illegible]	29.4
April	[illegible]	[illegible]	9.7	[illegible]	[illegible]	5.0	3.6	1.9	45.0
May	82.6	7.0	44.4	16.0	3.2	30.8	9.9	4.3	198.2
June	182.1	10.0	93.4	33.4	.8	20.3	2.7	1.2	349.9
July	53.8	3.7	27.2	9.2	.4	5.1	.5	.1	100.0
August	38.9	2.6	11.3	2.3	.7	2.0	.1	0	57.9
September	26.9	1.7	8.3	1.9	.4	1.8	.1	0	41.1
October	24.2	1.5	7.1	1.5	.4	1.6	.2	0	36.5
November	19.1	1.3	3.9	.9	.4	1.3	.1	0	27.0
December	16.2	1.2	2.5	.6	(1)	(1)	(1)	1.6	22.1
Year	502.8	33.4	217.2	70.8	[2] 7.6	[2] 74.9	[2] 17.2	20.3	945.2
1934									
January	15.6	1.5	2.2	.6	(1)	(1)	(1)	2.0	21.9
February	13.6	1.3	2.5	1.6	(1)	(1)	(1)	4.0	23.0
March	16.8	1.5	5.4	1.6	(1)	(1)	(1)	7.0	32.3
April	64.5	14.0	30.5	13.0	1.2	14.8	2.0	1.6	141.6
May	97.7	7.0	36.1	10.9	.7	7.0	.3	1.0	160.7
June	26.7	.5	7.0	2.6	.3	1.6	0	.4	39.1
July	13.5	.4	4.3	.9	0	.8	0	0	19.9
August	14.7	1.0	4.0	1.4	.3	.9	.1	0	22.4
September	17.4	1.1	4.4	1.3	.2	1.1	.1	0	25.6
October	14.6	1.0	3.3	1.0	.3	.9	.1	.1	21.3
November	11.0	.8	2.6	.7	.2	.8	.1	0	16.2
December	10.3	.8	1.9	.6	.3	(1)	(1)	1.0	14.9
Year	316.4	30.9	104.2	36.2	[2] 3.5	[2] 27.9	[2] 2.7	17.1	538.9

[1] Where no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
[2] Partial year. Missing months are included in the total for the unmeasured area.

TABLE 194.—*Mountain run-off to southwest area, San Luis Valley*—Continued

Year and month	Northern group: Rio Grande near Del Norte, 1,320 square miles	Northern group: Pinos Creek near Del Norte, 62 square miles	Northern group: Rock Creek near Monte Vista, 38 square miles	Northern group: Unmeasured, 89 square miles	Southern group: Conejos River near Mogote, 282 square miles	Southern group: Alamosa Creek at Terrace Reservoir, 115 square miles	Southern group: La Jara Creek near Capulin, 73 square miles	Southern group: Los Pinos River near Ortiz, 167 square miles	Southern group: San Antonio River at Ortiz, 110 square miles	Southern group: Unmeasured, 136 square miles	Total
1935											
January	10.4	(1)	(1)	1.0	1.9	0.7	(1)	(1)	(1)	2.0	16.0
February	11.1	(1)	(1)	1.0	2.4	.5	(1)	(1)	(1)	3.0	18.0
March	15.7	(1)	(1)	1.5	4.3	1.5	(1)	(1)	(1)	6.0	29.0
April	32.5	(1)	(1)	1.8	15.1	3.9	3.0	9.7	4.8	4.4	75.2
May	83.2	(1)	3.2	4.0	45.3	12.8	6.5	40.3	13.3	8.7	217.3
June	336.4	(1)	3.3	30.0	135.0	56.0	1.7	42.3	2.0	2.6	609.3
July	117.4	(1)	1.0	7.0	56.8	20.3	0	8.0	.3	0	210.8
August	40.7	(1)	.8	2.2	17.9	7.0	0	3.4	.3	0	72.3
September	30.5	(1)	.4	1.6	8.6	2.4	0	1.7	.2	0	45.4
October	14.6	(1)	.2	.9	5.8	1.6	0	1.4	.2	0	24.7
November	16.0	(1)	(1)	1.1	3.6	1.3	0	(1)	.1	0	22.1
December	11.6	(1)	(1)	.8	2.4	.6	0	(1)	(1)	0	15.4
Year	720.1		[2] 8.9	52.9	299.1	108.6	[2] 11.2	[2] 106.8	[2] 21.2	26.7	1,355.5
46-year mean	710.3				255.5						1,258.6

[1] Where no figure is given the run-off was not measured and its estimate has been included in the estimate for the unmeasured area.
[2] Partial year. Missing months are included in the total for the unmeasured area.

Using the derived natural flow figures for the Rio Grande and Conejos for the 46-year period and, except for the period of record of the other streams, including their drainages as a part of the total of unmeasured drainage area, estimates were completed to give the monthly water production for the entire southwest area, 1890–1935, as shown by table 194. In these estimates the run-off for the unmeasured drainage areas was derived by comparison to that for adjacent measured areas of like characteristics to the extent permitted by the period of record of the latter and finally the run-off for the northern and southern groups as a whole was extended to 1890 on the basis of curves of monthly run-off relations to the Rio Grande and Conejos River, respectively. All records, no matter how short, were therefore taken into account in the estimates.

As shown by table 194, the mean annual water production from mountain run-off in the period 1890–1935 for the southwest area was determined to be 1,259,000 acre-feet. Although considerable estimating was involved in this determination, it is to be noted that 77 percent of the total run-off accounted for in table 194 was measured and only 23 percent is based upon estimates.

In the southeast area, east of the Rio Grande and between the closed basin on the north and the Colorado-New Mexico State line on the south, the principal streams are Trinchera and Culebra Creeks. On the south, Costilla River flows for a few miles in Colorado but its source is in New Mexico and it joins the Rio Grande in the latter State. Although the water of Costilla River is largely consumed on Colorado lands, the production estimate for this river is, for this report, included in the Middle section or New Mexico area production. For the southeast area the water production derived is that for the mountain run-off at the rim of the valley floor or the foothill line. The available run-off records are as follows:

Trinchera Creek above Mountain Home Reservoir, 61 square miles, 1908, 1909, 1923–35.

Sangre de Cristo Creek near Fort Garland, 176 square miles, 1916, 1923–29, 1932–35.

Ute Creek near Fort Garland, 32 square miles, 1908, 19
1916, 1923–35.

Culebra Creek at San Luis, 220 square miles, 1909–19, 1927–

Except for Culebra Creek, and in some years for Trinchera Creek, these records do not include the winter months.

Dividing the area into north and south sections, the unmeasured drainage area of the north is 24 square miles and that of the south 53 square miles. The only regulation above the gaging stations is that of the Sanchez Reservoir on a Culebra Creek tributary and correction was made for this to give natural flow.

Because of the paucity of data, estimates of annual flow only were made in extending the records to the 46-year period 1890–1935. The annual run-off of Culebra Creek was extended by comparison with the natural run-off of the Rio Grande near Del Norte. Partial year records for Ute, Sangre de Cristo, and Trinchera creeks were completed by comparison with Culebra Creek record. The annual run-off of Sangre de Cristo Creek for the missing years 1908, 1909, 1930, and 1931 was estimated by comparison with the combined run-off of the other streams. The annual run-off, 1908, 1909, and 1923 to 1935, of unmeasured streams was derived by comparison with the run-off per square mile of measured streams. The unit run-off for the northern unmeasured area was taken at 75 percent of that for T

Creek, and that for the southern unmeasured area as percent of that for Culebra Creek. The combined annual run-off of all streams except Culebra Creek was estimated for the years 1910 to 1919 by using curves of annual run-off relations to Culebra Creek, and for the years 1890 to 1907 and 1920 to 1922 by similar curves giving the relation to the run-off of Rio Grande near Del Norte. The estimates of annual water production so derived for the southeast area are shown in table 195. As indicated, the mean annual water production for this area was determined to be 120,400 acre-feet. As previously stated, very little of this production reaches the Rio Grande, practically all of it being consumed in irrigation between the foothills and the river.

In the closed basin area the streams enter the valley around its semicircular rim and flow toward the sump area extending along the base of the Sangre de Cristo Range. Such waters of the streams and of the diversions from the Rio Grande that are not consumed in irrigation, by transpiration of native vegetation, or by evaporation, finally find their way to the sump. Here, in seasons of abundant run-off the waste waters collect in numerous small lakes, swamps, and low water-logged areas and are evaporated. In seasons of moderate run-off the areas of free water surface and swamp are greatly diminished, and after a series of dry years San Luis and Head Lakes constitute the only free water surfaces. Observations seem to indicate that a substantial fraction of the water production of the east side streams escapes to the artesian basin which underlies the valley and reaches some distance under the delta fan of each of the streams entering it. Records of the closed basin run-off entering the valley at the foothill line are available as follows:

La Garita Creek near La Garita, 61 square miles, 1919–35.
Carnero Creek near La Garita, 117 square miles, 1919–35.
Saguache Creek near Saguache, 490 square miles, 1910–12, 1914–35.

TABLE 195.—*Mountain run-off to southeast area, San Luis Valley, Colo.*

[Estimated natural run-off at rim of valley]

[Drainage area 566 square miles. Unit, 1,000 acre-feet]

Year	Culebra Creek at San Luis, 220 square miles (1)	Trinchera Creek above Mountain Home Reservoir, 61 square miles (2)	Sangre de Cristo Creek near Fort Garland 176 square miles (3)	Ute Creek near Fort Garland 32 square miles (4)	Northern group, unmeasured, 24 square miles (5)	Southern group, unmeasured, 53 square miles (6)	Sum of (2) to (6), inclusive (7)	Total (1)+(7) (8)	Percent of 40-year mean (9)
1890	52.0						77.0	129.0	107
1891	55.0						79.0	134.0	111
1892	40.0						58.0	98.0	81
1893	33.0						49.0	[illegible]	[illegible]
1894	35.0						51.0	[illegible]	[illegible]
1895	45.0						66.0	111.0	92
1896	38.0						55.0	93.0	77
1897	54.0						77.0	131.0	109
1898	52.0						76.0	128.0	106
1899	33.0						49.0	82.0	68
1900	39.0						56.0	95.0	79
1901	38.0						55.0	93.0	78
1902	27.0						39.0	66.0	55
1903	50.0						75.0	125.0	104
1904	34.0						49.0	83.0	69
1905	55.0						79.0	134.0	111
1906	59.0						86.0	145.0	120
1907	69.0						100.0	169.0	140
1908	41.0	13.2	17.5	12.9	7.2	7.7	58.5	99.5	83
1909	67.0	12.8	19.9	18.2	10.3	12.7	73.9	140.9	117
1910	50.4						78.5	128.9	107
1911	50.8						79.0	129.8	108
1912	59.5						89.0	148.5	123
1913	34.2						60.0	94.2	78
1914	62.8						92.7	155.5	129
1915	70.3						101.0	171.3	143
1916	52.4						80.7	133.1	111
1917	60.5						90.0	150.5	125
1918	56.2						85.0	141.2	117
1919	72.0						103.0	175.0	145
1920	62.0						90.0	152.0	126
1921	63.0						90.0	153.0	127
1922	59.0						84.0	143.0	119
1923	56.0	9.4	16.4	20.5	11.5	10.1	67.9	123.9	103
1924	49.0	16.9	46.6	23.6	13.2	9.3	109.6	158.6	132
1925	50.0	4.6	6.7	9.8	5.5	9.4	36.0	86.0	71
1926	45.0	26.5	33.8	7.0	3.9	8.5	79.7	124.7	104
1927	42.9	11.5	11.9	19.6	10.9	8.1	62.0	104.9	87
1928	37.9	17.1	24.0	16.3	9.1	7.1	73.6	111.5	93
1929	38.8	12.4	15.4	24.7	13.9	7.3	73.7	112.5	94
1930	39.9	14.9	19.3	14.8	8.3	7.5	64.8	104.7	87
1931	29.3	11.1	16.7	20.2	11.3	5.6	64.9	94.2	78
1932	41.1	17.8	25.6	27.8	15.6	7.9	94.7	135.8	113
1933	40.3	18.4	18.4	14.3	8.0	7.6	66.7	107.0	89
19[illegible]	29.6	7.8	7.3	9.7	5.4	5.6	35.0	65.2	54
[illegible]	42.2	15.5	13.5	19.8	11.1	7.9	67.8	110.0	91
Mean	48.1						72.3	120.4	

San Luis Creek near Villa Grove, 255 square miles, 1922-26.

Group B creeks—North and South Crestone, Willow, Spanish, Cottonwood, and Deadman, all near Crestone, 43 square miles, 1909, 1915, 1936.

Sand Creek near Crestone, in Group C—group area 102 square miles, 1936 only.

Of these records, only those for Saguache Creek include any winter months, and the others are, for the most part, only for the period May to October.

For estimating purposes the east side area below Villa Grove was divided into three stream groups. Group A, an unmeasured run-off drainage area of 72 square miles above the foothill line, includes Cotton, Wild Cherry, Rito Alto, and San Isabel Creeks. Group B, 43 square miles, includes the creeks as given in the above list of available records. Group C, 102 square miles, includes Pole, Sand, Medano, Zapato, and other small creeks south to the closed basin boundary, and is unmeasured except for the 1936 record on Sand Creek.

It will be noted that the run-off records for the closed basin are exceedingly meager as the basis for a long-time production estimate. Although estimates of the annual mountain run-off at the foothill line, or approximately 8,500-foot contour, were made for the 46-year period, 1890–1935 so as to be comparable with the estimates for other areas, attention is directed to the fact that the estimates for the earlier years may be somewhat wide since they were necessarily based for much of the period on a comparison to the run-off of the Rio Grande near Del Norte, which shows a rather poor correlation with closed basin run-off.

Incomplete years in the longest recorded period, that for Saguache Creek, 1911, 1912, and 1914–35, were completed by a comparison to the monthly distribution relation as shown by Rio Grande near Del Norte for concurrent years. Incomplete and missing years for the same period for La Garita, Carnero, and San Luis Creeks were estimated by reference to the Saguache Creek record; incomplete years by comparison to the monthly distribution relation shown by Saguache Creek for concurrent years, and missing years from curves of annual run-off relations to Saguache Creek. The sum of the annual run-offs of Saguache, La Garita, Carnero, and San Luis Creeks for the period 1911, 1912, and 1914–35 was then referred to the Rio Grande near Del Norte record to complete the annual estimates for this combined run-off for the period 1890–1935.

The estimates for the east side streams in groups A, B, and C were treated separately. Draining from the east, they were assumed to bear a closer relation to Trinchera and Culebra Creeks than to the western streams. For the streams of group B an estimated curve of relation to Culebra Creek run-off at San Luis was drawn by plotting the 1936 May–September run-off, the 1909 and 1915 April–October run-off, and the extended annual run-offs for these years against the run-off of Culebra Creek for corresponding periods. Th annual run-offs of Culebra Creek, including years es mated from the Rio Grande near Del Norte, were the applied to this curve to derive the estimates of annual run-off for group B streams, 1890–1936. The mean of these estimates was determined to be 32,700 acre-feet.

The mean annual run-off from group A streams was estimated by a comparison to the 46-year mean annual yields per square mile of San Luis Creek on the north and group B streams on the south, estimated at 45 and 760 acre-feet per square mile, respectively. The northern part of group A area, comprising 37 square miles, was considered to have a unit run-off greater than San Luis Creek but much less than the southern part of the area. The northern part was therefore assumed to have a mean annual run-off of 150 acre-feet per square mile, while the 35 square miles of the southern part was assumed to have a unit run-off of 700 acre-feet per square mile. This gave a composite mean annual run-off for group A of 417 acre-feet per square mile, or 30,000 acre-feet, as the estimated annual mean for the 1890–1935 period. The annual figures for group A were derived by direct proportion to those for group B.

The mean annual run-off from group C streams was estimated by comparison of the 1936 May to September run-off of Sand Creek, assumed to represent one-third of the run-off of the entire group, with the run-off fr group B streams for the same period. This gave a rati 30 to 26 which, applied to the estimated 32,700 acre-feet mean for group B, gave an estimate of 38,000 acre-feet for the 1890–1935 mean annual run-off of group C streams. Annual figures for group C were derived by direct proportion to those for group B as in the case of group A.

The summation of the water production estimates for the closed basin is given in table 196. This shows an estimated total mean annual production of 187,700 acre-feet.

In table 197 the estimates of annual production for the southwest, southeast and closed basin areas are brought together to give the totals for the San Luis section. As indicated, the total mean annual production 1890–1935 for this section was determined to be 1,567,000 acre-feet. This may also be taken as the Colorado production, although it is not strictly so since a part of the Los Pinos River watershed and all of the San Antonio River watershed above the gaging stations near Ortiz lie in New Mexico. The run-off from these New Mexico areas is included in the San Luis section production since the Los Pinos and San Antonio Rivers are tributary to the Conejos River which joins the Rio Grande in San Luis Valley. In the estimate of water production for the Middle Section in New Mexic of the run-off of the watershed of the Rio Chama, w

TABLE 196.—*Mountain run-off to closed basin area, San Luis Valley, Colo.*

[Estimated natural run-off at rim of valley]

[Drainage area, 1,140 square miles. Unit, 1,000 acre-feet]

Year	La Garita Creek near La Garita, 61 square miles (1)	Carnero Creek near La Garita, 117 square miles (2)	Saguache Creek near Saguache, 490 square miles (3)	San Luis Creek near Villa Grove, 255 square miles (4)	Sum of (1) to (4), inclusive, 923 square miles (5)	East side: Group A, 72 square miles (6)	East side: Group B, 43 square miles (7)	East side: Group C, 102 square miles (8)	Total (5) to (8), inclusive (9)	Percent of 46-year mean (10)
1890					101.0	32.0	35.0	41.0	209.0	111
1891					105.0	33.0	36.0	42.0	216.0	115
1892					65.0	27.0	29.0	34.0	155.0	83
1893					48.0	24.0	26.0	30.0	128.0	68
1894					52.0	25.0	27.0	31.0	135.0	72
1895					80.0	28.0	31.0	36.0	175.0	93
1896					60.0	26.0	28.0	33.0	147.0	78
1897					101.0	32.0	35.0	41.0	209.0	111
1898					98.0	32.0	35.0	41.0	206.0	110
1899					48.0	24.0	26.0	30.0	128.0	68
1900					62.0	26.0	28.0	33.0	149.0	79
1901					60.0	26.0	28.0	33.0	147.0	78
1902					30.0	21.0	23.0	27.0	101.0	54
1903					93.0	31.0	34.0	39.0	197.0	105
1904					50.0	24.0	26.0	30.0	130.0	69
1905					105.0	33.0	36.0	42.0	216.0	115
1906					116.0	35.0	38.0	44.0	233.0	124
1907					143.0	39.0	43.0	50.0	275.0	147
1908					67.0	27.0	29.0	34.0	157.0	84
1909					111.0	40.0	44.0	51.0	246.0	131
1910					80.0	31.0	34.0	39.0	184.0	98
1911	22.0	15.0	73.3	9.6	119.9	31.0	34.0	39.0	223.9	119
1912	17.0	12.0	60.4	17.0	106.4	35.0	38.0	44.0	223.4	119
1913					70.0	24.0	26.0	30.0	150.0	80
1914	20.0	13.0	67.1	14.0	114.1	37.0	40.0	46.0	237.1	126
1915	17.0	11.0	59.3	10.0	97.3	35.0	38.0	44.0	214.3	114
1916	18.0	12.0	62.1	11.0	103.1	32.0	35.0	41.0	211.1	112
1917	20.0	13.0	66.2	13.0	112.2	36.0	39.0	45.0	232.2	124
1918	12.0	9.0	48.3	3.5	72.8	34.0	37.0	43.0	186.8	99
1919	23.6	20.2	77.3	20.0	141.1	40.0	44.0	51.0	270.1	147
1920	14.4	12.3	68.7	15.0	110.4	37.0	40.0	46.0	233.4	124
1921	22.5	11.5	78.5	21.0	133.5	37.0	40.0	46.0	256.5	137
1922	11.7	9.9	51.7	4.7	78.0	35.0	38.0	44.0	195.0	104
1923	20.2	14.3	66.0	12.4	112.9	34.0	37.0	43.0	226.9	121
1924	29.8	27.0	83.7	33.4	173.9	30.0	33.0	38.0	274.9	146
1925	11.7	7.3	51.5	4.9	75.4	30.0	33.0	38.0	176.4	94
	16.6	10.9	59.5	12.6	99.6	28.0	31.0	36.0	194.6	104
	6.4	4.8	57.5	8.5	77.2	28.0	30.0	35.0	170.2	91
	9.6	17.5	73.6	18.0	118.7	26.0	28.0	33.0	205.7	110
	13.0	12.4	70.0	16.0	111.4	26.0	28.0	33.0	198.4	106
	8.8	8.1	38.8	1.3	57.0	27.0	29.0	34.0	147.0	78
1931	4.4	3.8	27.3	1.0	36.5	22.0	24.0	28.0	110.5	59
1932	7.4	4.8	54.0	6.2	72.4	27.0	29.0	34.0	162.4	87
1933	5.6	4.3	33.7	1.1	44.6	27.0	29.0	34.0	134.6	72
1934	3.5	2.8	20.6	.8	27.7	22.0	24.0	28.0	101.7	54
1935	9.2	8.6	42.1	1.5	61.4	28.0	30.0	35.0	149.9	80
46-year mean					87.0	30.0	32.7	38.0	187.7	

joins the Rio Grande in New Mexico, is included, although there is a portion of this watershed in Colorado. The latter is a somewhat smaller area than that drained by Los Pinos and San Antonio Rivers in New Mexico, but its run-off largely offsets that from this latter area as the Rio Chama drains an area of considerably higher average elevation and greater average precipitation.

Water Production in the Middle Section, New Mexico

In estimating the water production, this section was divided into northern and southern units. In the northern unit were included all streams entering the Rio Grande between the Colorado-New Mexico State line and Otowi Bridge at the upper end of White Rock Canyon, and in the southern unit those entering between Otowi Bridge and San Marcial. The production estimates represent the run-off at the foothill line available for use in the valley areas, and no account is n of possible run-off from precipitation on the valley

TABLE 197.—*Mountain run-off to San Luis section, Rio Grande Basin, Colo.*

[Estimated natural run-off at rim of valley]

[Drainage area, 4,098 square miles. Unit, 1,000 acre-feet]

Year	Southwest area: Rio Grande near Del Norte, 1,320 square miles	Southwest area: Conejos River near Mogote, 282 square miles	Southwest area: Sum of other streams, 790 square miles	Southwest area: Total, 2,392 square miles	Southeast area, 566 square miles	Closed basin, 1,140 square miles	Total	Percent of 46-year mean
1890	820	301	369	1,490	129	209	1,828	117
1891	860	311	372	1,543	134	216	1,893	121
1892	532	193	233	958	98	155	1,211	77
1893	392	141	158	691	82	128	901	58
1894	424	151	191	766	86	135	987	63
1895	650	233	301	1,184	111	175	1,470	94
1896	487	171	241	899	93	147	1,139	73
1897	823	291	344	1,458	131	209	1,798	115
1898	797	296	366	1,459	128	206	1,793	114
1899	393	134	146	673	82	128	883	56
1900	506	187	212	905	95	149	1,149	73
1901	487	178	209	874	93	147	1,114	71
1902	249	87	105	441	66	101	608	39
1903	760	314	334	1,408	125	197	1,730	110
1904	406	150	148	704	83	130	917	58
1905	853	318	361	1,532	134	216	1,882	120
1906	949	334	378	1,661	145	233	2,039	130
1907	1,164	356	394	1,914	169	275	2,358	150

TABLE 197.—*Mountain run-off to San Luis section, Rio Grande Basin, Colo.*—Continued

[Estimated natural run-off at rim of valley]

[Drainage area, 4,098 square miles. Unit, 1,000 acre-feet]

Year	Southwest area: Rio Grande near Del Norte, 1,320 square miles	Southwest area: Conejos River near Mogote, 282 square miles	Southwest area: Sum of other streams, 790 square miles	Southwest area: Total, 2,392 square miles	South-east area, 566 square miles	Closed basin, 1,140 square miles	Total	Per-cent of 46-year mean
1908	550	193	190	933	99	157	1,189	76
1909	909	323	370	1,602	141	246	1,989	127
1910	655	202	292	1,149	129	184	1,462	93
1911	1,078	406	429	1,913	130	224	2,267	145
1912	812	308	384	1,504	149	223	1,876	120
1913	575	158	180	913	94	150	1,157	74
1914	820	253	275	1,348	156	237	1,741	111
1915	643	238	261	1,142	171	214	1,527	97
1916	947	369	408	1,724	133	211	2,068	132
1917	913	320	398	1,631	150	232	2,013	128
1918	517	226	221	964	141	187	1,292	82
1919	795	246	351	1,392	175	276	1,843	118
1920	1,015	430	498	1,943	152	233	2,328	149
1921	1,026	260	233	1,519	153	256	1,928	123
1922	929	311	373	1,613	143	195	1,951	124
1923	879	394	394	1,667	124	227	2,018	129
1924	738	284	369	1,391	159	275	1,825	117
1925	740	233	255	1,228	86	176	1,490	95
1926	640	249	264	1,153	125	195	1,473	94
1927	1,020	344	372	1,736	105	170	2,011	128
1928	639	192	209	1,040	111	206	1,357	87
1929	965	340	370	1,675	113	198	1,986	127
1930	506	205	269	980	105	147	1,232	79
1931	353	151	149	653	94	110	857	55
1932	915	357	420	1,692	136	162	1,990	127
1933	504	217	224	945	107	135	1,187	76
1934	316	104	119	539	65	102	706	45
1935	720	299	337	1,356	110	160	1,616	103
46-year mean	710	256	293	1,259	120	188	1,567	......

floors. The foothill line varies from about 8,200 feet elevation in the north to about 5,500 feet in the south and due consideration was given to this fact in estimating the run-off from drainage areas having no stream-flow records.

The northern unit was divided into run-off from the east and from the west. Available records for eastern streams, above diversions, are as follows:

Costilla River at mouth of canyon, 229 square miles, 1907, 1908, 1911–17, 1920.
Rio Colorado below Cabresto Creek, 165 square miles, 1913–28.
Rio Hondo at Valdez, 38 square miles, 1917–33.
Rio Fernando de Taos near Taos, 64 square miles, 1913–28.
Rio Lucero near Arroyo Seco, 17 square miles, 1912–28.
Rio Pueblo de Taos near Taos, 67 square miles, 1911.
Rio Santa Cruz at Cundiyo, 86 square miles, 1930–35.
Nambe Creek near Nambe, 37 square miles, 1933–35.

Contributing areas on the east, unmeasured above diversions, include Latir Creek, Arroyo Seco, Rio Chiquito, Embudo Creek, Truchas River, Rio Frijoles, Tesuque Creek, and minor streams, totaling 506 square miles.

Available records for western streams are confined to Rio Chama and its tributaries. Records of the Rio Chama at Chamita, near the mouth, are available for the period 1913 to 1936. Unmeasured contributing areas not tributary to Rio Chama include principally Aguaje de la Petaca and Santa Clara River, totaling 230 square miles.

The period 1907–35 was taken for the extension of individual eastern stream ~~records,~~ and estimates of annual run-off to fill out the period were made by c parison with the available records. In addition t records listed, use was made of the record of Culebra Creek at San Luis, corrected for storage regulation, and of that for Rio Colorado above Cabresto Creek. Estimates were made either by annual relation curves based upon the period of concurrent record or by assuming the same relation to have existed for missing years as was shown by the years of concurrent record. Where possible, estimates were based on the comparative relation to two streams rather than to one. The mean annual run-off 1907–35 for the unmeasured streams was estimated by direct comparison to the mean annual run-off per square mile of measured streams adjacent or considered to have drainage characteristics similar to those of the unmeasured stream. The means for the unmeasured streams were then combined and estimates of the annual run-off 1907–35 for the total unmeasured area derived by assuming the annual run-offs to bear the same relation to the period mean that the annual run-offs for the total of the measured streams bore to their period mean. The total annual run-off for all eastern streams, 1890–1907, was estimated by reference to the gain in the Rio Grande between the Lobatos and Embudo stations using a relation curve established for the years of concurrent data.

For the western streams, the record of Rio Ch near Chamita was corrected for upstream irrigation the basis of the 1936 acreages and consumptive use figures reported by the Bureau of Agricultural Engineering (Part III of this report). The irrigation draft was derived by applying the unit consumptive use figures less precipitation to the acreages of the various classifications including irrigated land, native vegetation, water surfaces and the like, and was found to total 70,000 acre-feet. This was used as a constant correction for each year on the assumption that there would have been no shortage of Rio Chama run-off to supply this draft. The corrected Chamita flow is shown in column 11 of table 198. The mean run-off of the unmeasured streams, 1913–35, was taken at 150 acre-feet per square mile from comparison with that of the Rio Chama and other northern unit streams. For the 230 square miles of unmeasured area this gave a run-off of 35,000 acre-feet. This mean was distributed to the years 1913–35 in accordance with the distribution of the Rio Chama run-off in the same period, as shown in column 12, table 198. The total annual run-off for western streams, 1890 to 1912, was estimated by reference to the gain in the Rio Grande between Embudo and Otowi Bridge using a relation curve established for the years of concurrent data. Gains in this river s tion are largely the result of west side inflow.

TABLE 198.—*Mountain run-off to northern unit, middle section, Rio Grande Basin, New Mexico*

[Estimated natural run-off at foothill line of valleys, Colorado-New Mexico State line to Otowi Bridge]

[Drainage area 4,641 square miles. Unit, 1,000 acre-feet]

Year	Eastern drainage										Western drainage				
	Costilla River at Canyon mouth, 229 square miles	Rio Colorado below Cabresto Creek, 165 square miles	Rio Hondo at Valdez, 38 square miles	Rio Fernando de Taos near Taos, 64 square miles	Rio Lucero near Arroyo Seco, 17 square miles	Rio Pueblo de Taos near Taos, 67 square miles	Rio Santa Cruz at Cundiyo, 86 square miles	Nambe Creek near Nambe, 37 square miles	Unmeasured streams, 506 square miles	Total sum of (1) to (9) inclusive, 1,209 square miles	[1] Rio Chama near Chamita, 3,202 square miles	Unmeasured streams, 230 square miles	Total sum of (11) and (12), 3,432 square miles	Total sum of (10) and (13)	Percent of 46-year mean
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
1890										410.0			830.0	1,240.0	130.9
1891										470.0			1,040.0	1,510.0	159.4
1892										370.0			860.0	1,230.0	129.8
1893										310.0			480.0	790.0	83.4
1894										324.0			180.0	504.0	53.2
1895										350.0			660.0	1,010.0	106.6
1896										240.0			290.0	530.0	55.9
1897										410.0			960.0	1,370.0	144.5
1898										350.0			300.0	650.0	68.6
1899										210.0			380.0	590.0	62.3
1900										230.0			220.0	450.0	47.5
1901										295.0			370.0	665.0	70.2
1902										200.0			180.0	380.0	40.1
1903										445.0			770.0	1,215.0	128.2
1904										237.0			390.0	627.0	66.2
1905										450.0			790.0	1,240.0	130.9
1906										430.0			830.0	1,260.0	133.0
1907	38.0	42.0	15.0	6.0	15.0	16.0	21.0	9.0	104.0	266.0			950.0	1,216.0	128.3
1908	59.0	66.0	24.0	12.0	22.0	28.0	34.0	14.0	167.0	426.0			600.0	1,026.0	108.3
1909	64.0	72.0	26.0	13.0	24.0	30.0	37.0	16.0	181.0	463.0			760.0	1,223.0	129.1
1910	49.0	54.0	20.0	9.0	19.0	22.0	28.0	12.0	137.0	350.0			470.0	820.0	86.5
1911	38.2	42.0	25.0	12.0	24.7	27.5	27.0	12.0	134.0	342.4			870.0	1,212.4	127.9
1912	67.6	51.0	10.0	8.0	18.3	27.2	31.0	13.0	151.0	386.1			800.0	1,186.1	125.2
1913	28.5	30.7	12.0	4.2	13.7	12.8	16.0	7.0	80.0	204.9	349.1	22.0	371.1	576.0	60.8
1914	49.2	56.8	21.0	9.3	20.0	17.6	28.0	12.0	138.0	351.9	553.1	35.0	588.1	940.0	99.2
1915	69.9	76.2	23.0	12.8	20.9	28.1	37.0	16.0	220.0	503.9	735.3	46.0	781.3	1,285.2	135.6
1916	47.8	80.9	40.0	10.2	34.0	48.0	42.0	18.0	206.0	526.9	977.2	61.0	1,038.2	1,565.1	165.2
1917	54.3	58.4	25.0	2.8	23.0	29.0	31.0	13.0	152.0	388.5	549.6	34.0	583.6	972.1	102.6
1918	47.0	47.3	16.7	4.4	17.0	19.0	24.0	10.0	120.0	305.4	329.4	21.0	350.4	655.8	69.2
1919	68.0	62.9	18.2	13.6	18.0	30.0	32.0	14.0	150.0	405.9	688.9	43.0	731.9	1,137.8	120.0
1920	54.3	90.2	25.0	10.6	21.0	25.0	86.0	15.0	177.0	454.1	856.4	53.0	909.4	1,363.5	143.9
[illegible]	109.0	82.2	28.9	6.9	26.0	34.0	46.0	20.0	227.0	580.0	499.4	33.0	532.4	1,112.4	117.4
[illegible]	32.0	33.0	9.2	4.3	11.0	9.0	16.0	7.0	77.0	198.5	411.4	26.0	437.4	635.9	67.1
[illegible]	50.0	44.0	18.7	3.7	19.0	21.0	25.0	11.0	124.0	316.4	575.8	35.0	610.8	927.2	97.8
[illegible]	93.0	75.0	30.4	4.3	27.0	35.0	42.0	18.0	210.0	534.7	814.0	51.0	865.0	1,399.7	147.7
[illegible]	28.0	33.9	9.4	1.8	11.0	9.0	15.0	6.0	74.0	188.1	403.8	25.0	428.8	616.9	65.1
1926	45.0	50.0	28.6	14.4	26.0	33.0	32.0	13.0	156.0	398.0	619.5	39.0	658.5	1,056.5	111.5
1927	41.0	61.7	24.8	2.7	23.0	27.0	29.0	12.0	143.0	364.2	792.0	45.0	837.0	1,201.2	126.8
1928	33.0	60.2	15.5	5.6	16.0	17.0	9.6	10.0	117.0	283.9	386.8	24.0	410.8	694.7	73.3
1929	40.0	49.0	21.6	6.0	20.0	25.0	23.0	11.0	128.0	323.6	587.6	37.0	624.6	948.2	100.1
1930	44.0	49.0	17.6	6.0	17.0	20.0	24.0	10.0	119.0	203.6	432.5	27.0	459.5	763.1	80.5
1931	23.0	30.0	10.4	6.0	12.0	11.0	28.1	6.0	113.0	237.5	311.0	19.0	330.0	567.5	59.9
1932	53.0	67.0	28.2	9.0	25.0	33.0	35.0	15.0	170.0	434.2	848.6	53.0	901.6	1,335.8	141.0
1933	[illegible]	29.0	[illegible]	[illegible]	[illegible]	[illegible]	14.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1934	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.3	[illegible]	[illegible]	130.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1935	42.0	51.0	19.0	6.0	17.3	21.0	32.4	12.4	124.0	325.1	481.9	30.0	511.9	837.0	88.3
Mean										346.2			601.4	947.6	100.0

[1] Includes estimate of irrigation use above gaging station based on 1936 acreages and consumptive use figures, amounting to 70,000 acre-feet annually.

The estimates for the annual run-off of the eastern and western streams and the combined run-off for the northern unit are given in table 198. This shows a mean annual water production, 1890–1935, for the northern unit of the Middle section, New Mexico, of 947,600 acre-feet.

In the estimates for the southern unit of the Middle section no segregation was made with respect to eastern and western streams. The run-off of this unit is very much less than that of the northern unit and there appears to be less difference between the characteristics of eastern and western streams. Available stream flow records are as follows:

Santa Fe Creek above upper reservoir near Santa Fe, 22 square miles, 1913–35.

-oyo Hondo near Santa Fe, 14 square miles, 1913–22.

Rio Jemez near San Ysidro, 854 square miles, 1924, 1925.

Bluewater Creek near Bluewater, 235 square miles, 1913–19, 1921–35.

San Jose River near Suwanee, 2,765 square miles, 1913–17.

Rio Puerco at Rio Puerco, 4,795 square miles, 1913–25, 1927, 1934, 1935.

Bluewater Creek joins the San Jose River near the town of Grants, and San Jose River is tributary to the Rio Puerco above the Rio Puerco gaging station. Contributing areas of unmeasured run-off include Galisteo and Tijeras Creeks, Rio Salado, and minor streams, totaling 2,387 square miles.

Estimates for the missing years in the period 1913 to 1935 were made for Rio Puerco using an established curve of relation to the run-off of Rio Chama near Chamita and similarly for Arroyo Hondo by reference to the run-off of Santa Fe Creek near Santa Fe. Because of the very short record on Rio Jemez, its area was included with that of the unmeasured streams.

Above the Rio Puerco station at Rio Puerco water is used for irrigation, and correction was made for this in the water production estimates by adding an estimate of the irrigation consumption to the flow as measured at Rio Puerco. The survey of irrigated areas made in 1936 under the Rio Grande joint investigation showed areas in the Rio Puerco drainage above Rio Puerco station which were grouped in four units as follows: The Cuba unit on the upper Rio Puerco, 2,900 acres; the Cabezon unit on the upper Rio Puerco and Chico Arroyo, 2,600 acres; the Bluewater unit on Bluewater Creek, 13,500 acres; and the San Jose unit on San Jose River, 6,800 acres. The irrigation consumption in these units was determined by adjusting an estimate based upon a unit consumption of 3 acre-feet per acre to an estimate of the run-off in the irrigation season, March to October, above diversions. If this run-off was greater than the total consumption given by a unit use of 3 acre-feet per acre, the total consumption so derived was taken as the value to be used. If the run-off was less, the total consumption was taken as 90 percent of the run-off. To estimate the annual irrigation season run-off above diversions in each unit, the areas of contributing watershed were determined and the mean run-off, 1913 to 1935, computed from assumed values for the run-off per square mile. This mean was made to be consistent with the corresponding mean at the gaging station below the unit. Proportional distribution of the run-off by years was made by reference to the Bluewater record for run-off to the Bluewater and San Jose units and to an upper Rio Puerco record derived by subtracting the Suwanee station flow from that at the Rio Puerco station, for run-off to the Cuba and Cabezon units. Missing flows at the Suwanee station were estimated at 15 percent of those at Rio Puerco. The annual corrections to the Rio Puerco record for upstream irrigation, thus derived, are included in the 1913–35 figures given for the Rio Puerco in table 199.

The run-off of unmeasured streams in the southern unit was estimated by a comparison of their individual drainage characteristics to those of measured streams and the mean annual run-off per square mile of the latter, to derive the mean annual run-off 1913–35 for the total of the unmeasured group. Annual estimates for the latter for this period were derived from the relation, annual to mean, as shown both by the measured streams of the unit and by Rio Chama at Chamita in the same period, using the mean of the values given by these two comparisons.

In the absence of any more representative index, the annual run-off of all streams in the southern unit for

TABLE 199.—*Mountain run-off to southern unit, middle section, Rio Grande Basin, New Mexico*

[Estimated natural run-off at foothill line of valleys, Otowi Bridge to San Mar

[Drainage area 8,072 square miles. Unit 1,000 acre-feet]

Year	Santa Fe Creek near Santa Fe, 22 square miles	Arroyo Hondo near Santa Fe, 14 square miles	[1] Rio Puerco at Rio Puerco, 4,795 square miles	Unmeasured streams, 3,241 square miles	Total	Percent of 46-year mean
1890					610.0	158.4
1891					818.0	212.5
1892					600.0	155.9
1893					260.0	67.5
1894					120.0	31.2
1895					440.0	114.3
1896					125.0	32.5
1897					710.0	184.4
1898					185.0	48.1
1899					148.0	38.4
1900					102.0	26.5
1901					188.0	48.8
1902					72.0	18.7
1903					602.0	156.4
1904					168.0	43.6
1905					620.0	161.1
1906					630.0	163.6
1907					855.0	222.1
1908					270.0	70.1
1909					560.0	145.5
1910					295.0	76.6
1911					625.0	162.4
1912					618.0	160.5
1913	5.5	0.3	48.6	117.0	171.4	44.5
1914	8.8	.6	162.6	275.0	447.0	116.1
1915	12.5	2.2	295.9	448.0	758.6	197.1
1916	13.3	2.3	221.1	435.0	671.7	174.5
1917	2.6	.1	42.2	155.0	199.9	51.9
1918	4.9	.2	44.2	107.0	156.3	40.6
1919	19.0	1.4	234.8	385.0	640.2	166.3
1920	7.0	.1	91.5	277.0	375.6	97.6
1921	18.3	.6	90.8	204.0	313.7	81.5
1922	3.5	.1	6.7	90.0	100.3	26.1
1923	5.2	.3	30.6	153.0	189.1	49.1
1924	10.9	.7	57.2	240.0	308.8	80.2
1925	2.1	.1	43.5	122.0	167.7	43.6
1926	9.6	.6	188.7	315.0	513.9	133.5
1927	4.6	.2	213.0	374.0	591.8	[illegible]
1928	4.4	.2	43.4	119.0	167.0	[illegible]
1929	8.8	.6	137.6	260.0	407.0	[illegible]
1930	5.4	.3	71.1	158.0	234.8	[illegible]
1931	7.8	.5	20.5	84.0	112.8	[illegible]
1932	6.9	.4	291.1	462.0	760.4	197.5
1933	2.7	.1	64.2	140.0	207.0	53.8
1934	1.9	.1	80.9	104.0	186.9	48.5
1935	6.5	.4	152.9	246.0	405.8	105.4
46-year mean					385.0	100.0

[1] Corrected for upstream irrigation.

1890 to 1912 was estimated by reference to the gain in the Rio Grande between the Lobatos and Otowi Bridge stations. Between Otowi Bridge and San Marcial there is the extensive irrigation use of the Middle Valley so that this section of the river was not suitable for the above reference. The estimated total annual run-offs 1890–1935 for the southern unit of the Middle section are given in table 199. This indicates a mean annual water production for this unit of 385,000 acre-feet. The figures for the combined run-off of the northern and southern units which is the total run-off for the Middle section, are given in table 202. This shows a mean annual run-off for the Middle section of 1,332,600 acre-feet.

Water Production in the Elephant Butte-Fort Quitman Section, New Mexico, Texas, and Mexico

This is the run-off from the drainage area of the Rio Grande between San Marcial and Fort Quitr totaling 6,868 square miles and divided as follows:

	Square Miles
San Marcial to Elephant Butte	1, 747
lephant Butte to Leasburg	2, 163
sburg to El Paso	1, 327
Paso to Fort Quitman	1, 631
Total	6, 868

There are practically no permanent streams entering the Rio Grande in this section. The arroyos which produce most of the run-off as the result of intermittent summer storms are largely tributary from the west between San Marcial and Mesilla Valley. Two streams, Alamosa and Las Palomas Rivers, have a fairly constant spring-fed flow but this is all used in irrigation above the Rio Grande, so that only the arroyo flood flows reach the latter. The only available tributary run-off records are as follows:

Alamosa River near Monticello, 385 square miles, 1931–36.
Las Palomas River near Las Palomas, 190 square miles, 1931 (partial).

With this almost complete lack of run-off records in this section, the most feasible method of estimating the run-off appeared to be that of isolating the Rio Grande gains between upper and lower points, attributable to arroyo inflow. The valley agricultural area in the Elephant Butte-Fort Quitman section is primarily dependent upon water released, as required, from Ele-hant Butte Reservoir. No dependence is placed upon oyo inflow and little of it is diverted to the land. oreover, since the arroyo flow occurs as flash floods carrying large quantities of silt and debris, canal headings are frequently closed to avoid it. This situation makes it possible to estimate the quantity of side inflow between two river points by a process of elimination where detail records are available of river discharge, diversions, and return flows. Such records are available for that portion of the section between Elephant Butte and El Paso. A detail study involving the plotting of daily hydrographs and comparing of daily records was, therefore, entered into to derive the side inflow to two units, Elephant Butte to Leasburg, and Leasburg to El Paso. The following records, complete for the period 1924 to 1936, inclusive, were utilized. Except for the Rio Grande at El Paso record furnished by the International Boundary Commission, these are records compiled and furnished by the Bureau of Reclamation.

Rio Grande below Elephant Butte Dam.
Rio Grande at Percha Dam.
Rio Grande at Leasburg.
Rio Grande at El Paso (Courchesne).
Arey canal at Percha diversion.
Leasburg canal at Leasburg diversion.
East side canal at Mesilla diversion.
West side canal at Mesilla diversion.
Waste to river in Rincon division.
Waste to river in Leasburg division.
Waste to river in Mesilla division.
Discharge of drains in Rincon Valley.
Discharge of drains in Mesilla Valley.

The daily gains in each unit were derived by comparing the upper and lower river discharge, making due allowance for time lag and intervening diversions, waste and drainage return. The river hydrographs were then inspected to determine whether or not the gains thus shown were due to side inflow or to other causes such as lag in release of channel storage, increase in release of ground water storage following a reduction in flow at the upper river station, discrepancies resulting from the adopted time lag, or merely inaccuracies in records. Gains obviously due to these latter causes were eliminated and arbitrary corrections based on comparison of records, rate of increase and decrease, etc., applied where these conditions were combined with side inflow. Except in two or three unusual years, only the period April to October was considered. In a number of months of this period, no side inflow was found in many years. This period practically covers the entire season of arroyo flow as well as the normal irrigation season, although some water is used in all months except January. Frequently in the months preceding or following the period chosen, Elephant Butte Reservoir releases are quite irregular and this

TABLE 200.—*Estimated tributary inflow, Elephant Butte to Leasburg, 1924–36*

[Drainage area 2,163 square miles. Unit, 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1924				6.5	0.6	0.9	8.7	6.3	0	0.3			23.3
1925				0	0	0	16.5	16.3	52.5	.2			85.5
1926			4.1	9.9	39.0	2.4	18.1	8.4	2.5	0			85.4
1927		0.9	0	6.7	1.4	3.5	8.9	6.3	11.2	0			38.9
1928		.3	2.5	15.4	11.3	8.7	12.4	25.1	10.7	3.8	1.3		92.5
1929				2.2	4.0	3.5	20.6	46.2	11.0	11.9			99.4
1930				5.0	2.1	2.4	8.9	15.3	1.0	.9			35.6
1931				4.1	.2	1.1	2.5	15.6	2.9	.4			26.8
1932				1.1	1.8	.8	2.8	7.0	9.0	8.5			31.0
1933				.7	1.6	9.0	11.8	10.0	5.5	1.4			40.0
1934				.4	2.1	.3	1.8	10.2	2.6	1.1			18.5
1935				.8	1.4	0	.9	18.6	25.2	.1			47.0
1936	0	0	.8	.5	1.4	.3	4.7	7.2	2.2	.3	0	0	17.3
	0	.1	.6	4.1	5.1	2.5	9.3	14.7	10.6	2.2	.1	0	49.3

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irregularity makes it very difficult to isolate possible side inflow.

The tributary inflow, by months, in the period 1924 to 1936, as derived by this study, is given for the Elephant Butte-Leasburg unit in table 200 and for the Leasburg-El Paso unit in table 201. A mean annual side inflow in this period of 49,300 acre-foot is indicated for the upper unit and 32,400 acre-feet for the lower unit.

As a basis for extending the estimates of tributary inflow to cover the 46-year period 1890–1936 in order to provide some comparison with the water production estimates of the upper sections, the precipitation data for stations within or near each unit appeared to offer the only feasible approach. The stations used for the Elephant Butte-Leasburg unit were Elephant Butte, Hillsboro, Kingston, Garfield, Lake Valley, and Jornado experimental range; and for the Leasburg-El Paso unit, Agricultural College, Cambray, Newman, Lanark, and El Paso. The period of the record at these stations is shown on plate 2. Missing records back to 1890 were supplied by reference to the relation between all stations for their periods of record. In each unit estimates of tributary inflow for the years 1890 to 1923 were made by means of curves drawn to show the relation between the sum of the April–October precipitation at all of the stations of the unit and the corresponding tributary inflow. The annual tributary inflows or run-offs thus estimated, 1890–1923, and as derived by the study previously outlined for the years 1924–36, are shown in table 202.

To complete the estimates of tributary inflow to the Elephant Butte-Fort Quitman section two units remained—San Marcial-Elephant Butte and El Paso-Fort Quitman. From the precipitation-run-off data used in extending the tributary inflow estimates for the Elephant Butte-Leasburg and Leasburg-El Paso units, curves were developed to show the relation between April-October precipitation expressed as a percent of the 46-year mean and the run-off in acre-feet per square mile, using the total drainage area of each unit. These curves for the Elephant Butte-Leasburg and Leasburg-El Paso units are shown on figure 44. From the position of these curves, similar ones to represent the San Marcial-Elephant Butte and El Paso-Fort Quitman units were drawn to correspond as nearly as might be estimated with known general relations and probable run-off characteristics. These latter curves, shown dotted on figure 44, were then entered with the April-October precipitation in percent of the 46-year mean to derive the annual April-October run-offs for each unit. Stations for which the precipitation records were used were Rosedale, San Marcial, Chloride Ranger Station, Glorietta Ranch, and Elephant Butte in the San Marcial-Elephant Butte unit, and El Paso and Clint in the El Paso-Fort Quitman unit.

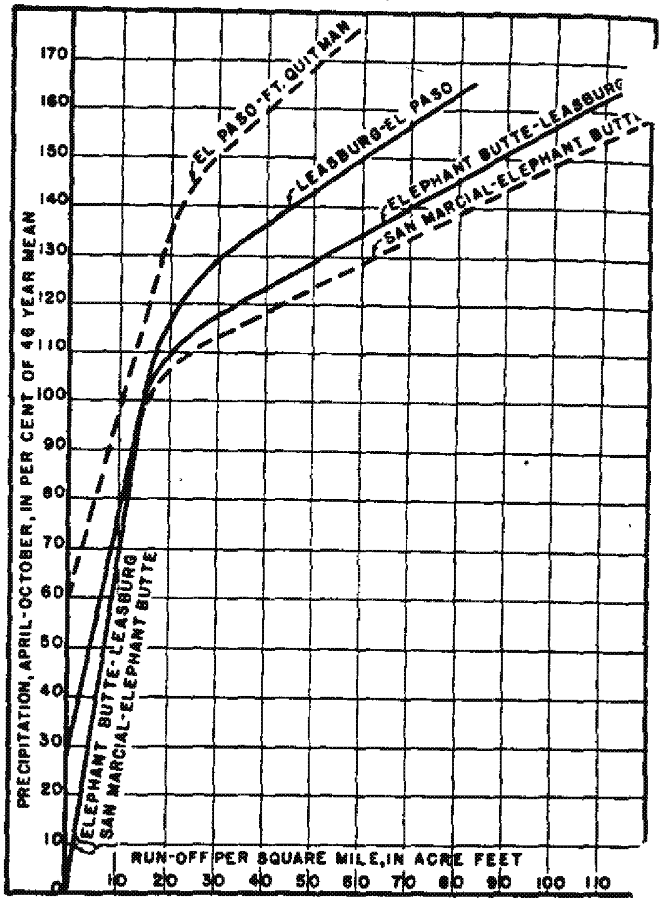

FIGURE 44.—Relation between precipitation and run-off in four units of the Elephant Butte-Fort Quitman section, Upper Rio Grande Basin

The annual tributary inflows or run-offs, 1890–1936, thus derived for these two units are shown in table 202. It is to be noted that this method of extension of the records by reference to precipitation cannot be expected to yield a high degree of accuracy in a region such as the Elephant Butte-Fort Quitman section where the erratic occurrence of rainfall is an outstanding characteristic. However, the complete lack of run-off data leaves no practicable alternative method. The study, described in the section of this report on water supply, to deduce the Rio Grande flow at San Marcial from Elephant Butte Reservoir data, clearly indicates the uncertainties involved and the impracticability of applying this method to a derivation of the tributary inflow to Elephant Butte Reservoir. During 1936 an attempt was made to measure and estimate the arroyo inflow to Elephant Butte Reservoir, but provision for satisfactory conditions to insure reliable estimates was not possible with the time and funds available. The May-October inflow so estimated for the western arroyos was only about 1,000 acre-feet, although the 1936 April-October tributary inflow to the San Marcial-Elephant Butte unit as derived by the study here was 15,000 acre-feet exclusive of the flow of Alamosa

TABLE 201.—*Estimated tributary inflow Leasburg to El Paso* [1]

[Drainage area 1,327 square miles. Unit 1,000 acre-feet]

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1924			4.2	7.0	11.4	10.4	18.4	4.9	6.0	0			62.3
1925				4.1	10.1	7.3	13.0	20.6	12.0	.7			67.8
1926			6.1	9.4	.1	6.7	15.2	5.0	11.3	.4			54.2
1927				.2	3.0	1.2	4.1	6.9	6.9	3.7			26.1
1928		3.3	3.8	4.6	9.2	2.2	7.6	4.6	1.9	3.5			40.7
1929			2.6	12.9	16.8	.7	6.8	9.8	.5	.7			51.8
1930				1.3	3.5	1.8	6.8	2.8	1.9	3.2			21.3
1931				5.9	2.0	.6	4.8	8.7	3.2	.8			26.0
1932				4.4	7.6	2.9	2.6	1.1	2.9	.3			21.8
1933				8.1	2.1	2.4	4.0	4.5	4.9	.6			26.6
1934			.4	.3	.1	.5	.6	1.1	.8	.3			4.1
1935				.3	.2	.7	2.1	8.7	1.2	.2			13.4
1936	0	.3	0	.4	1.1	.2	.5	1.6	.7	.2	0	0	5.0
Mean		.3	1.4	4.5	5.2	2.9	6.6	6.2	4.2	1.1	0	0	32.4

[1] To Courchesne gaging station.

TABLE 202.—*Mountain run-off to Middle and Elephant Butte-Fort Quitman sections, Rio Grande Basin, N. Mex. and Tex.*

[Estimated natural run-off at foothill line of valleys, Colorado State line to Fort Quitman, Tex.]

[Drainage area 19,581 square miles. Unit, 1,000 acre-feet]

Year	Middle section			Elephant Butte-Fort Quitman section					
	Northern unit, 4,641 square miles	Southern unit, 8,072 square miles	Total, 12,713 square miles	San Marcial-Elephant Butte unit,[1] 1,747 square miles	Elephant Butte-Leasburg unit, 2,163 square miles	Leasburg-El Paso unit, 1,327 square miles	El Paso-Fort Quitman unit, 1,631 square miles	Total, 6,868 square miles	New Mexico production, columns (3) to (6), inclusive
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1890	1,240.0	610.0	1,850.0	22	33	19	23	97	1,924.0
1891	1,510.0	818.0	2,328.0	24	18	3	0	45	2,373.0
1892	1,230.0	600.0	1,830.0	15	12	1	0	28	1,858.0
1893	790.0	260.0	1,050.0	44	170	77	48	339	1,341.0
1894	504.0	120.0	724.0	18	16	6	0	40	764.0
	1,010.0	440.0	1,450.0	81	69	34	28	212	1,634.0
	530.0	125.0	655.0	124	95	31	28	276	903.0
	1,370.0	710.0	2,080.0	159	260	90	105	614	2,589.0
	650.0	185.0	835.0	109	95	21	3	228	1,060.0
[illegible]	590.0	148.0	738.0	23	20	19	16	78	800.0
1900	450.0	102.0	552.0	18	21	18	21	78	609.0
1901	665.0	188.0	853.0	17	29	49	16	111	948.0
1902	380.0	72.0	452.0	24	37	20	31	112	533.0
1903	1,215.0	602.0	1,817.0	24	31	67	53	175	1,939.0
1904	627.0	168.0	795.0	33	135	68	72	308	1,033.0
1905	1,240.0	920.0	[illegible]	78	102	19	54	283	[illegible]
1906	1,250.0	330.0	[illegible]	23	33	17	38	[illegible]	[illegible]
1907	1,216.0	355.0	2,071.0	186	53	21	24	284	2,331.0
1908	1,026.0	270.0	1,296.0	25	27	14	13	79	1,362.0
1909	1,223.0	560.0	1,783.0	21	21	10	0	52	1,835.0
1910	820.0	295.0	1,115.0	26	18	7	0	51	1,166.0
1911	1,212.4	625.0	1,837.4	194	55	23	33	305	2,109.4
1912	1,186.1	618.0	1,804.1	90	128	103	32	353	2,125.1
1913	576.0	171.4	747.4	21	34	13	0	68	815.4
1914	940.0	447.0	1,387.0	105	172	70	67	414	1,734.0
1915	1,285.2	758.6	2,043.8	163	31	14	21	229	2,251.8
1916	1,565.1	671.7	2,236.8	143	149	22	15	329	2,550.8
1917	972.1	199.9	1,172.0	20	15	14	15	64	1,221.0
1918	655.8	156.3	812.1	24	33	16	11	84	885.1
1919	1,137.8	640.2	1,778.0	56	44	35	32	167	1,913.0
1920	1,363.5	375.6	1,739.1	24	37	19	1	81	1,819.1
1921	1,112.4	313.7	1,426.1	37	29	19	11	96	1,511.1
1922	635.9	100.3	736.2	16	18	8	0	42	778.2
1923	927.2	189.1	1,116.3	22	30	14	7	73	1,182.3
1924	1,399.7	308.8	1,708.5	20	23	62	11	116	1,813.5
1925	616.9	167.7	784.6	24	86	68	16	194	962.6
1926	1,056.5	513.9	1,570.4	36	85	54	28	203	1,745.4
1927	1,201.2	591.8	1,793.0	28	39	26	5	98	1,886.0
1928	694.7	167.0	861.7	25	92	41	24	182	1,019.7
1929	948.2	407.0	1,355.2	116	99	52	27	294	1,622.2
1930	763.1	234.8	997.9	24	36	21	5	86	1,078.9
1931	567.5	112.8	680.3	60	27	26	34	147	793.3
1932	1,335.8	760.4	2,096.2	26	31	22	38	117	2,175.2
1933	730.3	207.0	937.3	26	40	27	11	104	1,030.3
1934	321.2	186.9	508.1	30	18	4	0	42	560.1
1935	837.0	405.8	1,242.8	34	47	13	8	92	1,326.8
46-year mean	947.6	385.0	1,332.6	53.0	56.5	30.8	22.5	164.8	1,474.9
46-year median				25.0	34.0	21.0	16.0	111.0	
1936				23	17	5	18	63	

[1] Includes flow of Alamosa River which would not be inflow to Elephant Butte Reservoir because of irrigation use.

River, which it may be assumed was all used in irrigation.

The erratic character of the run-off in the Elephant Butte-Fort Quitman section and the difficulties involved in estimating it are well illustrated by the wide divergence between the 46-year means and the 46-year medians for the units of this section as shown at the bottom of table 202. For instance, the total mean annual run-off for the section, influenced largely by a few erratic years of high run-off, is 164,800 acre-feet, although as indicated by the median, the run-off in 23 of the 46 years was 111,000 acre-feet or less.

If the estimated mean annual run-off of 22,500 acre-feet in the El Paso-Fort Quitman unit is divided to Texas and Chihuahua, Mexico, in direct proportion to their respective drainage areas tributary to the Rio Grande in this unit, the Texas run-off is 11,000 acre-feet and that of Chihuahua 11,500 acre-feet.

PART I
APPENDIX C.—BIBLIOGRAPHY

BURKHOLDER, JOSEPH L.
1928. Report of the Chief Engineer, Middle Rio Grande Conservancy District, New Mexico. 248 p.

CONKLING and DEBLER.
1919. Water Supply, Irrigation, and Drainage Above El Paso. U. S. Dept. of the Int., Reclam. Service, 135 p., also charts, tables, and maps (unpublished).

DEBLER, E. B.
1924. Water Supply Requirements. U. S. Dept. of Int., Bur. of Reclam. (unpublished).

——— 1932. Final Report on Middle Rio Grande Investigation. U. S. Dept. of Int., Bur. of Reclam. (unpublished).

——— and ELDER, C. C.
1927. Preliminary Report on Investigations in Middle Rio Grande Valley, New Mexico. Middle Rio Grande Conservancy District. 157 p. (unpublished).

——— and WALKER, A. W.
1924. Water Supply for Rio Grande Project. U. S. Dept. of Int., Bur. of Reclam. 31 p. (unpublished).

EAKIN, H. M.
1936. Silting of Reservoirs. Technical Bull. No. 524 U. S. Dept. of Agr.

FOLLETT, W. W.
1898. Rio Grande Waters. U. S. Senate Document 229, 55th Congress, second session, 3 pts., 287 p., 10 maps.

FRENCH, J. A.
1910. San Luis Valley, Colorado. Report to the U. S. Bur. of Reclam. (unpublished).

GAULT, HOMER J.
1923. Middle Rio Grande Reclamation Project. Report to U. S. Bur. of Reclam. (unpublished).

HAMELE, OTTAMAR.
1924. The Embargo on the Upper Rio Grande. Report to U. S. Bur. of Reclam. (unpublished).

HEDKE, C. R.
1924. Consumptive Use of Water by Crops, New Mexico State Engineer's Office, 26 p. (unpublished).

——— 1925. Irrigation Development and Water Supply of the Middle Rio Grande Valley, New Mexico. Report to the Rio Grande Survey Commission, 38 p. (unpublished).

HENNY, D. C.
1925. Part of Statement of El Paso County Water Improvement District Number 1 and Elephant Butte Irrigation District to Rio Grande Compact Commission, 55 p. (unpublished).

HINDERLIDER, M. C.
1922–34. Biennial Reports, Colorado State Engineer's Office.

HOSEA, R. G.
1928. Irrigation in the Rio Grande Valley—1928. New Mexico State Engineer's Office, 90 p. (unpublished).

INTERNATIONAL BOUNDARY COMMISSION—UNITED STATES SECTION.
1935. Control and Canalization of the Rio Grande, Caballo Dam, New Mexico to El Paso, Tex. (unpublished).

MCCLURE, THOMAS M. (and predecessors).
Biennial Reports of State Engineer of New Mexico.

MEEKER, R. I.
1922. (May) Review and Brief Report, Rio Grande Interstate Water Conflict. Colorado State Engineer's Office, 18 p. (unpublished).

——— 1924. (May) Water Supply, Irrigation, and Drainage, Present and Future Conditions, San Luis Valley, Colorado. Colorado State Engineer's Office, 40 p. (unpublished).

——— 1924. (August) Review of Water Supply, Drainage, Irrigated Area, and Consumptive Use of Water; Rio Grande Basin above Fort Quitman, Tex. Colorado State Engineer's Office, 36 p. (unpublished).

——— 1926. (February) Report on Gaging Stations on the Rio Grande, San Marcial, N. Mex. to Fort Quitman, Tex. Colorado State Engineer's Office.

——— 1928. (November) Water Supply and Water Consumption San Luis Valley, Colorado. Colorado State Engineer's Office, 85 p. (unpublished).

——— and BURGESS, L. T.
1928. (November) 1925–28 Investigational Studies of Water Uses Under Elephant Butte Reservoir in New Mexico, Texas, and Mexico. Colorado State Engineer's Office, 164 p. (unpublished).

——— 1928. Rio Grande above Fort Quitman, Tex. Stream Flow Records, 1889 to 1927, Colorado, New Mexico, and Texas. Colorado State Engineer's Office, 46 p. (unpublished).

NEWCOMER, A. W.
1930. Depletion of Flow of Rio Grande at Colorado-New Mexico State Line. New Mexico State Engineer's Office, 5 p. and 10 tables (unpublished).

OSGOOD, E. P.
1928. Preliminary Report, Use, Control, etc., Waters above Fort Quitman. New Mexico State Engineer's Office, 16 p. and 1 map of San Luis Valley (unpublished).

——— 1928. Report on Water Supply, Irrigation, and Drainage in the San Luis Valley, Colorado, 1928. New Mexico State Engineer's Office, 200 p. (more or less) (unpublished).

——— and BLISS, JOHN H.
1928. Seepage Investigation on Rio Grande (unpublished).

RIO GRANDE COMPACT COMMISSION.
December 1928, January 1929, December 1934, January 1935, December 1935, Proceedings (unpublished).

RIO GRANDE PROJECT.
1916–35. Annual Histories of Operation and Maintenance, Office of Bureau of Reclamation (unpublished).

ROHWER, CARL.
1931. Evaporation from Free Water Surfaces, U. S. Dept. Agr. Tech. Bul. 271, 96 p.

STANNARD, J. D., and MILLER, D. G.
1913. Drainage and Water Development in San Luis Valley, Colorado. Report of Drainage Investigations, U. S. Dept. of Agr.

SIEBENTHAL, C. E.
1910. Geology and Water Resources of the San Luis Valley, Colorado. U. S. Dept. Int. Geological Survey Water Supply Paper 240, 125 p.

STOUT, FOWLER, and DEBLER.
1935. (February) Report of San Luis Valley Drain Committee. U. S. Dept. Int., Bur. of Reclam. 26 p. (mimeographed).

TIPTON, R. J.
1924. Soil Conditions and Drainage in San Luis Valley. Colorado State Engineer's Office, 58 p. (unpublished).

———
1924. Deduction of Acreage in San Luis Valley. Colorado State Engineer's Office (unpublished).

———
1930. (March) San Luis Valley, Present Method of Irrigation, its Relation to Water Consumption and Water-logging of Land, Change Through Additional Storage and Drainage Development Essential. Colorado State Engineer's Office, 64 p. (unpublished).

———
1933. (August) Synopsis of Engineering Report on Interstate Phases of Rio Grande and Proposed "Sump" Drain and State Line Reservoir. Colorado State Engineer's Office, 26 p. (unpublished).

———
1935. Resume of the Problem Concerning the Rio Grande Above Fort Quitman, Tex. Colorado State Engineer's Office, 37 p. (unpublished).

——— and HART, F. C.
1931. (March) San Luis Valley, Field Investigations, 1930 Consumptive Use Determination, Evaporation Experiments, Drainage Measurements. Colorado State Engineer's Office, 17 p., charts, tables, and 1 map (unpublished).

TIPTON, R. J., and HART, F. C.
1932. Field Investigations, 1931 Consumptive Use Determinations, Evaporation Experiments, Drainag Measurements—Sump Area Investigations, 1932. Colorado State Engineer's Office, 14 p., 19 tables, 2 charts (unpublished).

——— ———
1933. San Luis Valley, Field Investigations of 1932 Consumptive Use Determinations, Evaporation Experiments, Drainage Measurements, Sump Area Investigations. Colorado State Engineer's Office, 11 p., 24 tables, 2 charts (unpublished).

UNITED STATES DEPARTMENT OF STATE.
1934. Rectification of the Rio Grande. Convention between the United States of America and Mexico, and Exchange of Notes. Treaty Series, No. 864. 56 p.

UNITED STATES GEOLOGICAL SURVEY.
1905. Observations on the Ground Waters of Rio Grande Valley, by C. S. Slichter, Water Supply Paper 141. 83 p., 5 pls.

WORK, HUBERT.
1925. Review of the Department of the Interior on the Rio Grande Embargo (unpublished).

YEO, H. W.
1910. Rio Grande Area in New Mexico. Report to U. S. Bureau of Reclamation (unpublished).

———
1928. (About) Irrigation in Rio Grande Basin in Texas and New Mexico. New Mexico State Engineer's Office. 5 vols. (unpublished).

——— and BLACK, R. F.
1931. (February) Report on Water Supply, Irrigation and Drainage in the San Luis Valley and Adjacent Mountain Areas in the State of Colorado. New Mexico State Engineer's Office. vol. 1, 325 p.; vol. 2, p. 326 to 541; vol. 3, 5 maps.

PART II
GROUND WATER RESOURCES

Report of the United States Geological Survey

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PART II

⁻CTION 1.—GEOLOGY AND GROUND-WATER CONDITIONS OF THE Ↄ GRANDE DEPRESSION IN COLORADO AND NEW MEXICO[1]

General Statement

The investigation of the geology and ground-water conditions in the Rio Grande Valley was made as a part of the Rio Grande Joint Investigation under the auspices of the Water Resources Committee of the National Resources Committee. The investigation was made by the Ground Water Division of the United States Geological Survey under the direction of C. V. Theis and under general supervision of O. E. Meinzer, who is in charge of the Division. David G. Thompson, senior geologist in the Ground Water Division, was in the field from March 12 to May 3, 1937, and contributed greatly in organizing the work. Sections 1, 2, and 3 of part II were prepared on the basis of this investigation.

The Rio Grande flows from the heights of the San Juan Mountains in Colorado to the sea through a series of structural basins that were formed chiefly by faulting and other deformation of the older rocks and ⁻equent filling with sedimentary and volcanic ⁻its. This series of basins forms a structural depression that is referred to in this paper as the Rio Grande depression. The basins differ from one another in their physical characters, their present social and economic standards, the order in which they have been successively occupied by different races of men, and the completeness of their occupation. Therefore each basin is a geographic unit, not only in its physical aspect but also in its historical development. The impact of the environment and the reaction induced by successive incursions of groups differing radically in race, language, and customs have led to social and political differences as great as the separation in space and in topography.

The physical rather than the social or historical features of the several basins of the Rio Grande in Colorado and New Mexico are here set forth. The several parts of the region traversed by the Rio Grande, in spite of their differences, have many similarities, which can be traced back to a common geologic history. This history is here summarized to account for the striking differences in the topographic forms of the several basins and in their equally important hydrologic conditions.

[1] Kirk Bryan, senior geologist in the U. S. Geological Survey and associate of geology in Harvard University.

Sources of Data

Knowledge of the geology and geomorphology of New Mexico, particularly the north-central portion, has been gained over a long period by many observers. A general description of the successive valleys was first made by Lee[2] in 1907, and his description has been drawn on in this paper. The general stratigraphy and structure of the pre-Tertiary rocks was presented by Darton[3] in 1928 in a comprehensive paper that contains an extensive bibliography of earlier literature. For the area below the Socorro quadrangle, Harley's work on Sierra County[4] and the brilliant monograph by Dunham[5] have been useful.

The writer began work in the area in 1909, and at different times in 1916 and later years he made reconnaissances. In 1925, 1927, 1928, and 1929 he studied various problems under the auspices of the United States Geological Survey and other agencies. Since 1931, with the help of Harvard students and largely aided by different funds of Harvard University, he has been engaged in a general attack on the Tertiary geology and the geomorphology of the area. Dr. H. T. U. Smith has completed a study of the Abiquiu quadrangle. Prof. R. E. Nichols has investigated about 70 miles of the San José Valley from Grants to the Rio Puerco. Franklin T. McCann worked with the writer near Cuba, N. Mex., and again at the north end of the Ceja del Rio Puerco. Joseph E. Upson and Charles S. Denny are still engaged respectively in studies of the east side of the San Luis Valley and of the basin just north of the San Acacia constriction. The writer studied the Socorro quadrangle in 1925 and again in 1931. With J. E. Upson he completed a study of the Santo Domingo area in 1934. A. N. Dangerfield has begun a study of the Mesilla Valley. Each of these men and the writer have been assisted in the field by students of Harvard and other colleges. The enthusiasm and sacrifices of these volunteers would deserve separate mention if space permitted. The

[2] Lee, W. T., Water Resources of the Rio Grande Valley in New Mexico: U. S. Geol. Survey Water-Supply Paper 188, 59 pp., 1907.

[3] Darton, N. H., "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U. S. Geol. Survey Bull. 794, 356 pp., 1928.

[4] Harley, G. F., The geology and ore deposits of Sierra County, N. Mex.: New Mexico School of Mines, Bur. Mines and Mineral Resources, Bull. 10, 220 pp., 1934.

[5] Dunham, K. G., The geology of the Organ Mountains, with an account of the geology and mineral resources of Dona Ana County, N. Mex., New Mexico School of Mines, Bur. Mines and Mineral Resources Bull. 11, 272 pp., 1935 (1936).

studies recorded above are being prepared for publication, and, although several papers are in press, only preliminary announcements and a few papers had appeared in print by the winter of 1937.[6] The writer expresses his thanks to these coworkers and assistants for the use of material here included and for many pleasant hours in the field.

Broad Relations of the Rio Grande Drainage Area

The drainage area of the Rio Grande includes parts of Colorado, New Mexico, Texas, and Mexico, with diverse topographic characteristics. The region is commonly divided into provinces of somewhat homogeneous characteristics (fig. 45). The Southern Rocky Mountains of Colorado extend southward into New Mexico as two prongs. The Sangre de Cristo Mountains form the eastern prong and end at Glorieta. The Conejos and Jemez Mountains form the less · ·d western prong and end at the pueblo town of . Here, at approximately 35°30′ north latitude, the Colorado Plateau province, the Basin and Range province, and the Great Plains province border in a relatively small area. The Rio Grande, rising in the high San Juan Mountains, flows eastward through deep canyons as a clear mountain stream into the San Luis Valley. This broad open area of plains, with a general altitude above 7,500 feet, is obviously a depression in the mountain belt merely modified by the entrance of the river. It is the northern portion of the Rio Grande depression, which, beginning at Poncha Pass, about 50 miles north of the entrance of the Rio Grande, extends southward between the two prongs of the Rocky Mountains for nearly 200 miles. This part of the depression is diversified by hills, volcanic peaks, and lava-capped plateaus and is generally included in the Southern Rocky Mountain province. However, structurally it is continuous southward, with an offset to the west of about 30 miles, with a series of contiguous basins that form part of the Basin and Range province.

Within the Basin and Range province, as far as El Paso, the course of the Rio Grande lies generally within the basins and is roughly parallel to the ranges. At El Paso there is an abrupt change to a southeasterly direction, across the basins and ranges, in the area kn the Big Bend. Thence the river continues t southeastward down the slope of the coastal plain. The abrupt change in course at El Paso has led to various suggestions that the present Rio Grande has been formed by two rivers. According to these suggestions, the upper river once flowed southward in the broad basins of northern Mexico, where it evaporated, but it was captured by the headward erosion of the lower river.

The lower river, emerging from the series of canyons below Fort Quitman and rejuvenated by the influx of the Pecos and several large tributaries from the Mexican side, is a broad stream of low gradient, slightly incised in extensive mesquite-covered plains which become lower and lower. The smooth plains of the delta begin about 80 miles from its mouth and are irrigated in the subtropical Brownsville area. The isolated valleys of the upper river area are indeed remote from this "Winter Garden", which is in communication by sea with the whole world.

The Rio Grande above Fort Quitman is a complex stream in that it flows from basin to basin through canyons or other restrictions. It may be roughly likened to a stream flowing from one sand-filled tub to another through narrow troughs. Each tub differs in size and shape from the others and contains san different quality. In these tubs water is los.

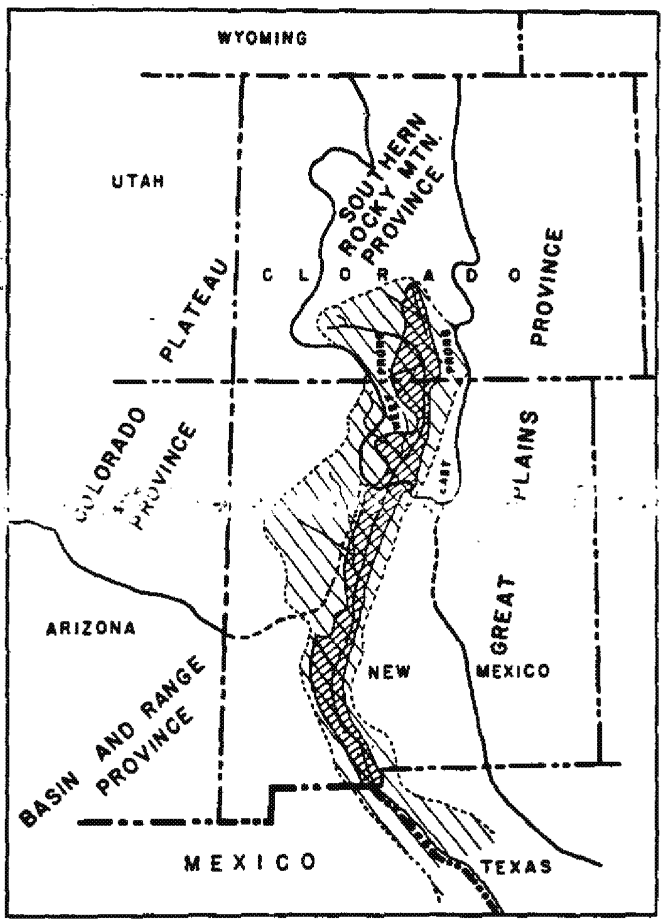

FIGURE 45.—The Rio Grande drainage and structural depression, in relation to the physiographic provinces of the region. (Structural depression shown by deep shading.)

[6] Bryan, Kirk, Harvard Geological Field School in New Mexico: Harvard Alumni Bulletin, Feb. 12, 1932; Second Geological Field School in New Mexico: Idem., Mar. 17, 1933; The Harvard Geological Field School—an aftermath and forecast: Idem., Mar. 16, 1934. Bryan, Kirk, and McCann, F. T., Successive erosion surfaces of the upper Rio Puerco, near Cuba, N. Mex.: Jour. Geology, vol. 37, 1936. Nichols, R. E., Flow-units in basalt: Jour. Geology, vol. 44, pp. 517–630, 1936. Bryan, Kirk, and McCann, F. T., The Ceja del Rio Puerco—a border feature of the Basin and Range province in New Mexico, Jour. Geology (in press). Cabot, E. C., Fault border of the Sangre de Cristo, north of Santa Fe, N. Mex., Jour. Geology (in press).

evaporation and is also gained by local rainfall on the -and. The troughs also differ in shape and length, and some of them there is a gain of water.

The basins consist of broad plains between mountains. Only in the lower part of the San Luis Valley does the river run essentially at the grade of the plains. In the other basins it is incised from about 250 to 500 feet and flows in an inner valley, or trench, that has a flat floor, 1 to 4 miles in width. These inner valleys contain the irrigated lands, meadows, and cottonwood groves on which the successive civilizations of the Pueblo Indians, the Spaniards, and the present American inhabitants have depended. To them the inner valley is the important feature, and names have been given to its wider portions and intervening contractions. In the following description the names of the inner valleys, or trenches, are used also to designate the structural basins in which they lie.

The several parts of the depression differ in their altitude above the river and in the degree of dissection. Some parts are smooth plains, others are a maze of steep-walled gulches, and still others are basalt-covered plateaus. All these areas, except the flood plain of the Rio Grande within the inner valleys and the flat floors of some of the principal tributary streams, have a deep water table and low run-off. The Santa Fe formation is the principal body of sedimentary deposits he structural basins which in this paper are collecly called the Rio Grande depression. It is somewhat permeable and produces sandy soils that promote infiltration of rain. Similarly, the widespread cover of gravel, which was deposited in several successive Pleistocene stages, is open and permeable. The basalt-covered areas are very conducive to surface infiltration, and large parts of the basalt-covered plains have no surface run-off, even in the most severe rain storms. A further characteristic of these surfaces is the presence of wind-borne or wind-laid soil over large areas. The sandy dissected slopes and the sandy beds of streams furnish at present and have furnished in the recent geologic past large supplies of sand to the wind. This material has been deposited on flat surfaces of gentle grade and forms a permeable soil that promotes infiltration and decreases run-off.

The principal characteristic of these areas which inhibits infiltration is the presence of caliche. This deposit of calcium carbonate forms crusts ranging from a mere impregnation of the soil to a layer of compact limestone 2 to 15 feet thick. This layer lies from a few inches to a few feet below the surface over large areas. It forms a barrier to the infiltration of rainfall that is effective in proportion to its thickness and the perfection with which it has been made and preserved.

e mountains and highlands that border the Rio ıde depression differ from the depression in many ways as regards water supply. In the first place, they generally, though not everywhere, stand at higher altitudes and hence receive a greater precipitation. Their water supply is not only greater but also more continuous, because much of the winter precipitation occurs as snow and hence runs off with relative slowness as the snow melts. Furthermore, these areas have a greater vegetative cover, which tends to delay the run-off.

In the second place, the steeper slopes and relatively impervious character of the rocks of the mountains and highlands promotes rapid run-off in contrast to the characteristics of the basins just set forth. Thus the greatest floods come from these highland areas, even though the only perennial streams of the region also run from them. The rocks of the highland areas are also variable in their permeability. On the whole, infiltration into them is moderate in quantity and the ground-water reservoirs are small, but there are notable exceptions. Thus, as will be brought out more at length, the great limestone plateau of the Sandia Mountains is fissured and cavernous and therefore forms a considerable ground-water reservoir to feed the springs at the east base of the mountains.

The importance of these major differences with respect to water supply is rather obvious, but their effects on the relative size of stream valleys and the relative efficiency of individual streams is likely to be overlooked.

Outline of the Structural Basins and Their Inner Valleys

San Luis Valley and Rio Grande Canyon

The first of the structural basins through which the Rio Grande flows is the San Luis Valley of Colorado, which begins at Poncha Pass and ends where shallow canyons in the rocks of the San Luis Hills begin. (See fig. 47.) South from these canyons, the river flows in an open valley, with the hills on the west and broad plains on the east. This area is economically and socially a part of the San Luis Valley, but structurally and in part hydrographically it is distinct. The State Line Bridge, about 6 miles north of the New Mexico line, marks the beginning of the Rio Grande Canyon—a narrow gorge in basalt. From a start as a narrow trench only 50 feet deep, the canyon deepens in the next 50 miles to Embudo, where the basalt-capped walls are 1,200 feet high. This deep canyon and the sage-covered basalt plateau in which it is incised effectively separate the San Luis Valley from the lower valleys, not only physically but also in an economic and social sense. Structurally this part of the depression is not well known, as the great floods of basaltic lava have covered its complexities and have given a surficial unity to an area that is structurally diverse.

Española Valley

In the next 25 miles the river runs through the Española Valley. (See fig. 48.) On the west this valley receives the Chama River and is connected with the Abiquiu area; on the east it receives a number of small streams that connect it with small irrigated valleys at the foot of the Sangre de Cristo Range. Economically the area around Santa Fe is part of this region, but, explained on page 224, Santa Fe Creek and the plains to the south of Santa Fe constitute an area that is hydrologically distinct.

White Rock Canyon

At Buckman begins the White Rock Canyon, known to the Spanish as Caja del Rio. It is a narrow gorge, 20 miles long, between the Sierra de los Valles and the Cerros del Rio.

Santo Domingo Valley

The next valley, marked by the entrance of Santa Fe and Galisteo Creeks from the east, is the comparatively small Santo Domingo Valley, about 20 miles long. (See figs. 48 and 49.) It ends at San Felipe, where there is a short and relatively insignificant constriction of the valley by the basalt plateau of Santa Ana Mesa and the little butte called San Felipe Mesa. The insignificant character of this constriction is out of proportion to the relatively large change in the character of the basin. Here the Rio Grande depression emerges from the Southern Rocky Mountain province into the Basin and Range province, and here the depression as a whole is offset to the west about 20 miles. The Santo Domingo Valley lies in this area of offset but it is related structurally to the basin at the north.

Albuquerque and Belen Valleys

The Albuquerque and Belen Valleys lie in a part of the Rio Grande depression which is 80 miles long and 25 to 35 miles wide with a general trend about 10° west of south. (See fig. 49.) The eastern border of the depression is a continuous belt of narrow but high mountains, named, from north to south, the Sandia, Manzanita, and Manzano Mountains and the Sierra de los Pinos. Canyons have been cut around and between these ranges, and consequently not only their westward slopes but also a considerable part of their eastward slopes drain to the Rio Grande. Each of these canyons affords a pass or means of access to the Estancia Valley and the plains beyond. The waters of the canyon north of the Sandia Mountains enter the valley at Bernalillo. Between the Sandia and Manzanita Mountains is Tijeras Canyon (Canyon de Carnuel), whose waters enter the valley 4 miles south of Albuquerque. Between the Manzanita and Manzano Mountains is Hell Canyon (Canyon del Diablo), whose waters enter the valley near Isleta. Between the Manzano Mountains and the Sierra de los Pinos i[illegible] Canyon, whose waters enter the valley near [illegible] The pass at the south end of the Sierra de los Pinos is less well defined, though adequate for a rough wagon road. The water of this area, passing through the gulch called Agua de Torres, reaches the river at La Joya.

A part of the structural basin occupied by the Albuquerque and Belen Valleys is higher than the adjacent region to the west. The western prong of the Rockies, locally called the Sierra Nacimiento, ends in the Sierrita Mesa. West of this prong the Colorado Plateau province is relatively low. Farther south it comes into contact with the basin along the Ceja del Rio Puerco, a westward-facing escarpment. This escarpment extends southward nearly 60 miles but forms the boundary of the basin for only about 30 miles, or as far as Cerro Colorado. In this 30-mile stretch the surface of the basin, underlain by valley fill, stands 400 to 500 feet higher than the adjacent Colorado Plateau province. From Cerro Colorado the boundary of the basin crosses the broad valley of the Rio Puerco in a vague southwesterly course to the Rio San José. Thence south for 25 miles, to the north end of the Sierra Ladron, the boundary is a well-defined but diversified eastward-facing escarpment of sedimentary rocks capped with basalt. Here the [illegible] narrows toward the south end of the Belen Valle[illegible] San Acacia.

The inner valleys known as the Albuquerque and Belen Valleys are separated from each other by a partial constriction at Isleta. This constriction is not a canyon but only a narrow place in the flood plain formed by the outcrop of a layer of basalt. The lower end of the Belen Valley is marked by the entrance from the west of the Rio Puerco, the longest tributary of the Rio Grande within New Mexico, and the Rio Salado, another important tributary.

San Acacia Constriction

The San Acacia constriction, in itself a small feature, marks an important change in the shape and form of the Rio Grande depression. The inner valley narrows and becomes a canyon about 300 feet deep and less than half a mile long. The rock walls are of dark-gray andesite, in contrast to the characteristic gravelly bluffs of the valleys to the north and south.

Socorro Valley

The Socorro Valley extends about 38 miles, from San Acacia to San Marcial, and is about 1 to 3 miles wide. (See fig. 50.) From San Acacia to San An[illegible] the river is near the east side of the valley, and [illegible] all the irrigated land lies west of the river. From [illegible]

Antonio south to San Marcial the river flows nearer the middle of the inner valley, but even here the flood lain on the east side is narrow and discontinouus.

The basin in which this valley lies is complex. In the northern portion it is only 8 to 12 miles wide and lies between mountains on the west, and a highland on the east. South of San Antonio the plains widen out and the course of the river is southwestward to San Marcial. The great basin called the Jornada del Muerto lies to the east, and plains 6 to 8 miles wide extend westward to the south end of the Magdalena Range.

The marked structural change at San Acacia is obviously connected with this constricted northern portion of the Socorro Valley and with the border basins into which the river flows south of this area.

San Marcial Constriction

The constriction at San Marcial is due to a great basalt flow which forms a cliff southeast of the town and which covers about 140 square miles of the Jornada del Muerto east of this point. According to Lee's theory,[7] the river once ran southward from this point through the broad Jornada del Muerto and thence across La Mesa into Mexico and was later diverted from this course by the lava flow at San Marcial.

Engle Valley

From San Marcial the river still bears somewhat ɛst of south and runs for more than 40 miles in a narrow valley west of the Fra Cristobal Mountains. A dam 250 feet high at Elephant Butte has converted this area into a reservoir.

Elephant Butte Canyon

Beginning a few miles north of the dam site, the river runs in a narrow canyon cut in the rocks of the north end of the Sierra Caballo.

Rincon Valley

From Elephant Butte Canyon the river emerges into a basin that lies on the west side of the Sierra Caballo and extends far south of it. In this basin the river runs in a valley somewhat wider than the Engle Valley for nearly 50 miles. This valley is called the Rincon or Las Palomas Valley, after one or the other of the towns within it. In its lower part the valley turns sharply eastward for a distance of about 12 miles.

Seldon Canyon

The Seldon Canyon, below the Rincon Valley, is about 18 miles long and is wide enough for a railroad and highway. It is somewhat diversified in aspect, as it cuts through rocks of differing hardness. The trend of the canyon is southeastward; ~~and its~~ lower end is directly south of San Marcial. Thus in this series of narrow valleys and constrictions about 100 miles long, the river has accomplished a great bend to the west of more than 20 miles.

Mesilla Valley

The Mesilla Valley has a southeasterly course diagonally across the trend of the Jornada del Muerto and its supposed southern extension, which is called La Mesa. The Mesilla Valley is 50 miles long and about 1 to 4 miles wide. The lower stretch of about 20 miles is essentially parallel to the north-south trend of the Franklin Mountains. The river then turns sharply southeastward into the El Paso Canyon.

El Paso Canyon

The El Paso Canyon is a gorge between the Franklin Mountains and the Cerro Rodadero, also called Cerro de Muleros, cut partly in rock and partly in deformed beds of sand and gravel. This canyon separates the Mesilla Valley from the El Paso Valley and has special importance because here are also the international boundary and one of the principal cities of the region.

El Paso Valley

The El Paso Valley has a southeasterly trend across the Hueco Basin, which, with the Tularosa Basin, to the north, has a north-south trend. The valley is about 90 miles long and ends at Fort Quitman, in a canyon at the south end of the Quitman Range.

Older Rocks of the Highlands and Mountain Ranges

Pre-Cambrian Complex

The oldest rocks of the region are great masses of schist, gneiss, and granite which together form a crystalline complex considered to be of pre-Cambrian age. Near El Paso the complex is overlain by upper Cambrian and Ordovician strata, but farther north the oldest overlying rocks are of Pennsylvanian age. In the southern part of the region the pre-Cambrian age of the complex seems to be well established, but the scattered areas farther north show a less definite age relation. However, the different areas of these rocks, although widely separated and but little studied in detail, appear to have a common antiquity by reason of their high degree of foliation and metamorphism and the marked unconformity between them and the overlying Pennsylvanian rocks.

The schists are of both igneous and sedimentary origin, and there are large thicknesses of quartzite, which in some places is the dominant rock. These metamorphic rocks are intruded by great masses of igneous rock, chiefly granite and granodiorite.

e, W. T., Water resources of the Rio Grande Valley in New Mexico and their opment: U. S. Geol. Survey Water-Supply Paper 188, p. 23, 1907.

Throughout the geologic history subsequent to their formation these rocks have been resistant to erosion and have formed highlands. From them pebbles have been carried into all the later rocks, and many quartz and quartzite pebbles have been rehandled several times as the later formations have been successively uplifted and eroded. At present these crystalline rocks form large parts of the higher ranges, particularly in northern New Mexico and in Colorado, and they furnish easily identifiable débris to the streams.

Pennsylvanian and Older Paleozoic Rocks

At the beginning of Paleozoic time a sea invaded the area from the south. In this sea the early Paleozoic rocks are laid down as a thin mantle overlying the pre-Cambrian complex. The land surface cut on the older crystalline rocks to the north must have been low, as the deposits in these early seas were mostly shale and limestone. The Bliss sandstone, El Paso, Montoya, and Fusselman limestones, and Percha shale have a total thickness of 460 to 1,350 feet and represent the time from the Upper Cambrian to the Upper Devonian. However, as slight uplift and erosion occurred after the deposition of each formation, the maximum thickness of these beds is not present in any one place. The northerly outcrops of these beds are in the San Andreas and Oscura Mountains and near Chloride. North of this latitude these formations are unknown. The Lake Valley limestone, of Mississippian age, has a maximum thickness of 210 feet. It overlaps the older rocks as a thin wedge extending north to latitude 34°30′, where its last known exposure is in the Sierra Ladron.

The Magdalena group, of Pennsylvanian age, consists largely of limestone with some shale and a variable amount of sandstone and conglomerate at the base. These rocks form a huge plate 900 to as much as 2,500 feet thick, extending from the south to the north so as to overlap the older sedimentary rocks just described and to extend over the crystalline complex northward into Colorado and beyond.

Near El Paso the pre-Pennsylvanian rocks cover considerable parts of some of the smaller ranges. In general these rocks are of little importance either as yielding run-off or as sources of material for later sediments. The Magdalena group is, however, of very large importance. It covers most of the Caballo, San Andreas, Socorro, and Ladron Ranges and forms nearly all of the Sierra de los Pinos-Manzano-Sandia uplift, where it is generally 900 to 1,200 feet thick. It is resistant to erosion under the present climate and forms part of the highest areas, but it furnishes some large blocks and pebbles that are carried by ephemeral streams 10 to 12 miles from the outcrops. The older basin deposits also contain pebbles of this limestone. West of the Franklin Mountains the basin deposits are mostly conglomerates of limestone pebbles, derived in part, however, from the early Paleozoic limestones. the west flank of the Sangre de Cristo Mountains basin deposits contain very few limestone pebbles, although there are large outcrop areas of the Magdalena within the range.

Permian Rocks

The Permian rocks consist of the Abo sandstone and the complex assemblage called the Chupadera formation.

The Abo sandstone has a thickness of 600 to 1,000 feet and is a slabby sandstone of strong brown-red color. It is generally resistant to erosion and furnishes characteristic pebbles that occur in the basin deposits of all ages. Its areas of outcrop are generally small, however, and it is relatively unimportant in the formation of the present ranges.

The Chupadera formation varies in character from place to place. Within the Rio Grande drainage area it contains red sandstone and shale, with gypsum beds at the base and limestone with subordinate red shale and gypsum in its upper part. To the north and west the gypsum disappears from the lower member and the limestone from the upper, so that the formation is largely red and gray sandstone and red shale. In the northern part of the area the thickness is generally less than 500 feet, whereas to the south and particularly the southeast thicknesses of 2,000 to 5,000 feet a known.[8] Both the limestone and the red beds of this formation cover large areas and in many places form high escarpments and plateaus. The limestones are grayer and more porous than those of the Magdalena group, and therefore the pebbles and fragments derived from them are easily recognized. Such fragments are plentiful in the Santa Fe formation east of Socorro and in many recent stream deposits. Red sandstone also occurs as pebbles west of the Joyita Hills and also west of Rosario siding, in the Santo Domingo Valley. The red beds ordinarily disintegrate on weathering into sand and clay having a persistent red color. The flood waters of many streams are colored red by the erosion of these beds and by somewhat similar red coloring matter from the Triassic and Jurassic rocks. Rio Colorado, a tributary of the Rio San José, the Chama River, the upper Rio Galisteo, and many smaller and less well-known streams carry red mud in floods. To what extent the persistent red or pinkish color of the Pliocene deposits is due to redeposition of this red coloring matter remains in doubt, but the Santa Fe formation east of Socorro, with its large content of Permian limestone fragments, doubtless owes its deep-red color to the transfer of fine mud from the red beds of the Chupadera formation.

[8] Darton, N. H. "Red Beds" and associated formations in New Mexico, with outline of the geology of the State: U. S. Geol. Survey Bull. 794, pp. 21-26, 1928.

Triassic Rocks

Within the Rio Grande drainage area the Triassic ·stem is represented mostly by red sandy shale of the ,hinle formation, which has a deep-red color and a thickness of 200 to 800 feet. In the Nacimiento uplift and the Chama Basin the Chinle is underlain by a massive gray to white pebbly sandstone called the Poleo sandstone.

Jurassic Rocks

According to the most recently published work,[9] the Jurassic rocks in New Mexico may be divided into the Wingate sandstone and the Morrison formation. The Wingate sandstone lies above the Chinle formation and its equivalents and is referable to the Jurassic only with some doubt. The Morrison formation of these writers includes the Todilto limestone of previous writers and also the sandstone previously called the Navajo sandstone.

The Wingate sandstone is a reddish buff to white massive sandstone diminishing from a thickness of about 300 feet at Thoreau to about 80 feet east of the Rio Grande. This sandstone, together with the gypsum of the overlying Todilto limestone member, usually forms a scarp that may be subordinate to higher cliffs, as in the scarp north of the Chama River.

The basal member of the Morrison formation in New Mexico is the Todilto limestone member, which con-.ts of 50 to 100 feet of gypsum and a thin bed of ıresh-water limestone. West of longitude 107° it is overlain by a massive sandstone, which, like the Wingate, is reddish buff to white and which has been called Navajo sandstone in previous reports. Overlying this sandstone, where present, and extending over the northern half of the State, is a series of soft white to brown sandstones, and green, red, and purple shales. The thickness of this upper part of the Morrison ranges from 150 to 900 feet. This sandstone and shale series of the Morrison is resistant to erosion only where protected by the overlying Dakota sandstone. Generally the soft unctuous clays weather to slippery mud that induces landsliding and rapid erosion.

The Wingate sandstone and the sandstones in the Morrison formation generally weather to sand rather than sandstone blocks. The shales of the Morrison yield clay and some sand. The gypsum of the Todilto limestone member increases the quantity of sulphate in the streams.

Cretaceous and Early Tertiary Rocks

Lower Cretaceous rocks are somewhat rare in New Mexico, and generally the Upper Cretaceous directly overlies the Morrison or older rocks. The Upper Cretaceous varies in thickness and characteristically consists of buff sandstones and dark shales. Within the Rio Grande drainage area it includes, in upward succession, the Dakota sandstone, about 80 to 100 feet thick; the Mancos shale, a dark shale, about 900 to 2,000 feet thick; the Mesaverde formation, consisting of massive buff sandstones, shale, and coal and ranging in total thickness from about 500 to 2,500 feet; the Lewis shale, a dark-gray shale, about 80 to 2,000 feet thick; the Pictured Cliffs sandstone, about 50 to 300 feet thick; the Fruitland and Kirtland formations, a heterogeneous sequence of sandstone, coal, and white, gray, and drab shales, ranging in total thickness from about 700 to 1,600 feet; and the buff Ojo Alamo sandstone, about 125 to 400 feet thick, which may be of Tertiary age. Above the Cretaceous rocks are the early Eocene, Puerco and Torrejon formations, consisting largely of gray and dark shale and soft sandstone, reaching a thickness of about 800 feet on the west side of the Sierra Nacimiento. The Galisteo sandstone, probably of Eocene age, crops out near Cerrillos and also on the east and southeast border of the Santo Domingo Valley. It consists of poorly cemented sandstone and conglomerate with red and green clay and ranges from about 1,300 to 3,800 feet in thickness. The Wasatch formation, which crops out largely in the Sierra Nacimiento, includes a basal sandstone, 100 feet or more thick, and sandy shales of variegated color ranging from red and purple to yellow, which reach several hundred feet in thickness.

All the Cretaceous and Eocene beds described in the preceding paragraphs consist of sandstones and shales with an aggregate thickness reaching 16,000 feet, but by reason of local erosion and nondeposition of beds, the ordinary thickness of the whole sequence is nearer 5,000 feet. The common character of the Cretaceous and early Tertiary beds is reflected in their weathering and topography. Generally the sandstones form escarpments, mesas, and cuestas, and the shales form badlands or broad smooth plains. Some of the sandstones are so thin or so friable as to have much the same topographic expression as the shales. Generally the Dakota, the Pictured Cliffs, the Mesaverde, the Ojo Alamo, and the basal sandstones of the Wasatch form conspicuous cliffs. The variations in the thickness of these beds and the sporadic lenses of a similar sandstone that occur in otherwise predominantly shale members afford the chief variations in the topography.

The shales weather to gummy clays that are important hazards to travel in wet weather. The sandstones weather to fine-grained sand. Consequently the streams of areas underlain by these rocks have a large load of fine material and a minimum of gravel. Such gravel as exists consists of iron and lime concretions and pebbles of quartz, quartzite, and chert derived

[9] Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., Correlation of the Jurassic ations of parts of Utah, Arizona, New Mexico, and Colorado: U. S. Geol. Survey P. Paper 183, pp. 30-31, 1936.

from the conglomeratic phases of the sandstones, together with thin plates of the more thoroughly cemented sandstone layers. Fine-grained alluvium, mostly sand but containing much colloidal clay, has accumulated in broad valley flats which are now deeply cut by arroyos. Here originate the heavy loads of detritus carried by the Rio Galisteo, Rio Puerco, and Rio Salado, which are the principal silt-bearing tributaries of the Rio Grande. Only the large area of outcrop on the Chama River is not subject to excessive erosion. Here, because of the high altitude, the climate is more humid and vegetation more luxuriant. Here also many surfaces are covered by a veneer of quartzite and porphyry pebbles of Quaternary age, which, with the help of relatively late lava flows, form an effective barrier to excessive erosion.

First Uplift of the Mountain Ranges

Throughout the long Paleozoic era New Mexico was largely a low-lying country, for much of the time partly covered by the sea. During the Triassic and Jurassic periods the region was mostly dry land but was relatively low. The great thicknesses of Cretaceous and early Tertiary rocks were laid down in seas or on low-lying and at times swampy plains. Strong deformation did not occur in this area until after the Wasatch formation, of Eocene age, had been deposited, when, as shown by Renick,[10] the Sierra Nacimiento was upthrust.

The uplift that initiated the present topography of the region and determined its character as a mountainous plateau was foreshadowed by volcanic activity in late Cretaceous time and by similar activity associated with localized uplift at the end of early Tertiary time. However, volcanic activity and uplift on a large scale began in mid-Tertiary (Miocene) time. Differential uplift and erosion of the mountains and sedimentation in the basins began with this great outburst of volcanism and has continued intermittently to the present day.

Tertiary Period of Volcanism

The Tertiary rocks are now localized in their outcrops by reason of later deformation and erosion. The known centers from which the floods of lava came are relatively few in number, but it seems likely that the lavas from different centers coalesced and that almost certainly the water-laid débris derived from the main areas of accumulation mingled in basins of deposition between the volcanic centers. The mere absence of volcanic rocks cannot be considered evidence that they were not at one time present.

The volcanic centers important in a knowledge of the Rio Grande depression are the San Juan Mountains of Colorado, the Sierra de los Valles, the Datil-Mogollon area, the Organ Mountain area, and the Cer Hills area.

The San Juan Mountain region, in southwestern Colorado, is about 100 miles in diameter. Here, as described by Cross and Larsen,[11] the aggregate thickness of the several groups of lavas and tuffs is more than 33,000 feet, but usually not much more than 5,000 feet is present at any one place. The flows consist of rhyolite, latite, and andesite. Basalt was extruded largely toward the end of the epoch of volcanism, in the flows of Pliocene and later date. These later flows, known as the Hinsdale formation, approximately correspond in time and in type to the flows in the Santa Fe formation and are discussed with that formation.

The Sierra de los Valles area, in the eastern part of the Jemez Mountains, is similar in many respects to the San Juan region except for size. It includes a great thickness of older volcanic rocks, which have been much faulted and deformed. These rocks, largely andesite and rhyolite, are of pre-Pliocene age and appear to have been erupted more or less contemporaneously with the bulk of the San Juan lavas. Volcanism was interrupted by faulting and erosion, and the mountain was much reduced in size, so that the sedimentary deposits of Pliocene time overlapped the region. However, eruptions of rhyolitic as well as basaltic continued, and a thick tuff member of the Santa formation was formed during the Pliocene. Many of the thin tuff beds of the Santa Fe formation doubtless had their origin in this volcanic center. Volcanic rocks occur in the area between these two centers in detached masses. These are the San Luis Hills, areas in foothills of the Sangre de Cristo Range from Trinchera Creek south to Hondo Creek, hills rising in the basalt plateau such as Cerro Chiflo and Cerro No Agua; and other detached areas. These rocks have been little studied, and whether they represent extensions of the San Juan flows or were extruded from separate vents of about the same age is uncertain.

The Datil-Mogollon area is very large. Great masses of lava and tuff 2,000 to 4,000 feet thick form the mountains and plateaus from the border of the Rio Grande depression, 20 miles west of Socorro, westward into Arizona, and from the Datil Range southward to Silver City. This great region, 60 miles from north to south and more than 150 miles from east to west, has been little studied.

The igneous rock of the Cerrillos Hills and the similar bodies in the Ortiz,[12] San Pedro, and South Mountains

[10] Renick, B. C., Geology and ground-water resources of western Sandoval County, N. Mex.: U. S. Geol. Survey Water-Supply Paper 620, pp. 54–55, 1931.

[11] Cross, Whitman, and Larsen, E. S., A brief review of the geology of the San Juan region of southwestern Colorado: U. S. Geol. Survey Bull. 843, 138 pp., 2 figs., 16 pls. (including 2 maps in pocket), 1935.

[12] Ogilvie, I. H., Some igneous rocks from the Ortiz Mountains, N. Me[x.]: Geology, vol. 16, pp. 230-238, 1908.

are intrusive rocks of stocklike and laccolithic form, ..hough dikes and sills of the same types also occur. ..se rocks were intruded into Upper Cretaceous rocks ..d hence are given an Eocene date. North of the State highway in the La Bajada escarpment, in the gulches leading to Santa Fe Creek northwest of La Bonanza, and elsewhere occur andesite (?) flow breccias, mud flows, and tuffaceous water-laid conglomerates with interbedded rhyolite and basalt flows.

Initial Basins

The end of the great volcanic period merged into the beginning of the series of movements by which the Rio Grande depression was formed, and with the existing meager evidence it is impossible to give the complete sequence of events. It appears, however, that initial basins were formed, into which streams carried gravel and sand derived from the erosion of the previously extruded lavas and into which tuffs from the still-lingering volcanoes were blown or washed by the streams, and that these deposits were deeply eroded and in places faulted before the succeeding Santa Fe formation was deposited. The evidence for these conclusions is somewhat fragmentary, and it is impossible to form a clear picture of the size, shape, or position of these initial basins.

Santa Fe Formation and the ..iocene Rio Grande

The outstanding characteristic of the Rio Grande is that it flows through broad but not wholly smooth plains between mountains. These plains are underlain by great thicknesses of largely unconsolidated sand and gravel, which are here referred to as the basin deposits. In many localities the existence of these deposits is known very imperfectly from deep wells, but in other places gulches as much as 1,000 feet deep, that have been cut by the Rio Grande and by its tributaries, expose these beds and afford opportunities for study.

For a distance of 40 miles north of the city of Santa Fe the tributaries of the Rio Grande have cut deep gulches in which the deformed beds of the basin deposits are admirably exposed. To this material Hayden [13] in 1869 applied the name Santa Fe marl, and from it Cope [14] obtained vertebrate fossils representing a large fauna which he considered of middle Miocene age. Since that time the beds have become generally known as the Santa Fe formation, and there has been much discussion of the age of the vertebrate fauna. The extensive collections and elaborate studies of Frick [15] indicate that the fauna is of lower Pliocene age. Unfortunately, it is not known whether the fauna occurs at the base or at the top of the formation nor whether the full thickness occurs in the Santa Fe region. In considering other basins whose deposits seem otherwise comparable with deposits of the type locality, correlation is hampered by the scarcity of fossils and by the diverse physical characters of the beds. The existing fossil evidence for the region is not presented in this paper.

The meager finds of fossils indicate that basin deposits of Pliocene age are widely distributed. The further reference of the basin deposits to a single period of deposition contemporaneous with the beds of the type locality near Santa Fe rests on four general criteria: (1) All the beds are slightly cemented, and the finer-grained members have concretions of calcium carbonate; (2) all the deposits are deformed, mostly by normal faults, although in the centers of the basins the deformation is so slight as to pass unnoticed except under intensive search; (3) the beds within any one basin are of diverse lithologic types, ranging from coarse fanglomerate to fine silt and clay, and abrupt changes in the kind and sizes of the contained pebbles are characteristic; and (4) these markedly different materials attributed to one formation conform in their arrangement to a geographic pattern consistent with the laws of deposition in basins. The main body of sedimentary deposits of the Rio Grande depression, from the north end of the San Luis Valley to and beyond El Paso, is considered to be of the same general age and to belong to the Santa Fe formation.

The basins of Santa Fe time were presumably depressed relative to the contiguous highlands by faulting, which seems to have been the dominant geologic process in the area. In places the basins once extended far beyond the present limits of the formation, and the bordering highlands may have been much reduced. Whatever the method of deformation, it is probable that, during the period of filling, the basins were enlarged by erosion of the highlands, and deposition occurred in these border areas. In general, the basins appear to have been elongated into ovals and to be divisible into two major types—basins with a through-flowing river and basins with enclosed drainage.

A basin with a through-flowing river has deposits of a threefold division—the two sets of fan deposits and the axial zone of the river deposits. Each set of fan deposits grades in size toward the axis of the basin but may otherwise be quite dissimilar to the other set in its several parts. The river-laid beds, consisting of

[13] Hayden, F. V., Preliminary field report of the United States Geological Survey of Colorado and New Mexico, 155 pp., 1869.

[14] Cope, E. D., Notes on the Eocene and Pliocene lacustrine formations of New Mexico, etc.: U. S. Geol. and Geog. Suveys W. 100th Mer. Ann. Rept. pp. 115-130, 1874; Notes on the Santa Fe marls and some of the contained vertebrate fossils: ..elphia Acad. Sci. Proc. for 1874, pp. 147-152, 1874; On the antelope deer of the .. Fe marls: Idem. for 1875, p. 257, 1876; A new Mastodon (*M. productus* Cope, .. Fe marls): Am. Naturalist, vol. 9, p. 56, 1875; On the distribution of the Loup Fork formation in New Mexico: Am. Philos. Soc. Proc., vol. 21, pp. 309-324, 1884.

[15] Frick, Childs, New remains of trilophodont-tetrabelodont mastodons: Am. Mus. Nat. History Bull. vol. 59, pp. 505-652, 56 figs., 2 pls., 1933. Matthew, W. D., Fauna lists of the Tertiary Mammalia of the West: U. S. Geol. Survey Bull. 361, pp. 115, 118, 1909.

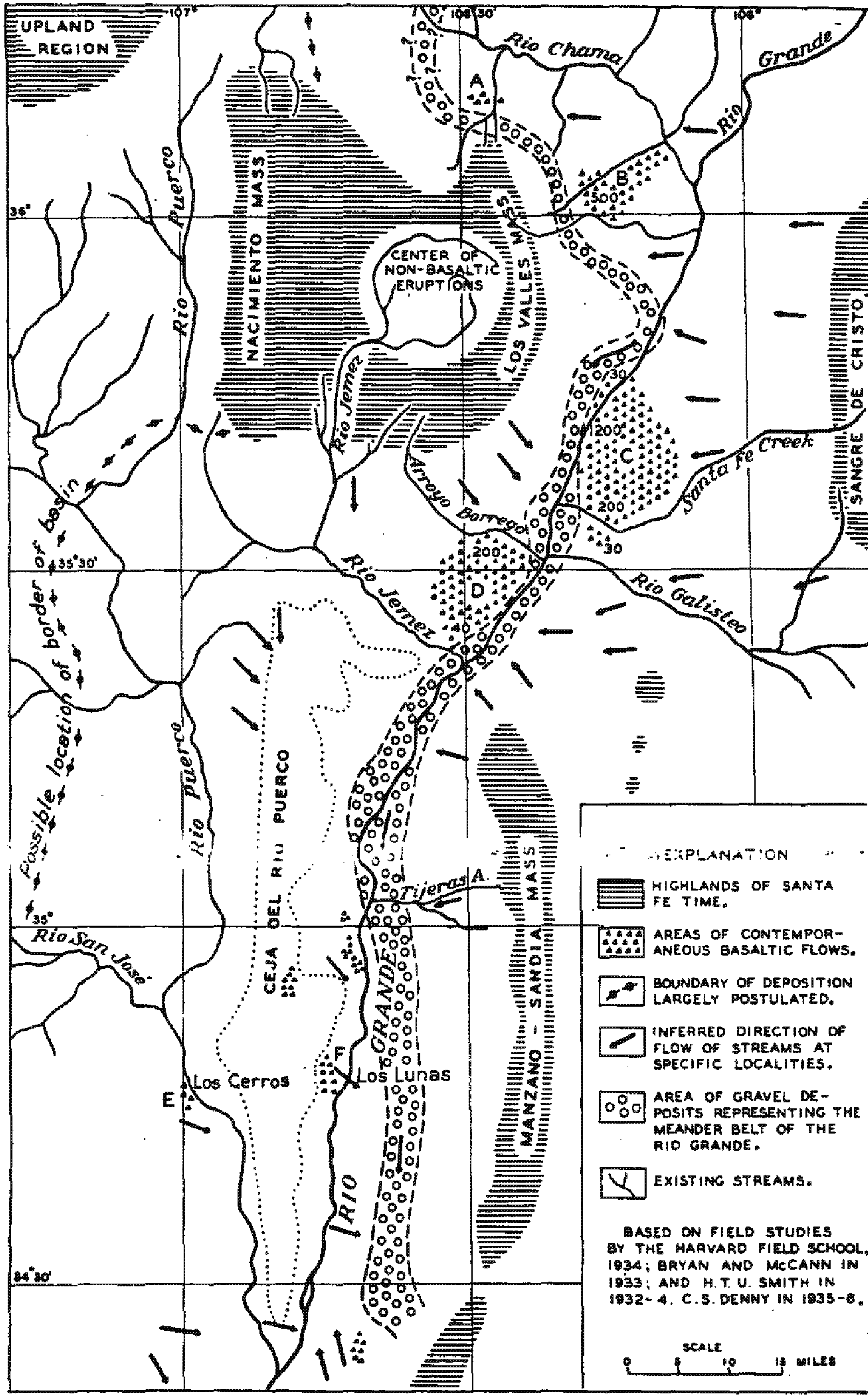

FIGURE 46.—The Pliocene Rio Grande in central New Mexico.

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channel gravel and of sand, silt, and clay deposited on the flood plain, comprise these elements in proportions that are determined by the rate of deposition and the rate of depression of the basin. In general, as these rates increase flood-plain deposits will exceed channel gravel in quantity; as the rates decrease channel gravel may be the only type of material deposited. Wind-blown sand is also likely to occur in association with the flood-plain deposits or may be concentrated in a zone at the lower border of the set of fan deposits on the side of the basin away from the prevailing wind direction.

An enclosed basin has a central or axial lake or playa, the existence of which depends in part on the size of the drainage area, the altitude of the adjacent highlands, and the climate. Such a basin has fan deposits and axial lake or playa deposits. The deposits of salt lakes and playas are similar in character, and criteria for distinguishing them from each other are not completely worked out. A change from salt lake to playa and back again may occur in any basin by reason of fluctuations in climate. In playas silty and sandy clays are deposited in which the evaporating water leaves impregnations and films of gypsum and more soluble salts. These salts may remain as impregnations or may be gathered into scattered crystals or may be more or less completely rearranged in plates in the bedding planes or cracks of the clays. However, the lakes may deposit true clay and fresh-water limestone, or marl, in their central parts, and they are likely to be marked by shore features. On evaporation, they deposit bedded gypsum and beds of the more soluble salts, such as sodium sulphate and sodium carbonate. With good exposures a decision can usually be made as to whether lakes or playas existed in a locality.

The Santa Fe formation was deposited in both drained and undrained basins. Its outstanding characteristic is that, in several more or less separate structural basins the gravel of a through-flowing stream lies near the axis of the basins. These gravel deposits are so thoroughly water-worn and well-shaped and are so cleanly washed as to indicate that they are the deposits of a perennial river that was larger than the present Rio Grande. This river ran from north to south, from basin to basin, much like the present river. On its course the several basins were strung like beads on a cord (fig. 46).

The most northerly known outcrops of the river gravel in the Santa Fe formation are at the north end of White Rock Canyon. Here they are interbedded with pinkish fan deposits that are of coarser grain at each outcrop toward the east and merge into the arkosic fan deposits of the type area of the Santa Fe formation. Flows of andesite-basalt, which become more numerous to the south, are also interbedded. The pebbles of the river gravel range from an inch to more than 6 inches in major diameter ~~and~~ are composed largely of quartzite and massive volcanic rocks. The obvious source for quartzite is in the pre-Cambrian that crops out over large areas to the north. The source for the volcanic pebbles is obviously the San Juan volcanic area, also to the north.

Similar gravel occurs 20 miles farther south, at the south end of White Rock Canyon. Here the river gravel is interbedded with the andesite-basalt flows and also with the tuff member of the Santa Fe formation. From White Rock Canyon the gravels can be followed throughout the Santo Domingo Valley into the Albuquerque and Belen Valleys, where the most southerly outcrops [16] are on the east side of the valley in the gulch leading down from Abo Canyon and also near Contreras. In the more southerly outcrops the largest pebbles are about 3 inches in major diameter and there is, therefore, a slight southerly decrease in size.

The work of Smith [17] shows that not only at the head of White Rock Canyon but elsewhere to the north and west in the Abiquiu quadrangle, the fan deposits of the Santa Fe formation become finer from the base of the Sangre de Cristo Range to the west and south. They also contain much wind-blown sand, as if the border of a river flat were being approached. Basalt flows are interbedded. In Santa Clara Canyon and also near Cerro Pedernal the finer-grained sediments and the basalt flows are cut off and let down to the east and north by the faults that bound the present basin. It is obvious that the formation once continued farther west and south in what is now the elevated Sierra de los Valles mountain region. On the assumption that the river ran on the far side of the contemporaneous lava flows, it should have had a course like that shown in figure 46. That on this course the Pliocene river occupied the position of what is now Chicoma Peak, altitude 11,507 feet, and Cerro Pedernal, altitude 9,867 feet, is a testimony to the amount of post-Santa Fe uplift and erosion. The course of the Pliocene River farther north is uncertain.

To the south of the Belen Basin and specifically of Abo Canyon the course of this ancient river is almost wholly conjectural. Observations by the writer and later work by C. S. Denny make it evident that the Pliocene Rio Grande could not have flowed through the Socorro area. It must have flowed to the east of this enclosed basin and may have had its course over the present Sierra de los Pinos into the Jornada del Muerto, which was in Pliocene time, as at present, a depressed area.

The course of the river still farther south is unknown. Much of the material attributed to the Santa Fe forma-

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[16] Denny, C. S., personal communication.

[17] Smith, H. T. U., The Tertiary and Quaternary geology of the Abiquiu quadrangle, N. Mex. (Doctor's thesis, Harvard Univeristy Library), 1935.

tion is coarse-grained and probably belongs to a group of fan deposits. Fine-grained material, such as might have been deposited on a river flood plain, occurs near Las Cruces, beneath La Mesa, and also near El Paso.

Volcanic Rocks Interbedded with Sedimentary Strata of the Santa Fe Formation

Volcanism continued during Santa Fe time but was generally less intense and somewhat different in type from that of the preceding great period of Tertiary volcanism. Outpourings of basalt and andesite-basalt were common, but in the Sierra de los Valles and perhaps in other localities eruptions of rhyolite occurred.

Andesite-basalt was poured out in large quantities in the San Juan Mountains. Cross and Larsen [18] have mapped these lavas as part of their Hinsdale formation. There were numerous local vents, at some of which great thicknesses of basalt were piled up as at Los Mogotes, on the Conejos River, a volcanic pile nearly 1,000 feet high. Generally these basalts are 200 to 500 feet thick. Near the western border of the San Luis Valley the basalt overlies gravel and sand (the Los Pinos member of the Hinsdale formation) and dips gently under the floor of the valley, where it has been found in wells. Near La Jara the andesite-basalt lies 250 to 300 feet below the floor of the valley. At Antonito and for many miles to the south the andesite-basalt is at the surface and forms the western edge of the great lava plateau. South and east of the San Luis Hills the interbedded basalts crop out in San Pedro Mesa and its northerly extension, where they have thicknesses of 50 to 200 feet. The lavas are much deformed by faulting and warping. In the Fort Garland area they are overlain by great thicknesses of deformed fan deposits. On the west side of San Pedro Mesa they are carried down below the surface and have been found in wells in the plains between the mesa and the canyon of the Rio Grande. According to the unpublished work of Upson, the Hinsdale basalt and associated beds are younger than the true Santa Fe.

Lavas interbedded with the sediments of the Santa Fe formation occur in the Abiquiu reentrant. In Santa Clara Canyon Smith [19] has measured 166 feet of basalt in a section of Santa Fe beds 612 feet thick. Other basalt flows occur stratigraphically both higher and lower. Between Santa Clara and Bear Creeks there are 500 feet of interbedded basalt flows. Interbedded flows also occur in Cerro Pedernal and nearby.

The Cerros del Rio is probably the area of most intense eruption in Santa Fe time. Here more than 1,200 feet of lava and cinders, mostly andesite-basalt, were piled up. This great thickness is exposed about midway in White Rock Canyon, opposite the mou Rito de los Frijoles. To the north the basalt is i bedded with fan deposits and river gravel. The most northerly tongues of lava extend past Buckman. To the south the basalt is also interbedded in the Santa Fe formation. At the lower end of White Rock Canyon there are only four flows, with a total thickness of about 200 feet. Farther south, on the lower course of Santa Fe Creek, about 200 feet of basalt, including a small cinder cone, forms the walls of a small canyon, and gravel and sand are exposed above and below it. The dip is about 5° east, and one flow forms a cuesta ridge for several miles south.

The next area of interbedded flows is in Santa Ana Mesa, which lies west of San Felipe. This complex plateau consists of the stripped surfaces of the interbedded and deformed basalt of Santa Fe age and two flows that are younger than the Santa Fe. The most easterly outcrops occur in a ridge, east of San Felipe, where two basalt flows, interbedded with fan deposits and river gravel, dip about 10° east. To the west of the river the flows extend westward for 10 miles. The thickness of basalt exceeds 200 feet in places. The so-called Bernalillo Volcano lies just south of this area. According to Renick,[20] this irregular butte consists of a maze of dikes intruded into about 300 feet of f conglomerate, grit and sand containing a consider amount of basalt fragments, many of which are scor- ceous and glassy. The sediments are much deformed by the intrusion of the dikes.

Acuma Hill, immediately west of Isleta, is formed of nearly horizontal basalt flows. To the east and north there is only one flow exposed. It dips gently eastward and overlies deformed beds consisting largely of water-laid basaltic cinders. To the north the deformed beds contain less basaltic débris, but beyond a short interval they are again overlain by a basalt sheet which forms the mesa 3 miles north of Isleta. To the east, toward Isleta, there are outcrops of basaltic cinders and cindery basalt. At least 50 feet is exposed, but if, as seems likely, the dip is to the south, the total thickness concealed under the drifted sand of this locality may be much greater. The pueblo of Isleta is built on an outcrop of basalt, which, with the associated terrace gravel, forms a flat-topped hill about 20 feet above the flood plain of the river. Obviously this hill once had a river flat on the west side and hence was the "island" from which the name Isleta is derived. The basalt of the "island" is a much weathered gray rock. It is similar to the basalts in Acuma Hill and seems unquestionably to be the remnant of a flow interbedded in the Santa Fe formation. About 3 miles west

[18] Cross, Whitman, and Larsen, E. S., A brief review of the geology of the San Juan Mountain region of southwestern Colorado: U. S. Geol. Survey Bull. 843, pp. 94-100, 1935.

[19] Smith, H. T. U., op. cit., pp. 60-65.

[20] Renick, B., Geology and ground-water resources of western Sandoval Cou N. Mex.: U. S. Geol. Survey Water-Supply Paper 620, pp. 56-57, 1931.

Acuma Hill there is a low dome of basalt that rises above the level of the Llano de Albuquerque. It also probably formed of lava of Sante Fe age, as it differs in topographic aspect from the Quaternary flows that lie south of it.

West of Los Lunas, 6 miles south of Isleta, basalt interbedded in the Santa Fe formation forms a high flat-topped butte. On the northwest flank fan deposits containing beds of basaltic debris and a conglomerate of rhyolite-pumice pebbles dip gently to the north and are overlain by about 50 feet of basalt. On the southwest flank fan deposits with two interbedded basalt sheets dip about 10° northwest. In the east flank of the butte there is about 200 feet of basalt in several flows. This block appears to be in fault contact with the western part of the butte.

Los Cerros are a group of ragged hills in the valley of Rio Puerco extending from 1 to 3 miles south of the railroad crossing near the mouth of the stream. Several flows of basalt are interbedded in fan deposits. Faulting has tilted the beds at angles of 10° to 20°, and there are many landslides. The probable thickness and source of this interbedded basalt are not known.

At San Acacia a sheet of andesite forms the gap through which the river runs. Its gentle eastward dip is in accord with the local dip of the Santa Fe formation, and there seems to be little question that it is contemporaneous with the local fan deposits of Santa Fe age.

In the Socorro quadrangle, north of Nogal Canyon, at the base of the mountains, an andesite flow and a basalt flow are interbedded with playa deposits of Santa Fe age. South of the Socorro quadrangle volcanics interbedded in the Santa Fe formation have not been reported.

In the type locality of the Santa Fe formation, 10 miles north of the city, near Pojaoque, beds of volcanic ash, 1 to 5 feet thick, occur in the reddish fan deposits. The materials are well sorted and probably fell from the air and were only in part reworked by streams. On the west side of Santo Domingo Valley water-laid rhyolite ash, containing large fragments of rhyolite and obsidian and one small rhyolite flow, attains a thickness of more than 1,000 feet. It overlies and is interbedded with fan deposits and is faulted with them. The contained fragments and boulders are larger in outcrops near the Sierra de los Valles and the source of the material is obviously in that direction. Near the mouth of Cochiti Creek and north of it this body of tuff thins and is interbedded with and deformed with river gravel and basalt flows of Santa Fe age. It records a period of volcanism in the Sierra de los Valles during Pliocene time. In the Albuquerque-Belen Basin tuff beds, conglomerates of pumice pebbles, and fragments of pumice in fine sands and silts are fairly common. This content of volcanic material can be attributed in part to material contributed to streams by the volcanic activity in the Sierra de los Valles. Part of the material, however, may have been derived from the erosion of still older tuff beds. Volcanic material that perhaps has the same origin occurs in Socorro Valley.

Deformation of the Santa Fe Formation

Because of the cover of later sand and gravel, the Santa Fe formation is concealed in so many places that the amount and character of its deformation may easily pass unnoticed. Many of the early workers in the region failed to observe or else disregarded the deformation. However, in those localities where the beds have been intensively studied deformation is evident and has become one of the principal criteria for distinguishing the formation from the Quaternary sand and gravel. In the centers of the larger basins the dips are low and range from 1° to 5°, or the beds may be so nearly flat as to appear to be undeformed. Adjacent to the borders of the basins the dips usually steepen and range from about 15° to 60°.

Most of the existing mountains and highland areas were also mountainous in Santa Fe time. They were reduced in Pliocene time and were rejuvenated to form the present ranges. Other mountains appear to have been new-born, as, for example, the Socorro-Lemitar uplift. So far as present information goes, all the ranges, with the exception of the Magdalena Mountains and the part of the Sangre de Cristo Range north of Sierra Blanca, owe their present position to the post-Santa Fe uplift.

The pattern of the faults by which the basins underlain by beds of the Santa Fe formation were carried down and the highland blocks uplifted is not completely known. So far as these faults have been discovered or are inferred on reasonable grounds, they are shown on figures 47 to 49.[20a] In areas that have been properly studied and where adequate exposures exist the faults are numerous. Some of the fault patterns are relatively simple en échelon systems; others are complex combinations of groups of faults having trends in three or more directions. The inferred faults are, for lack of detailed information, shown on the maps in simple pattern. There are also within the basin deposits many faults that have not been found or cannot be followed from the single outcrop in which they are expressed, because of the lack of distinctive horizons in the beds.

In general there are two structural types—the more or less symmetric basin and the asymmetric basin. Thus the Albuquerque-Belen Basin appears to have a fault system on both east and west sides. The Santo Domingo and Española Basins are also of this type, although the faulting on the west side of the Española Valley, in the Abiquiu reentrant, appears to have been

[20a] Fault patterns of these figures in part based on preliminary data, subject to revision in detail.

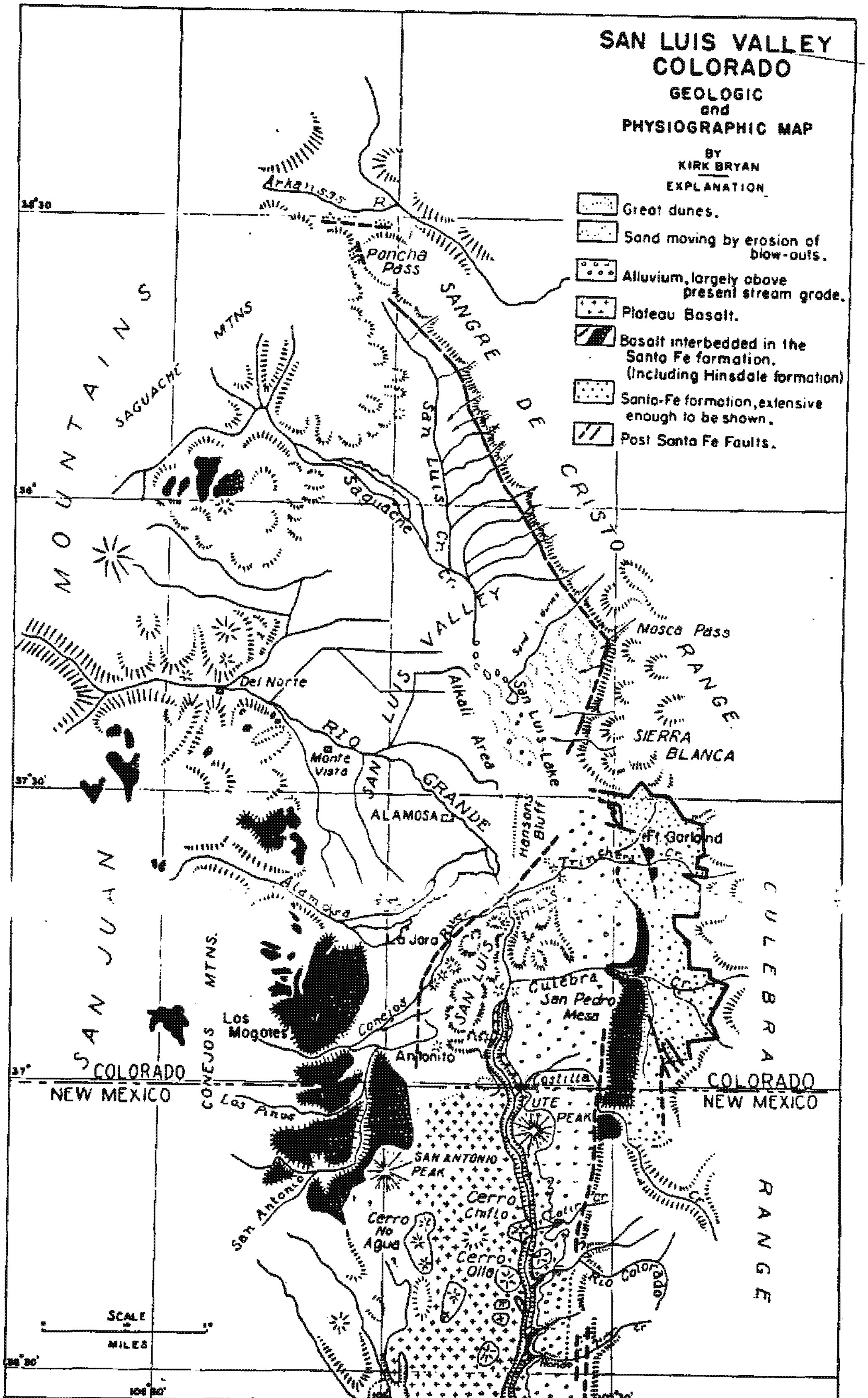

FIGURE 47.—Geologic and physiographic map of the San Luis Valley, Colo.

less severe than that directly opposite, to the east, at the base of the Sangre de Cristo Mountains.

ther structural basins are markedly asymmetric . have a fault system on one side and a depositional contact on the other. The structural basins east and west of the Socorro-Lemitar Range are the best examples. The San Luis Valley northwest of the San Luis Hills is also of this asymmetric type, with depositional contacts on the west side and strong depression to the east and southeast on faults now wholly concealed but easily inferred. In this valley the asymmetry of the post-Santa Fe faulting was preserved by the later Quaternary faulting.

The foregoing discussion raises the question as to rotation of the mountain or highland blocks. How many are true tilted fault blocks? To what extent has the Rio Grande depression been merely let down into the adjacent highland area, which has itself suffered little disturbance in the process? The plateau region west of the Albuquerque-Belen Basin has a folded structure of gentle arches and monoclines broken by faults related in pattern to these folds.[21] These structural features appear not to have been disturbed or deformed by the post-Santa Fe faulting, nor is there any direct evidence of tilting toward the west. Along this border the Santa Fe depression appears to have been carried downward with respect to the plateau as a ple graben. Somewhat similar but less clearly essed relations exist on the west side of the Abiquiu reentrant.

The Sandia-Manzano-Los Pinos uplift has long been considered a typical fault block.[22] Each of these ranges is capped, more or less completely, by limestone of the Magdalena group, which dips eastward away from the basin. The limestone is resistant to erosion and gives, particularly to the Sandia Mountains, a decidedly asymmetric and youthful aspect. However, as the limestone was deformed both by folding and by faulting in pre-Santa Fe time, the dip of the rocks may be more largely the result of this earlier deformation than of tilting of a post-Santa Fe block. So far as the Manzano Mountains are concerned, the fault boundary with the Santa Fe must lie about 5 miles west of the foot of the range. Red sandstone and shale of presumed Permian age crop out at Hubbel Spring and at Los Ojuelos, localities in the plains west of the mountain front. The Permian beds can be traced eastward from Los Ojuelos to the foot of the mountains, where they lie in fault contact with pre-Cambrian rocks. Thus the range has a front eroded in part from soft Mesozoic rocks, and its border with the Santa Fe is inconspicuous.

The general linear character of the depression is broken by reentrants and offsets. The San Luis Basin (see fig. 47) has a trend east of south as far south as Saguache Creek, where the western border retreats to the west. South of Saguache Creek the basin has a north-south trend. The eastern border also changes to a north-south trend at Mosca Pass, beyond which this irregular-shaped basin is cut off by a northwestward-trending fault on the northern flank of the San Luis Hills.

The area southeast of the San Luis Hills, conventionally a part of the San Luis Valley, is marked by a strong reentrant about 10 miles deep and 40 miles long, the Fort Garland-Costilla reentrant. As shown by Upson [23] this area is outlined to the east by a complicated set of faults and more or less shut off from the basin by the outcrop of basalt in the Santa Fe formation in San Pedro Mesa and its northern extensions.

The great plateau that extends southward from the San Luis Valley is presumably a representative of the basins. However, the western boundary is so masked by basalt that the structural relations are not clear and have not been adequately studied. A large number of hills of older rock project from the lava plain and doubtless represent portions of the bordering highlands. The hills of pre-Cambrian rock, such as Cerro Aire and Cerro Montosa, and hills of Tertiary volcanic rock, such as Cerro No Agua and Cerro Chiflo, must represent an almost complete closure of the depression.

The eastern border of the depression has a great reentrant from Hondo Creek south beyond Taos, a distance of 15 miles. Thus in the vicinity of Taos the mountain front is set back 10 miles to the east. The plains are mostly undissected and, as there are almost no outcrops of the basin deposits, the assumption that this reentrant originated by faulting is largely inferential. (See fig. 48.)

In the next section to the south the eastern border extends westward in the great Picuris prong of crystalline rock as far as the present canyon of the river. Against this prong the basin deposits are down-faulted in what appears to be a simple pattern to the north and a more complex one to the south. Directly south of this prong is the Picuris reentrant, more or less outlined on the north by faults. However, on the eastern border and part of the southern border the Santa Fe has a depositional contact on the older rocks, but its disturbed condition within the reentrant gives assurance that this also is a structural depression.

Almost directly opposite the Picuris prong and reentrant is the Abiquiu reentrant, about 20 miles from

[21] Hunt, C. B., and Dane, C. H., Preliminary map showing geologic structure of the San Juan Basin, U. S. Geol. Survey, 1933.)

[22] An aberrant conception is that of Darton, who conceives of the Sandia and other s being faulted anticlines (Darton, N. H., "Red Beds" and associated forma- New Mexico, with an outline of the geology of the State: U. S. Geol. Survey 4, p. 99, 1928.)

[23] Upson, J. E., unpublished data.

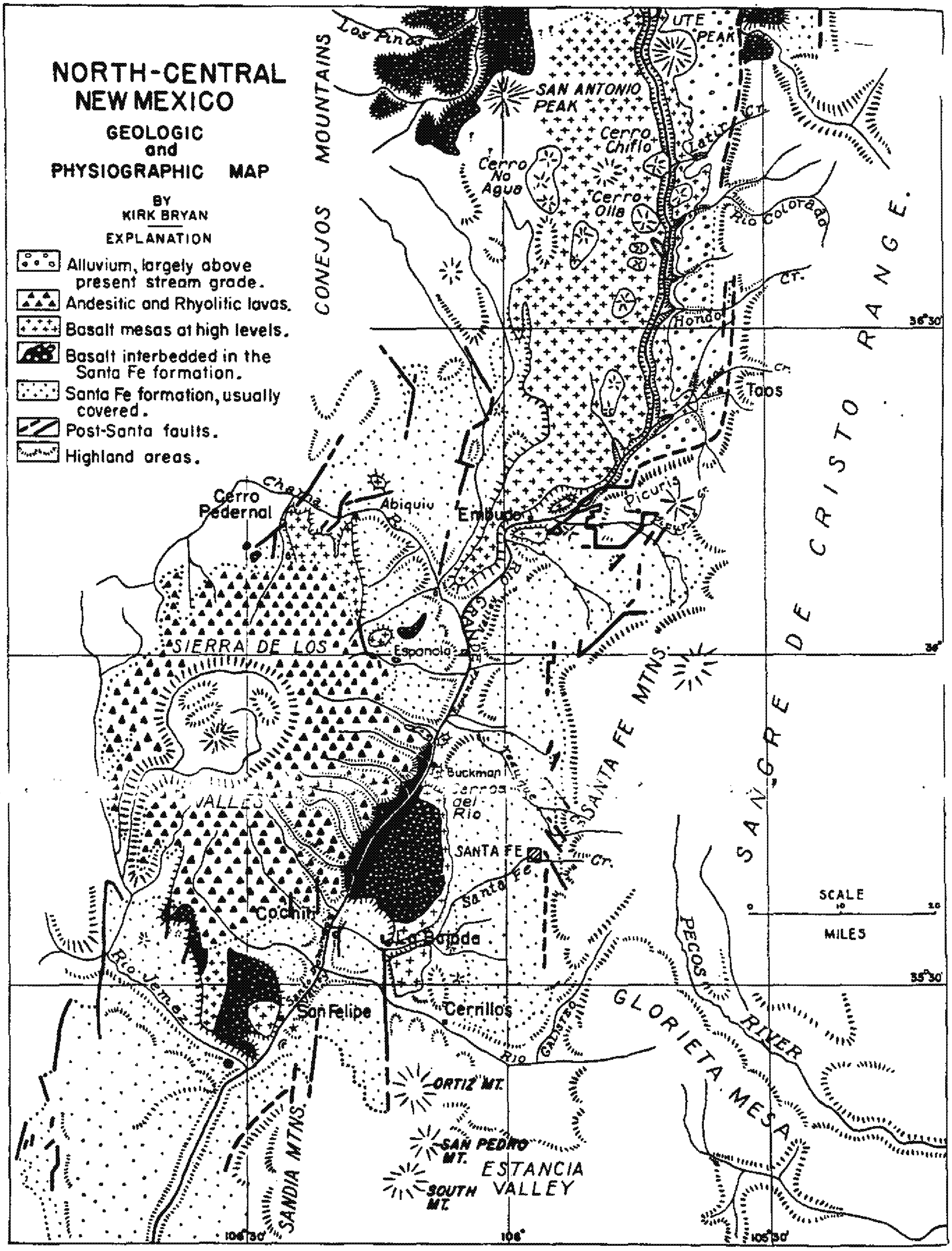

FIGURE 48.—Geologic and physiographic map of north-central New Mexico.

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north to south and 20 miles from east to west. The 't systems of this area are obscured by overlying ;, but Smith [24] has found a complicated pattern to the north and south. On the south the faults appear to belong to an en échelon system. Each fault has a more or less north-south or northwest-southeast trend, but the whole system provides for letting the Santa Fe down on a more or less east-west line. On the northern border of the reentrant the fault pattern is more complex.

Separating the subbasin west of Santa Fe from the Santo Domingo Valley is a prong of older rocks projecting northwest from the Ortiz Mountains. The Cerrillos Hills, composed of andesite intrusions and other crystalline rocks, form the southern portion of this prong. The northern portion is blanketed by Quaternary basalt, so that there is no distinction on the surface between this prong and the basalts of Santa Fe age that form the Cerros del Rio. The west side is marked by a strong north-south fault which passes through Rosario siding. The east side is covered by Quaternary gravel, but doubtless detailed study will show the presence of faults.

The Santo Domingo Valley lies in the area in which the 20-mile offset between the general axes of the basins to the north and those to the south is accomplished. Apparently both the north and south boundaries of the structural depression are marked by series of north- faults arranged in more or less en echelon systems. ..s and faults, largely unmapped, affect the basalt interbedded in the Santa Fe that forms White Rock Canyon to the north of the valley. Later flows of rhyolite conceal most of the structure west of the river in this vicinity. There are deformed lava beds of Santa Fe age in part overlain by Quaternary basalt, in the south-central part of the area in Santa Ana Mesa. In the western part of the area near the northern border, east of Jemez, the Santa Fe formation is much faulted and older rocks are exposed in places. Part of this complicated structure has been mapped by Reiche [25] and is shown on figure 49.

The Albuquerque-Belen Basin thus offset with respect to the northern Espanola-Santa Fe Basin has a general north-south trend. It is one of the largest and most symmetrical of the basins. The eastern boundary lies at the base of the Sandia-Manzano-Los Pinos uplift. The plains are so little dissected and are so thoroughly covered with Quaternary alluvium that the faults are almost wholly inferred. However, at the mouth of Tijeras Canyon east of Albuquerque, at a point just east of the Candelaria ranch, the brecciated fault face on the granite is exposed on the south side of the canyon, and on the north side there is a small exposure of deformed gravel.

The northwestern border consists of four en echelon faults, each increasing in throw to the south and offset to the west.[26] There are also several subsidiary parallel faults. To the south of the Cerro Colorado the boundary of the Santa Fe crosses the Rio Puerco in a southwesterly direction. Faults are probably present, but this area is unmapped. From a point near the mouth of the Rio San Jose the fault has been mapped by Darton [27] as far south as Arroyo Pato. Here there is an unmapped interval before reaching the fault at the base of the Sierra Ladron. Denny [28] has shown that in the area east of the Sierra Ladron the Santa Fe is faulted against a pre-Santa Fe formation, which is in turn faulted against the older rocks on the line shown by Darton on the map above cited. The post-Santa Fe fault thus lies somewhat farther east, as shown on figure 49.

The general effect of these two fault systems on the east and on the west is to enclose a basin which has a general north-south trend. It is in the nature of a true graben or dropped block, 25 to 35 miles wide and 80 miles long.

The Socorro Basin is structurally diverse. From San Acacia south for 15 miles it is a narrow asymmetric trough, with its deepest portion near the complicated fault system at the base of the Socorro-Lemitar uplift. On its eastern margin the Santa Fe thins to a wedge and rests unconformably on the older rocks of the low plateaus to the east. (See fig. 50.)

Near San Antonio this narrow trough widens. Great plains underlain by Santa Fe beds extend to the Magdalena and San Mateo Ranges and also between them. To the east the basin merges with the Jornada del Muerto. This great depression is doubtless underlain by the Santa Fe formation, but it is almost wholly covered by later Quaternary and recent deposits.

South of San Marcial faults are known along the west base of the Fra Cristobal Range and Sierra Caballo. Faults are also reported north of Rio Percha, outlining a small graben between the foot of the Black Range and a group of outlying hills to the east. This graben has a north-south trend, but there is no information as to its shape in cross section. It lies parallel to the Jornada del Muerto, which is presumably also a down-faulted basin. Still farther south only two localities are known where the Santa Fe rests in fault contact with the older rocks. As Dunham [29] points out, there is little question that the basins are underlain by more or less deformed beds presumably of Santa Fe age. The surface of the basins, such as that of the Jornada del Muerto, are erosion surfaces cut on these beds. The faults by which the defor-

[24] ..h, H. T. U., op. cit.

[25] ..eiche, Parry, unpublished work for the U. S. Soil Conservation Service.

[26] Bryan, Kirk, and McCann, F. T., The Ceja del Rio Puerco, a border feature of the Basin and Range province in New Mexico (in press).

[27] Darton, N. H., "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U. S. Geol. Survey Bull. 794, pl. 26, 1928.

[28] Denny, C. S., unpublished data.

[29] Dunham, K. C., op. cit., pp. 174-183.

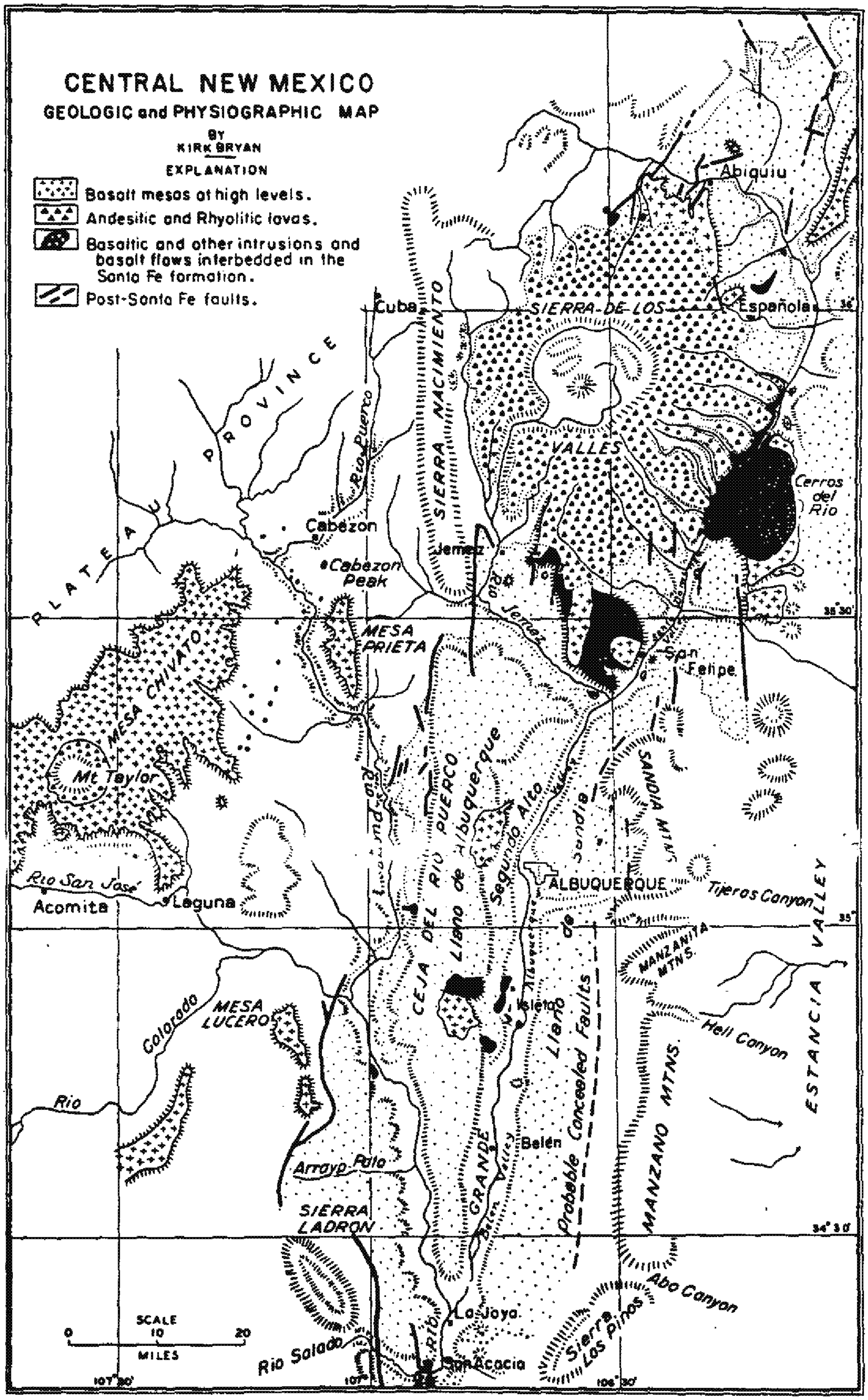

FIGURE 49.—Geologic and physiographic map of central New Mexico.

mation was accomplished are concealed. Dunham as-mes that a fault exists on the east side of the Organ untains, and Sayre,[30] of the United States Geological urvey, has demonstrated a fault at the east base of the Franklin Mountains by geophysical means.

Development of Existing Topography

Ortiz Surface

The Rio Grande depression is a structural depression consisting of minor basins and reentrants and having a border of diverse types that merges to the south into a number of similar basins. The structural depression is only in part coincident with the present course of the river.

Broad surfaces of erosion slope toward the present position of the river course in several localities. These surfaces are capped by gravel characteristic of the existing tributaries and in places are protected by basalt flows. They represent one or more long periods of erosion with stabilized grades. By projecting the gradients of the individual surfaces toward the Rio Grande it appears that they would reach the position of the river about 500 feet above its present channel throughout the Albuquerque-Belen Basin.

This surface, as thus projected from existing remnants, represents a long period of erosion that followed e post-Santa Fe uplift of the mountains. From the ticularly well-displayed and long-studied remnants round the Ortiz Mountains, it is called the Ortiz surface. During this period the Rio Grande was about 500 feet above its present position at White Rock Canyon, and about 450 feet above its present position at the mouth of the Rio Puerco. By the end of the period a considerable part of the material of the basins was carried away; the basins, except some areas of interbedded lavas, were wholly reduced to plains; parts of the bordering highlands were beveled; and the original fault scarps were largely destroyed. The larger highland masses retained most of their original altitude except for the stripping of the wedges of the Santa Fe formation that overlapped their borders. On the flanks of the larger masses and within the smaller masses only the resistant rocks, such as quartzite, limestone, granite, and the Tertiary volcanics, stood out as residuals. The Mesozoic and early Tertiary sedimentary rocks were much reduced. For example, the area of the upper Rio Puerco is a part of the bordering highland of the Albuquerque-Belen Basin. Here practically all the Mesozoic rocks except the Poleo sandstone were reduced in Ortiz time.[31] On the Ortiz surface the Rio Grande attained what is essentially its present course, and with each successive lowering of gradient, it has merely preserved this course or modified it by minor adjustments to the position of hard and soft rocks.

In the area north of White Rock Canyon the Ortiz surface is not easily distinguished from other and higher surfaces. South of the Albuquerque-Belen Basin, this surface has not been certainly identified. It may be coincident with the top of the Jornada del Muerto and La Mesa. These surfaces lie about 450 feet above the river near San Marcial and 350 to 370 feet above the river near El Paso. On the west side of the Jornada del Muerto large areas of Cretaceous rocks are beveled at grades corresponding to this level. The present course of the Rio Grande west of the Jornada del Muerto was undoubtedly established at this time.

Post-Ortiz Deformation and Deposition

In general the Ortiz surface appears not to have been much deformed. However, Smith [32] believes that some deformation has occurred in the Chama Valley and that there has been progressive uplift in Quaternary time. It may be that, as the correlation of the pediments and terraces is perfected, warping in different localities may be established. Some areas, particularly north of White Rock Canyon, may have been broadly uplifted.

Uplift of the ranges in Quaternary time has been established in the San Luis Valley and at the west base of the Magdalena Mountains.

The portion of the San Luis Valley north of the San Luis Hills has been depressed in post-Santa Fe time and may be subject to continuing movement. As Siebenthal [33] pointed out, a large number of artesian wells penetrate fine sand and clay, which continue from the surface downward for several hundred feet. To this material, which is obviously post-Santa Fe, he applied the name Alamosa formation. Near La Jara wells penetrate to basalt that is considered to be of Hinsdale age and therefore younger than the Santa Fe formation. Here the depth of the Alamosa formation is between 350 and 400 feet. Elsewhere in the valley the depth is probably greater, but no sharp division from the underlying beds can be made in the existing well logs.

The Alamosa formation is exposed in Hanson's Bluff, where 41 feet of sand, fine gravel, and clay is overlain by 8 feet of more recent gravel and conglomerate. The beds contain large numbers of shells representing animals that live in fresh water, belonging to four species that are usually attributed to the late Pliocene or early Pleistocene.

Except for this exposure, the characteristics of the Alamosa formation must be inferred from the well logs. Those published by Siebenthal indicate that the material is fine-grained, but it seems probable that there is more gravel than is indicated by these logs. Siebenthal

[30] yre, A. N., informal communication.
[31] ryan, Kirk, and McCann, F. T., Successive pediments and terraces near Cuba, Mex.: Jour. Geology, vol. 44, pp. 145-172, 1936.

[32] Smith, H. T. U., op. cit.
[33] Siebenthal, C. E., op. cit., pp. 40-41.

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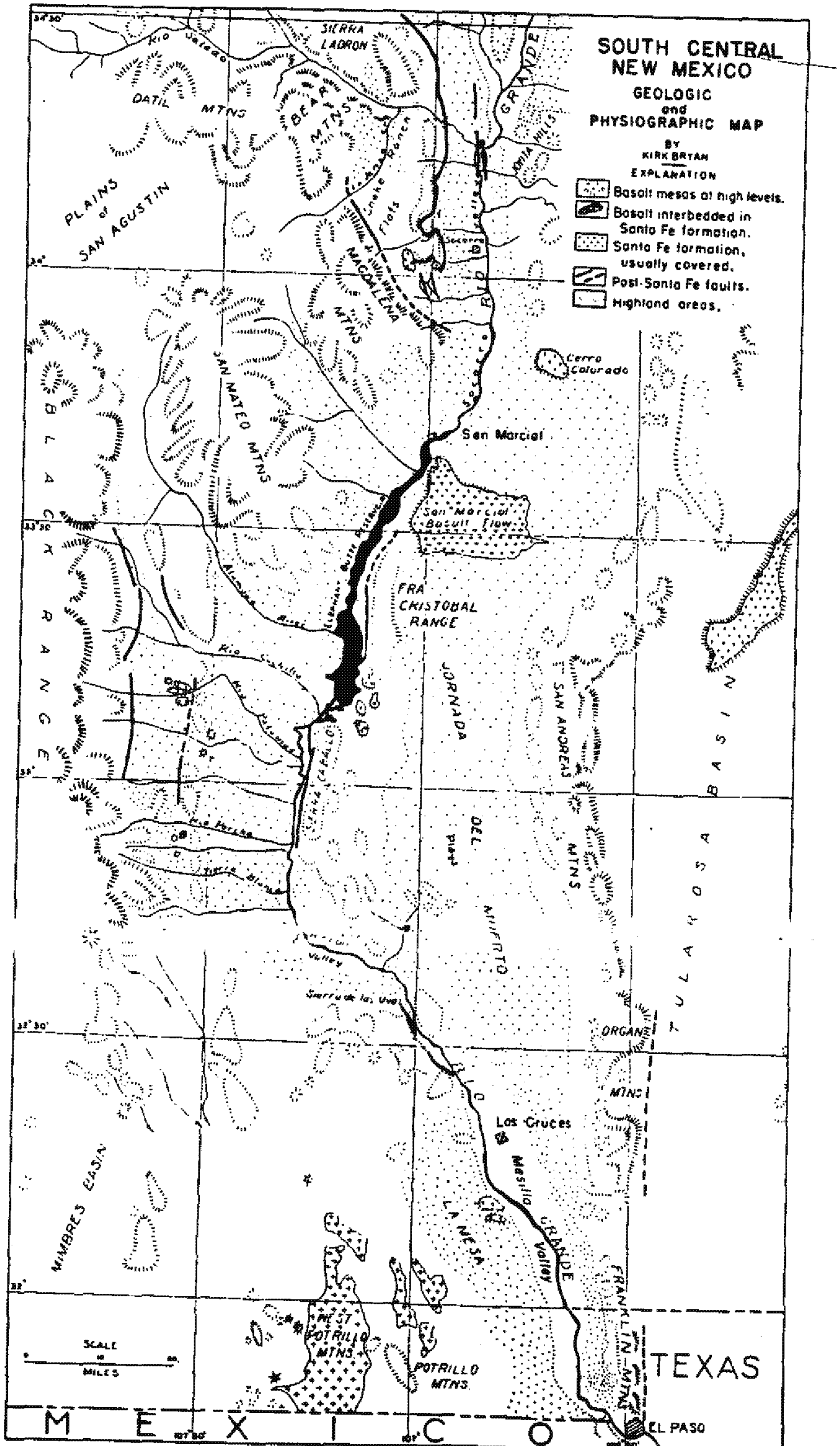

FIGURE 50.—Geologic and physiographic map of south-central New Mexico.

believed that the beds were laid down in a lake, but against such a theory there can be cited several facts. gravel embankments or other shore features are known. A deep lake would provide no mechanism except the feeble activity of wave-induced currents for the transportation of sand from west to east, yet sand is shown in every well log and occurs in Hansons Bluff. Furthermore, alkaline and colored waters are found in the wells of the present area of alkali and swamp—that is, to the north of the Rio Grande fan. It is believed that water of this type indicates ground-water discharge throughout the period of deposition of the Alamosa formation rather than the existence of a lake. It thus seems probable that the valley floor was gradually lowered with deposition, and that the beds were laid down on alluvial plains similar to those of the present time. Temporary lakes may have existed as incidents to subsidence or as a result of the shifting of areas of rapid deposition from place to place. The existence of the Alamosa formation testifies to deformation and the bold western scarp of the Sangre de Cristo Mountains is also evidence of relatively late fault movement on the east side of the basin.

The northeast base of the Magdalena Mountains is marked by a line of fault scarps about 5 to 40 feet high, extending almost continuously from the north end of the range southeastward to Water Canyon. These s are somewhat weathered and brush-covered but d a recent uplift of the range relative to the plains. The Snake Ranch Flats, which lie between the Magdalena and Socorro Mountains, are drained by streams heading on the Magdalena Range which join La Jenze Creek or pursue courses across the Socorro uplift. The flats are smooth, aggraded slopes to which each storm adds new material. Wells in the flats penetrate alluvium that cannot be differentiated in the logs from the underlying Tertiary sediments. It is evident, however, that this is a basin originating in Pleistocene or recent time and still in the process of being filled.

Post-Ortiz Erosion Surfaces

By the time the Ortiz surface was completed the river appears to have been established in essentially its present course, but nevertheless the later history of the Rio Grande is complex. The river in New Mexico lowered its channel but remained stabilized at successive stages for considerable periods of time.

With each successive lowering of the river channel, the tributary streams were also incised, and broad plains of erosion were cut.[34] In the Santo Domingo Valley, where detailed studies [35] have been made, there are two well-developed surfaces, or partial pediments, below the Ortiz—the La Bajada and Peña Blanca pediments. Between the Peña Blanca pediment and the present flood plain there are two terraces.

The La Bajada surface is well displayed near the village of La Bajada. In some places it is nearly complete, but in others it is only a partial pediment. It continues south into the Albuquerque-Belen Valley, where it forms most of the surface of the Llano de Sandia. If projected to the river it corresponds to a river level about 300 feet above present channel. In the Socorro region it appears to be the same as the Tio Bartolo [36] surface. Exact correlation from the Rio Grande up the Rio Puerco has not been accomplished, but apparently the La Bajada is the equivalent of the La Jara pediment near Cuba.[37]

The Peña Blanca surface is less developed than the La Bajada and represents a stabilization of the grade of the river for a shorter period. It corresponds to a river channel about 175 feet higher than that of the present. It is prominent just east of Bernalillo and forms much of the complex bench west of the river called the Segundo Alto. In the Socorro area it apparently corresponds to the Valle de la Parida surface,[38] and on the Rio Puerco to the Rito Leche.[39]

Still farther down the river, in the Mesilla Valley, Dunham [40] has distinguished the Picacho surface, which reaches the river about 100 feet above its present channel. Dangerfield [41] has distinguished two less developed surfaces which reach the river at lower altitudes and also a terrace 20 feet above the river.

The Present Flood Plain and Associated Terraces

Since the pediments were formed the present flood plain has developed, and two types of low terraces have been formed. The first type results from the deposition of fans by tributaries and subsequent lateral planation by the river. The river changes its course from one side of its flood plain to the other at frequent intervals, and many such changes have occurred since the Spanish conquest. Whenever the river flows at one side of its flood plain, the tributaries that enter from the opposite side build fans on the flood plain. The larger tributaries build large fans very rapidly and may raise their channels 20 to 50 feet at their emergence upon the flood plain. In many places the fans of tributaries coalesce to form foot slopes, or "ladera", at the base of the bluffs that bound the flood plain. When the river shifts its course, however, it cuts laterally at the base

[34] , Kirk, and McCann, F. T., Successive pediments and terraces of the upper in New Mexico: Jour. Geology, vol. 44, pp. 145–172, 1936.

[35] an, Kirk, and Upson, J. E., unpublished data.

[36] Bryan, Kirk, Pediments developed in basins with through drainage as illustrated by the Socorro area, N. Mex. (abstract): Geol. Soc. America Bull., vol. 43, pp. 128–129, 1932.

[37] Bryan, Kirk, and McCann, F. T., op. cit., p. 160.

[38] Bryan, Kirk, op. cit.

[39] Bryan, Kirk, and McCann, F. T., op. cit., p. 164.

[40] Dunham, K. G., Geology of the Organ Mountains, etc.; New Mexico School of Mines, Bur. Mines and Min. Res., Bull. 11, p. 179, 1935.

[41] Dangerfield, A. N., unpublished data.

of the fans and may wholly remove them, and the tributaries also readjust their grades and dissect their previously deposited fans. By swings of the river from side to side, there are formed low terraces of irregular height. This process was described many years ago by Keyes,[42] who attributed to it all the terraces of the Rio Grande and even the higher erosion surfaces, or pediments. The process occurs to some extent on all rivers, and it is of particular importance in the valleys of the great rivers of arid regions. The terraces of this type are formed at irregularly spaced intervals of time, dependent on the vagaries of the shifting river. Their height depends on the size of the tributaries and the length of time during which the fan was built before a shift in the river course put a stop to deposition.

The second type of terrace differs from the type just described in that it is built by the main river, not by the tributary. It is composed of the characteristic rounded gravel and clean sand of the river, not of the relatively unsorted and angular gravel and sand of the intermittent and ephemeral tributary streams. Such terraces represent a cutting downward and an upbuilding of the river grade. The Rio Grande, however, is relatively so powerful in lateral planation on its present grade that it has largely removed the deposits that it laid down at the higher grades formerly existent.

The broad flood plain of the river is one of its conspicuous features. Except in the constrictions between the successive valleys, the flood plain is from 1 to 4 miles wide. Here are the irrigated lands, the oases, whose products in food and in hay concentrate the population. Here are the markets and the centers of civilization for the widely scattered ranches and mining camps of bordering highlands.

The deposits underlying the flood plain consist of unconsolidated sand, gravel, silt, and clay. Some of these sediments have been deposited recently, and in fact there seems to be no question that the river channel and the flood plain have been rising in the last few years. The depth of the flood-plain deposits constitutes an unsolved problem. The river in its larger floods scours deeply and rehandles the previously deposited materials. In such periods of high water it is capable of handling gravel that at ordinary times is unknown in the river bed. The depth to gravel in the river bed is thus a rough measure of the depth of scour in great floods. In installing its diversion weirs the Middle Rio Grande Conservancy District found gravel at depths of about 30 feet below the low-water channel at the Angostura dam, between San Felipe and Cochiti, at the Isleta dam, and at San Acacia. Near Albuquerque the piers of the Barelas Bridge are set in a bed of gravel at a depth of 60 to 65 feet. Thus it appears that scour in the larger valleys is deeper than in the constrictions between them. Scour d… flood only gives a minimum depth of the flood-deposits. Thus wells near Albuquerque find loose material to a depth of 200 feet, more or less, and the mineral character of the water is more or less uniform to this depth. These facts indicate that the flood-plain deposits, resting on the Santa Fe formation, have a maximum thickness of at least 200 feet. At El Paso drilling at the so-called international dam site at the head of the gorge showed, as reported by Slichter,[43] a depth of 86 feet of sediments above bedrock. It seems probable that there is in the larger valleys from 100 to 250 feet of relatively recent deposits of flood-plain type above the Santa Fe formation.

[42] Keyes, C. R., Aggraded terraces of the Rio Grande (N. Mex.): Am. Jour. Sci., 4th ser., vol. 24, pp. 467–472, 1907.

Post-Ortiz Volcanism

Contemporaneous with the development of the Ortiz surface there was extrusion of basaltic lava. Part of this lava may have been poured out before the surface was wholly complete and may account in part for the preservation of surfaces slightly above the normal Ortiz grade. Basalts attributed to Ortiz time in this sense include the "plateau basalts" of the Rio Grande Canyon, the Vallecitos and Black Mesa basalts of the Abiquiu area; the basalt of the Alto de Mesa Santa Ana, the great flows of Mount Taylor and the M… Prieta, the high-level basalts south of the Rio Jose, those in the southern part of the Socorro M… tains, and the San Marcial flow.

During the stages following the Ortiz, basaltic lava flows were poured out in different localities. In the Abiquiu area a small basalt flow was extruded on the Santa Clara (La Bajada?) surface. The largest flows were extruded near the beginning of the La Bajada stage from craters north of White Rock Canyon. These lavas poured into the canyon of the river and, joined by other basalt from now concealed vents, completely blocked it. The river level was raised above the La Bajada level of 300 feet and changed in position. The new canyon was similarly blocked and lava sheets welled over the partly dissected Ortiz surface at altitudes more than 500 feet above the river. The basalt from north of the canyon flowed on the east side of the Cerros del Rio and joined lavas from cinder cones north and south of Santa Fe Creek to form an extensive basalt sheet whose remaining portion is the Mesa Negra de la Bajada, extending eastward from the escarpment at La Bajada. The river cut a new canyon but was again displaced by floods of rhyolitic mud descending from a great cone that formed in the Sierra de los Valles at this time. This mud consolidated into great sloping sheets that reach more th…

[43] Slichter, C. S. Observations on the ground waters of Rio Grande Valley (N… and Tex.): U. S. Geol. Survey Water-Supply Paper 141, p. 1, fig. 2, 1905.

1,000 feet in thickness. The river was permanently displaced to the east, and the location of the present 'te Rock Caynon was fixed at this time.

.e formation of the thick deposits of rhyolitic mud does not represent the last important eruption of the Sierra de los Valles. Apparently long afterward, when the cone that had formed at this time was much eroded, new volcanoes, including the present Cerro Redondo, were formed. Obsidian flows from these eruptions were carried only a short distance down Jemez Creek. Thereafter, the only activity came from the south flank of Cerro Redondo, where a small pumice cone broke out at the locality called El Cajete. Pumice from this eruption was blown out with great force, and small bodies of it can be found east and south of the Jemez many miles distant from the source. The date of this eruption is at least as late as Peña Blanca time, as bodies of this pumice have been found on surfaces of this stage near Cochiti.

Near the pueblo of San Felipe a small cone is the center of a late basalt flow that mantles the Santa Fe lavas of Santa Ana Mesa and extends down upon the Peña Blanca surface. An erosion outlier east of the river is the round butte that is called Mesa San Felipe.

The Albuquerque volcanoes consist of five small cones and a small field of basalt. The basalt lies mostly on the Llano de Albuquerque, which is a remnant of the [illegible] surface. At the north end the lava flowed down the Segundo Alto to levels about 150 feet above the river, and therefore the eruption probably occurred within the Peña Blanca stage.

West of Los Lunas, on the Llano de Albuquerque, there is a considerable area of late basalt. It is associated with a mass of lava of Santa Fe age which forms a broad dome to the north. It may, however, be distinguished by its greater freshness of aspect, by the sharpness of its cinder cones, and by its extension down a broad swale cut a little below the ancient surface of this plain. It seems probable that this flow is much later in date than the broad Ortiz surface on which most of it lies.

In various localities to the south there are basaltic lava flows which generally lie on erosion surfaces and are apparently of about the age of La Bajada and Peña Blanca surfaces. There are flows at the south end of the Socorro Mountains, at the south end of the Sierra los Pinos near Hillsboro,[44] and near the Elephant Butte Dam, in the Sierra Caballo. On the west slope of the Mesilla Valley[45] there is a small cone and lava flow on the Picacho surface, of equivalent date. There are also large areas of basalt on La Mesa which were doubtless extruded more or less in the Picacho stage and thus long after the erosion surface of La Mesa was formed.

[44] ...y, G. T., op. cit., pp. 81-83.
[45] ...am, K. G., op. cit., p. 178.

Summary of Ground-Water Conditions

General Statement

The topography and geology of the Rio Grande drainage area significantly affects its water supply. The topography affects the water supply directly because it very largely determines the amount and distribution of the precipitation. There is, in general, in the Rio Grande drainage area an increase in precipitation with altitude. Thus there is a general increase in precipitation from south to north with increasing altitude. The inner valleys and the San Luis Valley are in the rain shadow of the mountains and therefore have low precipitation. These facts are well shown by the rainfall map of the Rio Grande drainage area.[46] At altitudes above about 7,000 feet much of the precipitation occurs as snow, which tends to sustain the flow of the streams in the spring and summer. The slope of the surface also influences the amount and rapidity of direct run-off, and conversely the amount of infiltration and of ground-water recharge and ground-water run-off, which sustains the flow of the streams.

The distribution of the rocks of different kinds also affects the amount and rapidity of the direct run-off and the amount and rate of infiltration into the ground. The texture of the rocks and the size, shape, and position of the rock bodies largely determine the amount of ground-water recharge, storage, and discharge. Thus the stratigraphy and rock structure control in large degree not only the distribution, depth, and yield of the wells but also the distribution, yield, and constancy of the springs and therefore of the streams that are fed by definite springs or by diffused seepage. The stratigraphy and rock structure are also the principal factors that determine the chemical character of the water derived from wells, springs, and spring-fed streams.

Mountains and Highlands

The mountains and highlands that border the Rio Grande depression not only receive a greater precipitation but also have a higher proportionate rate of run-off than the intervening basins. They consist largely of consolidated rocks whose pore spaces are small and moderate in number. Generally these rocks are fissured and jointed and may in places be covered by a mantle of soil. There is some storage of water in these weathered portions of the rocks, but even under favorable conditions storage in most of the formations is only moderate in amount, and, because of steep slopes and deep-cut canyons, discharge from these natural underground reservoirs is easy, and at the end of long dry summers it may be almost complete. Under these circumstances springs dry up and streams have little or no water. The largest ground-water recharge occurs in some of the limestones and basalts.

[46] See pl. 3, pt. I.

The San Juan Mountains are not only the largest mountain range bordering the Rio Grande depression but also among the highest, having many summits above 12,000 feet. The precipitation exceeds 50 inches in places, and there is much winter snow. Here rise the Rio Grande and its strong headwater tributaries—the San Antonio, Conejos, and Alamosa Rivers. The greater part of the mountain area is blanketed with volcanic rocks that have an average thickness of 5,000 feet. These rocks have numerous joints and cracks, and most of them weather to fairly deep soils. There are also considerable areas of glacial drift and of landslide masses. All these characteristics of the area provide storage of groundwater that is discharged into the streams at the bottoms of the deep-cut canyons. The low-water flow of the river and its tributaries is largely maintained from these sources.

The Sangre de Cristo and Culebra Ranges in Colorado are high, reaching altitudes of 14,000 feet. The mountains are steep and the drainage basins narrow. The rocks are mostly pre-Cambrian granite and schist, which have been scraped clean by glaciation and are therefore little weathered. There is thus a quick run-off and little ground-water storage, and most of the streams have only a small low-water flow. The larger streams, Culebra and Costilla Creeks, have headwater canyons on the east side of the crest and thus reach into areas of sedimentary rock from which they draw a relatively large low-water flow because there is relatively more soil and greater ground-water storage. In New Mexico this range is wider, and in the interior there are belts of Pennsylvanian limestone, shale, and sandstone. Thus in spite of lower altitudes and less precipitation, many of the creeks, such as the Rio Colorado and Santa Fe Creek, have relatively sustained low-water flows.

The Chama River heads in the southern part of the San Juan Mountains, in the Conejos Mountains in New Mexico. The annual precipitation reaches 40 inches on the higher summits of this range. There is moderate ground-water storage in the weathered rock and in masses of glacial débris. The Chama River not only has a large spring flow from melting snow but also a considerable low-water flow.

The Jemez Mountains are about 40 miles square but consist of two unlike portions. The west side is the Sierra Nacimiento consisting mostly of granite and schist flanked on the west by upturned sedimentary rocks. The north end of the range, San Pedro Mountain, has a summit area of more than 100 square miles above 10,000 feet. Here the relatively deep winter snows and ground-water storage provide a water supply for creeks draining into the Chama River to the north, the Rio Puerco to the west, and the Rio de las Vacas, a tributary of Rio Jemez. All have a small low-water flow in summer. The eastern part of the range, the Sierra de los Valles, is made up largely of volcanic rocks. The most extensive formation is a rhyolite tuff whic open and porous. It forms great plateaus with a s direct run-off and large ground-water storage. Springs that break out at the base of the tuff furnish the low flow of streams such as the Rio Jemez. The formation also contributes to the ground-water discharge of the Rio Grande in White Rock Canyon.

The Sandia, Manzano, and Los Pinos Ranges reach altitudes exceeding 10,000 feet, but the mountains are narrow and the drainage basins of the streams have very small areas at the higher altitudes. Most of the streams drain to the Rio Grande through gaps in the range. Most of the limestone plates that cap the mountains dip eastward. They are much broken by joints and have large solution cavities. The direct run-off is moderate and there is large ground-water storage, but the dip of the rocks is so steep that drainage of these reservoirs by springs is relatively easy. The distances to the river from these springs, some of which are large, is so great that no perennial streams from them reach the Rio Grande.

The western upland bordering the Albuquerque-Belen Basin is largely underlain by Cretaceous and Tertiary sedimentary rocks. Here originate the Rio Puerco and the Rio Salado, two important tributaries of the Rio Grande. The Rio Galisteo, which rises the south end of the Sangre de Cristo Range, eas the Rio Grande, has the larger part of its draina basin in the Cretaceous rocks and has similar characteristics. Quick run-off and low ground-water storage are characteristics of these rocks. The general altitude of the drainage basins is also low and most of the precipitation is rain rather than snow. Sharp flashy floods are characteristic. The rocks weather largely to sand, silt, and clay. The clay resulting from the weathering of these rocks is colloidal, and when it is wet it can be easily transported by the streams. During a long period of time alluvium was stored in the flood plains of the main streams and their tributaries, but beginning about 1885 deep channels were formed from downstream headward, and even yet these channels are continuing to widen and, in places, to deepen. The erosion of these channels has produced large volumes of fine-grained material, commonly called silt,[47] which is carried into the Rio Grande and which since the building of the Elephant Butte Dam has been deposited in the Elephant Butte Reservoir. If the estimated volume of the original channels of the Rio Puerco is subtracted from the volume of the channels as determined in 1927 and the remainder is divided by 42, the

[47] Bryan, Kirk, Silt studies on American rivers: Nat. Research Council Rept. and Circ. Ser., No. 92 (Rept. Com. on Sedimentation), pp. 34-48, 1930; Channel e of the Rio Salado, Socorro, N. Mex.: U. S. Geol. Survey Bull. 790, pp. 17-19 Historic evidence on changes in the channel of Rio Puerco, a tributary of th Grande in New Mexico: Jour. Geology, vol. 36, pp. 265-282, 1928.

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number of years between 1885 and 1927, the result is the mean rate of silt production by enlargement of the channels. This figure is 9,000 acre-feet a year, or about .0 percent of the quantity of silt annually deposited in the Elephant Butte Reservoir. If the very considerable quantity of silt produced by channel widening and deepening in the Rio Galisteo and the Rio Salado is added, it is apparent that these three tributaries are the major factors in the silt problem of the Rio Grande. It is also evident that channel enlargement is a prime factor in silt production.

The highlands and mountains south of the Albuquerque-Belen Basin are relatively small and relatively low. None of the tributary streams are perennial, and many of them seldom yield even flood water to the river. Part of the Jornada del Muerto and most of La Mesa contribute no surface flow to the river. The largest tributaries originate in the Black Range. The volcanic rocks of this range furnish good ground-water storage, and some of the streams have a low-water flow, which is, however, consumed by evaporation or infiltration into the basin deposits and thus fails to reach the river.

The Basin Deposits

Classification of the basins.—The basins between the mountains are characterized by low rainfall, low direct run-off, and high ground-water storage. In this respect they resemble the other basins of the basin and range province. They differ from those other basins principally in being strung like beads along the line of the Rio Grande. Each has its local drainage area and local water supply and discharges water by evaporation and transpiration in the low land of its inner valley, but each also receives and discharges water of the main river and some of them of major tributaries also.

The intricacies of the individual basins can be best understood if the hydraulic regime of ground-water reservoirs is first considered. Ground-water reservoirs in the Rio Grande depression may be divided into two main classes and these in turn may be subdivided as follows:

A. Geologically enclosed basins, in which the permeable rocks, consisting chiefly of parts of the Santa Fe formation, later sedimentary deposits, and associated lava rocks, are completely surrounded by essentially impermeable bedrock, so that virtually all water that is precipitated on the basin or comes in by surface flow from other drainage areas must either be consumed within the basin or overflow across the bedrock by surface flow. These basins may be divided into the following subtypes:

1. Basins that are enclosed hydrologically as well as geologically. The basin receives no water from any other basin, and all the precipitation within its drainage area is consumed by evaporation, transpiration, or chemical combination, without flow to the outside.

2. Geologically enclosed basins that receive surface flow from other basins but do not discharge any surface water. All precipitation within the drainage area of the basin and the accretion of water by surface flow from one or more other basins is consumed within the drainage area of the basin by evaporation, transpiration, or chemical combination.

3. Geologically enclosed basins that discharge water by surface flow but do not receive any surface flow from any other basin. All precipitation within the drainage area of the basin is consumed by evaporation, transpiration, or chemical combination, except for the loss by surface flow to the outside.

4. Geologically enclosed basins that receive surface flow from one or more other basins and also discharge water by surface flow. All precipitation within the drainage area of the basin plus the surface inflow is consumed by evaporation, transpiration, or chemical combination, except for the loss by surface flow to the outside.

B. Geologically open basins, in which the permeable rocks (Santa Fe formation, later sedimentary deposits, associated lava rocks, etc.) are incompletely enclosed by bedrock or are incased by bedrock part or all of which is permeable. Thus the basin is geologically open, and there is opportunity for water to percolate underground into or away from the basin. The hydrologic connection may be effected through bodies of permeable bedrock. These basins also may be subdivided, as follows:

1. The basin has no surface inflow from any other basin and no surface outflow, but it loses water by percolation to one or more other basins that have lower water tables.

(*a*) The loss is large, so that the basin has a low water table. Precipitation in the drainage area of the basin is consumed by immediate evaporation and transpiration from the soil, by chemical combination, and by underground leakage.

(*b*) The loss is small, so that the basin has a high water table. Precipitation in the drainage area of the basin is consumed by evaporation, transpiration, and chemical combination as in a geologically enclosed basin except for the loss underground.

2. The basin has no surface inflow from any other basin and no surface outflow, but it receives water by percolation from one or more other basins that have higher water tables.

3. The basin receives surface flow from other basins and either loses or gains water by percolation.

(*a*) Underground loss large.
(*b*) Underground loss small.
(*c*) Underground gain.

4. The basin has surface outflow and either loses or gains water by percolation.

(*a*) Underground loss large.
(*b*) Underground loss small.
(*c*) Underground gain.

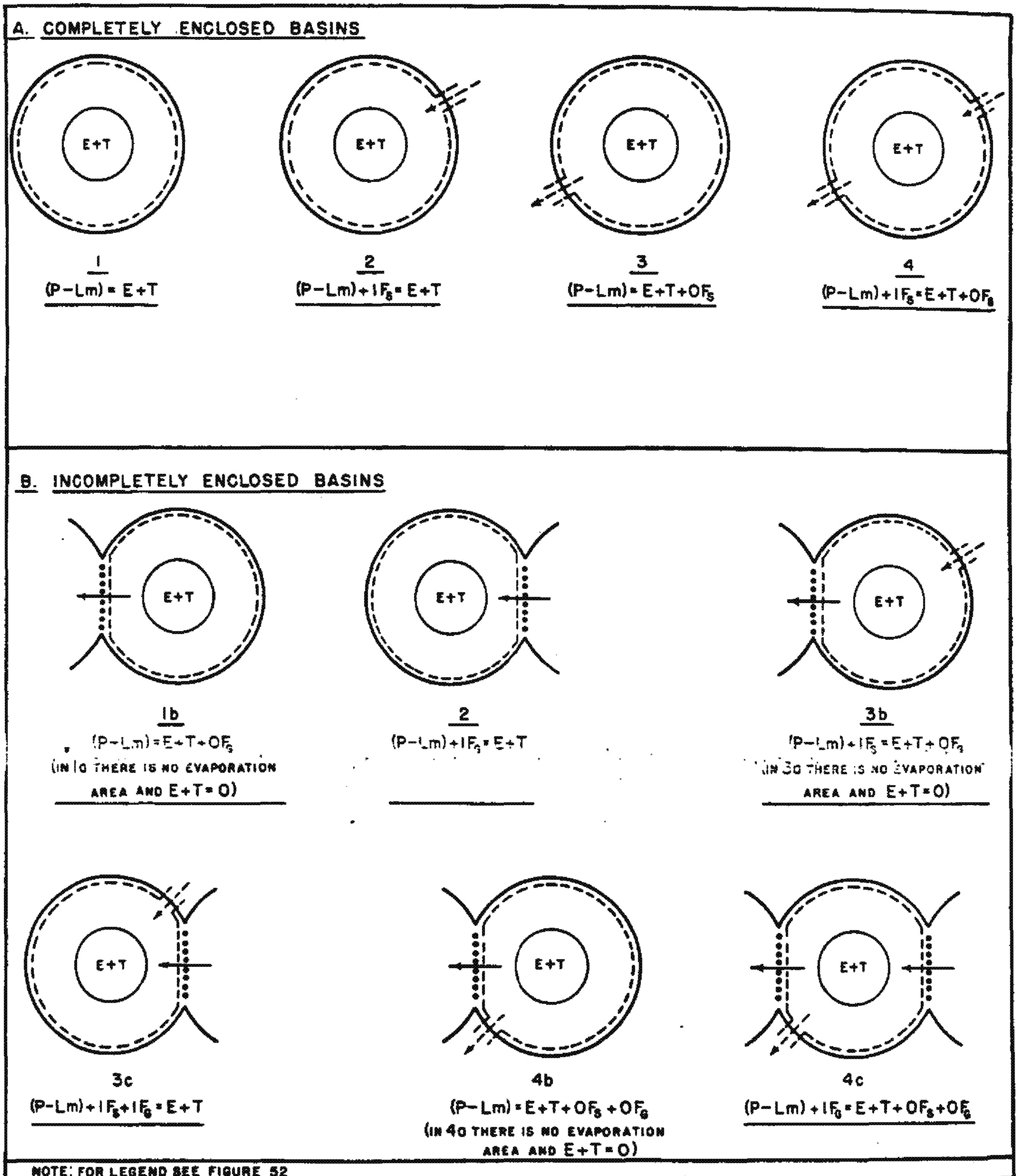

FIGURE 51.—Ground-water basins "completely" or "incompletely" enclosed.

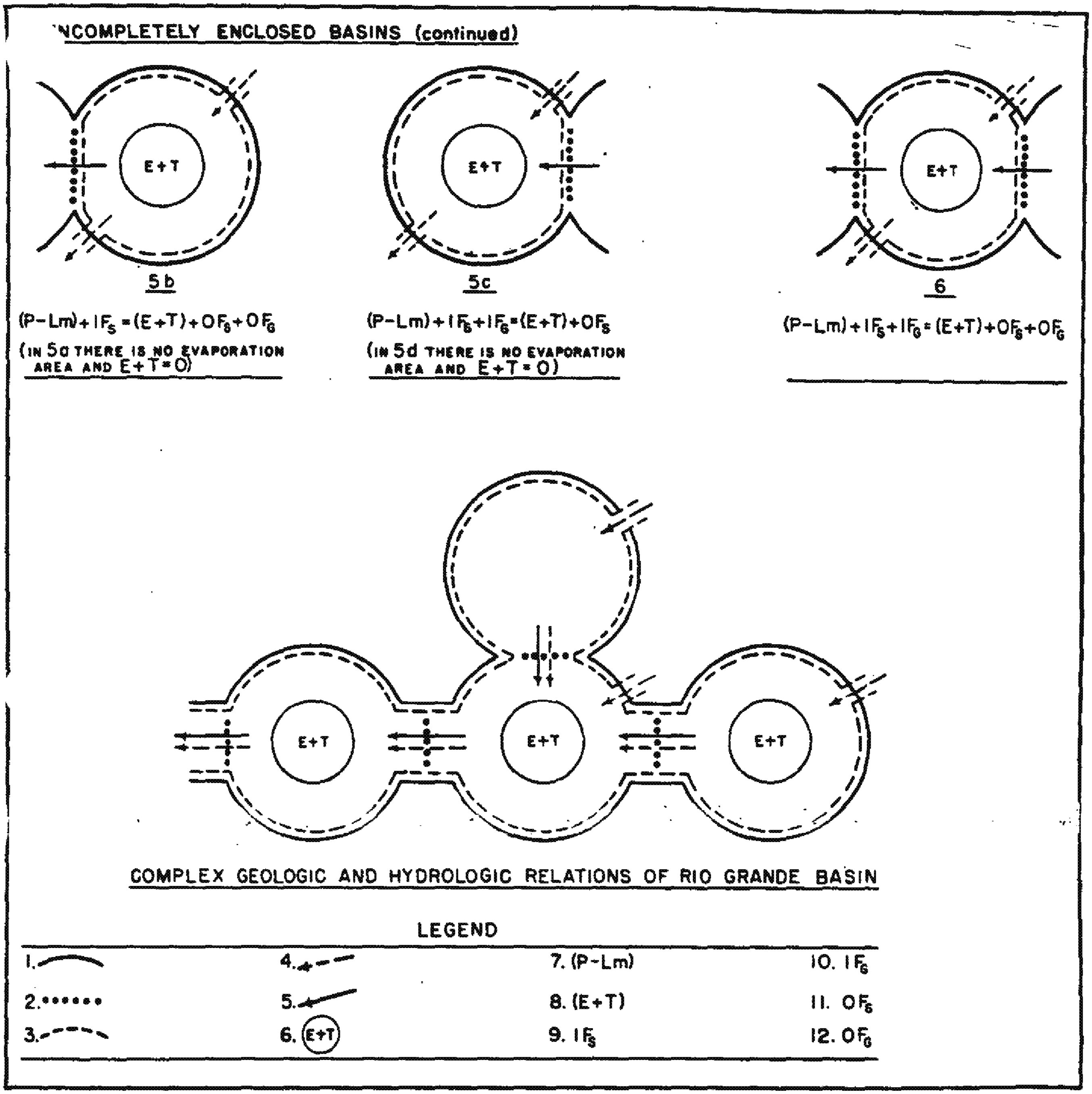

FIGURE 52.—Ground-water basins "incompletely" enclosed and diagram showing complex geologic and hydrologic relations of the Rio Grande Basin.

EXPLANATORY NOTE

1. Impermeable boundary of ground-water basin.
2. Permeable boundary of ground-water basin.
3. Topographic and drainage boundary.
4. Flow of surface water.
5. Flow of ground water.
6. Conventional representation of area of shallow ground water or shallow lake with intense evaporation and transpiration.
7. Approximate quantity of infiltration; equal to the amount of precipitation on the basin less the immediate loss from the soil by evaporation and transpiration.
8. Quantity of water lost from basin by evaporation and transpiration from the ground-water body.
9. Quantity of water brought into basin by surface streams.
10. Quantity of water brought by underground flow.
11. Quantity of water lost to basin by flow in surface streams.
12. Quantity of water lost to basin by underground flow.

5. The basin has both surface inflow and outflow, and either loses or gains water by percolation.
   (*a*) Underground loss large.
   (*b*) Underground loss small.
   (*c*) Underground gain.
6. The basin has both surface inflow and outflow and also underground inflow and outflow.

The accompanying diagrams, figures 51 and 52, have been prepared without regard to the size and shape of the basins and considering only the possible variations in geologic and hydrologic conditions. The simpler basins, A–1 and A–2, do not occur in the Rio Grande drainage area, but the Estancia Valley and the plains of San Agustin are nearby examples, and many additional examples could be cited from Nevada and southeastern California.

The basins of the Rio Grande drainage area are open geologically and also open hydrologically. As they are surrounded by higher ground, however, they generally gain rather than lose underground water. The only possibility of loss underground is to the next lower basin on the river. However, some of them are so nearly enclosed both geologically and hydrologically, even at their southern or lower ends, that they are, except for the surface flow of the Rio Grande, almost perfectly isolated as to water supply from adjacent basins. As nearly all the basins receive surface or ground water from sources other than the river, however, most of the basins classify in B–5–c or B–6.

Hydrology of the basins.—In the light of the general principles set forth above the several basins of the Rio Grande can be reviewed. The San Luis Valley is almost completely closed geologically by the barrier of the San Luis Hills to the south. South of Antonito there is no known barrier to underground flow through the gravel and basalt into the plateau and thence to the canyon of the river. However, only water that infiltrates in the Hinsdale formation in Los Pinos Creek Valley or near the mouth of Antonito Creek could travel in this direction, as the slope of the surface and of the water table are to the east and north from Antonito northward. Furthermore, seepage studies in Rio Grande Canyon show no notable gain of water in this area.[48] In this same area surface water, in part diverted from other streams, goes down Poncha Creek for use in irrigation south of the San Luis Hills. The basin of this creek is wholly in the relatively impermeable Tertiary volcanics (Conejos? andesite), and there is probably little leakage to the deep underground. Whatever is lost by wastage at the end of the canals goes into the river and is lost to San Luis Valley. In the area between the Sierra Blanca and the northeast end of the San Luis Hills the basin is open to the drainage of Trinchera Creek. As Trinchera Creek ~~is the~~ higher, both surface and ground water may be fed into San Luis V but part of the water, both surface and undergr goes south of the barrier and is lost to the valley.

The eastern portion of what is called San Luis Valley south of Trinchera Creek drains both on the surface and underground to the Rio Grande. Part of the water from the lower part of Culebra Creek enters above State Line Bridge (Lobatos gaging station) a few miles north of the New Mexico line. The ground water in the vicinity drains directly west only in part, and much of it must mingle with the ground water from Costilla Creek in the permeable beds that underlie the plain and must reach the river south of State Line Bridge.

The great plateau south of the San Luis Hills has a low surface run-off and high rate of percolation into the ground. Thus on the west side only a very few streams reach the Rio Grande and these have generally only small and discontinuous flows in the basalt plateau. On the east side of the plateau several streams originating in the Sangre de Cristo Range reach the river. Costilla and Latir Creeks, the Rio Colorado, Hondo Creek, and Taos Creek are the principal streams. Each stream enters the Rio Grande Canyon through a narrow and usually short canyon. These streams carry to the river relatively large quantities of water, and each has a small but substantial low-water flow. Howe the Rio Grande also gains water from the ground tween the State Line Bridge and Embudo.[49] This invisible inflow as measured on eight occasions between 1911 and 1928 amounted on the average to 119 second-feet. Deducting for evaporation losses leaves a net gain of about 100 second-feet, or 73,000 acre-feet a year.

The mean difference in flow between the Embudo and State line stations for the period 1889 to 1926 is, in round numbers, 250,000 acre-feet a year. Of this quantity, 187,000 acre-feet is accounted for by the surface flow of the Rio Colorado, Hondo Creek, Taos Creek and the Rio Embudo. Thus only about 63,000 acre-feet is to be accounted for by the remaining streams and by the ground-water inflow. It appears, therefore, that the mean ground-water flow must be considerably less than the 73,000 acre-feet a year shown by the special measurements of 1911 to 1928. If the quantity is as much as 50,000 acre-feet, there is in the 75 miles of canyon a ground-water inflow of 650 acre-feet to the mile.

The Española Valley receives both surface and ground water from the Abiquiu reentrant and also from the Picuris reentrant. It receives surface and ground water from the Tesuque Valley near Buckman. There is, however, a surface and ground-water divide between Tesuque and Santa Fe Creeks. This divide lies in the Santa Fe formation, and there is no imperme

[48] Bryan, Kirk, Geology of Rio Grande Canyon: New Mexico State Engineer 9th Bienn. Rept., pp. 106–120, 1930.

[49] Bryan, Kirk, op. cit., pp. 111–114.

barrier. The surface and ground water of Santa Fe Creek and of an area extending about 20 miles south the north brink of the Galisteo Valley drains to the canyon of Santa Fe Creek in the Mesa Negra de la Bajada. Here the ground water is brought to the surface by a barrier of older rocks formed by Tertiary, Permian, and Cretaceous rocks and intrusives in the Cretaceous. Some of it is lost by evaporation and some spills through the barrier and emerges again above the village of La Bajada.

The White Rock Canyon is a topographic separation between the Española and Santo Domingo Valleys. It is cut mostly in the interbedded basalts of the Santa Fe formation and at levels 300 feet or more above the river in later volcanics. These rocks are permeable to water. They probably form only a partial obstruction to water flowing southward from the Española Valley. Without question they transmit water from both sides but particularly from the west side of the canyon. Springs are common in the canyon, and there is a gain of water not only from the creeks but also from the ground.

The Santo Domingo Valley is bounded on the east by a geologic barrier composed of different rocks which are apparently effective in preventing movement of ground water. Some ground-water flow breaks out in Santa Fe Creek above La Bajada, derived from such r as overflows the barrier and also water that nates by reason of rainfall on the mesa. The interbedded basalt that crops out in Black Butte is crossed by Santa Fe Creek in a canyon east of Cochiti. Here also ground water is brought to the surface and in part dissipated by evaporation. The Rio Galisteo, which drains a large area of highland outside the basin, crosses into the basin at Rosario siding, and thence to the river flows in a flood plain with a high water table where some ground water is lost by evaporation. Several streams flow in from the mountains on the west. All lose their surface flow at the boundary of the Santa Fe formation and contribute to the ground water.

The Albuquerque and Belen Valleys lie in a very large basin. The topographic barrier between the valleys is at Isleta, and as it is formed by a basalt sheet interbedded in the Santa Fe formation it offers only a partial obstruction to the flow of water underground. Otherwise the Albuquerque and Belen Valleys constitute a unit. Surface waters from outside the basin are received in one or the other of these valleys through Jemez Creek and Rio Puerco and from the east side of the Sandia and Manzano Mountains through Placitas, Tijeras, Hell, and Abo Canyons. At its south end the Belen Basin is much narrowed between erra Ladron and the Joyita Hills. The fault on the west side forms the boundary between the Santa Fe formation and the pre-Santa Fe basin deposits. The latter are generally more thoroughly cemented and are less permeable, but there is some opportunity for ground-water connections. The actual gap at San Acacia is a narrow gorge in a sheet of andesite interbedded with the Santa Fe formation. The flood plain in this gap is narrow, and underflow in it through the flood-plain deposits must be reduced to a minimum.

The Socorro Valley is underlain by beds of the Santa Fe formation deposited in a basin separate from the main basin. The lithology of the beds is somewhat different, but there is no reason for believing that their permeability is lower except in a zone 1 to 2 miles wide at the base of the Socorro and Lemitar Mountains. This basin merges to the south into the Jornada del Muerto and the basins west of the river. Leakage to these basins is impossible on account of their higher altitude, but on the other hand ground-water inflow must take place from these areas. Whether ground water from the inner valley in the vicinity of San Marcial can pass west of the Elephant Butte Reservoir depends largely on hydrologic conditions. When the reservoir is full, the valley fill is saturated with water to an altitude close to that of the town of San Marcial, and there is no hydraulic gradient on which movement can take place. When the reservoir is empty or at low level there is a gradient, but whether it is enough to cause significant movement is doubtful.

Rincon Valley is largely enclosed on the east and north. It is open to the west, but this part of the basin is higher and must contribute water to rather than gain water from the Rio Grande Valley. At the lower end of the basin, in Seldon Canyon, the basin is not wholly closed, but it is so narrow that ground-water losses are almost impossible except through the gravel below the river bed.

Mesilla Valley is almost closed at both ends, but is open to the sides. It seems from the somewhat meager information available that ground-water levels in La Mesa are higher than the floor of the valley and that there must be a ground-water gain. Loss of ground water into Mexico west of El Paso seems unlikely, as the enclosed basins to the south appear, according to a reconnaissance by A. N. Sayre, of the United States Geological Survey, to have altitudes higher than the valley floor above El Paso. The gorge at El Paso has at least 86 feet of alluvium above bedrock, and Slichter's measurements[50] show that underflow is small.

El Paso Valley is open on both sides and ground-water gains occur, but it is so constricted at Fort Quitman that ground-water losses in this pass are probably low.

[50] Slichter, C. S., Ground waters of the Rio Grande: U. S. Geol. Survey Water Supply Paper 141, pp. 9-14, 1905.

PART II
SECTION 2.—GROUND WATER IN THE SAN LUIS VALLEY, COLORADO[1]

Introduction

Location and General Features of the Area

The San Luis Valley, in the south-central part of Colorado, lies in a broad depression between two mountain ranges converging to the north. The Sangre de Cristo Range, which forms the east boundary, reaches altitudes of over 14,000 feet. The ranges on the west side include the Saguache, San Juan, Conejos and La Garita Mountains, with altitudes between 13,000 and 14,000 feet. The valley floor has an altitude ranging from about 7,500 to about 8,000 feet. Alamosa, near the center of the valley, lies at an altitude of about 7,540 feet. The San Luis Valley is the first of a series of basins along the Rio Grande, below its head in the San Juan Mountains of Colorado.

The entire length of the valley from north to south is about 150 miles, and its greatest width is about 50 miles. The San Luis Hills, extending northeast from Antonito on the south to Fort Garland on the east, separate the valley into two parts. This report deals only with that part lying north of these hills, which is hydrologically distinct from the south part. The area covered by this report lies chiefly in Alamosa and Saguache Counties but partly also in Conejos, Costilla, and Rio Grande Counties.

The Rio Grande enters the valley at Del Norte, on the western border, and flows southeast across the valley in the direction of Alamosa, there turning abruptly south toward the San Luis Hills, passing through them in a narrow gap. A low divide, located a few miles north of the Rio Grande and parallel to it, separates topographically the area to the north. This area is generally referred to as the closed basin area. The Conejos River, which rises in the western mountains, flows east and then northeast along the western flank of the San Luis Hills to join the Rio Grande. In addition, there are numerous smaller streams.

Most of the valley has a remarkably flat surface, with the lowest portion along an axis near the eastern border of the valley. From this low land the valley floor rises to the foothills, steeply toward the east, and more gently toward the west, at first not more than 3 to 6 feet to the mile but gradually increasing toward the margins of the valley.

Alamosa, the county seat of Alamosa County, is the largest town in the valley. According to the census, it had a population of 5,107 in 1930. The next largest town is Monte Vista, whose population in 1930 was 2,610. Smaller towns in the valley include La Jara, Center, Del Norte, Sanford, Antonito, Manassa, Fort Garland, Saguache, Moffat, Hooper, and Mosca.

The entire valley floor is underlain by a body of unconfined water at shallow depth. The only large use that is at present made of this body of ground water is from a number of standby irrigation wells in the agricultural area on the west side of the valley. These wells are pumped in periods of water shortage. Beneath the body of shallow ground water and separated from it by a confining bed lies a large body of artesian water, which occurs in numerous strata in the basin deposits or the valley fill. The artesian water has been developed extensively for domestic, stoc[k] and irrigation uses, over 6,000 flowing wells hav[e] been drilled in the valley.

The geology and ground-water conditions of the San Luis Valley were studied and described by Siebenthal.[2] The geology is reviewed by Bryan in the preceding section of this report.

Acknowledgments

The ground-water work was begun on March 11, 1936, by T. W. Robinson, assisted by H. A. Waite, who began work April 21, 1936. From April 15, 1936, to January 15, 1937, A. DiGiacomo devoted part of his time to establishing and measuring periodically the depth to water in observation wells. He also assisted in the inventory of artesian wells. On July 17, 1936, G. M. Dyer was assigned to the inventory of artesian wells, continuing with this work until January 9, 1937. E. F. Taylor was employed in the period from November 9, 1936, to January 16, 1937, to run levels to observation wells.

Grateful acknowledgment is made to George M. Corlett, attorney for the Rio Grande Water Users' Association, for general information regarding the use of water in the valley; to W. D. Carroll, irrigation division engineer, and Dan Jones, Jr., deputy State

[1] By T. W. Robinson and H. A. Waite, Geological Survey.

[2] Siebenthal, C. E., Geology and water resources of the San Luis Valley, C[olorado]: U. S. Geol. Survey Water-Supply Paper 240, 1910.

hydrographer for the San Luis Valley, for cooperation ' data supplied by them; to I. R. Richardson, presi- of the Adams State Teachers College at Alamosa, a... M. G. Hester, superintendent of buildings, for laboratory facilities and office space. C. R. Bollier, city water commissioner at Alamosa; W. F. Bowers, city manager of Monte Vista; Hugh H. Collum, of Center; and C. H. Hall, of La Jara, furnished valuable information regarding the number and discharge of artesian wells in the respective towns. Special acknowledgments are due to Grant E. Oxley, Robert E. Schwarzbeck, Horning Bros., Axel Arnell, Victor Crow, E. P. Wagner, and Mr. Van Nostrand for cooperation in the use of their wells in field tests. Ray Wells, Charles Speiser, A. E. Biggs, and T. C. Shepherd, well drillers in the valley, gave valuable information regarding artesian wells. W. A. Haynes, of Center, gave freely of his time, spending several days in the field, in supplying information concerning irrigation wells. Acknowledgments are also due A. M. Collins, Howard K. Linger, J. H. Oliver, and Ben King, who control large tracts of land on the east side of the valley, for data furnished in regard to artesian wells, and to the many residents of the valley for their wholehearted cooperation in supplying information at all times.

General Ground-Water Conditions

.ctically all the ground water that occurs in the ..r-bearing beds of the valley fill in the San Luis Valley is meteoric in origin—that is, it is the result of precipitation in the form of rain or snow on the valley floor and on the tributary drainage area. By far the greater part of the precipitation on the drainage area falls as snow. A part of the precipitation that falls directly on the valley floor percolates downward to fill the interstices of the sedimentary deposits, while a part of the run-off of the streams discharging into the valley percolates away from the stream channels as contribution to the ground water. Recharge to the ground water from the latter source is materially aided by the numerous gravity diversions for irrigation. The common method of irrigation is by "subbing" or subirrigation. In this method large quantities of water are spread over the land surface in order that they may percolate downward to saturate the underlying material and raise the ground-water level. Sufficient water is spread over the land to raise the ground-water level to the root zone of the plants and to maintain it in that position throughout the growing season. Saturation of the aquifer, however, is not by simple downward percolation but is the resultant of downward percolation in the areas of recharge and lateral percolation p· from those areas.

upper surface of a zone of saturation, except where that surface is an impermeable ~~body~~, is known as the water table.[3] Such a zone of saturation corresponds to the water in a reservoir and is often referred to as a "ground-water reservoir". Its upper surface—the water table—is free to rise during periods of recharge or to fall during periods of discharge, similar to the water surface in an ordinary reservoir. The quantity of water represented by a rise or fall of the water table, however, is far less than that represented by a rise or fall of the same magnitude in a reservoir of equal size. The quantity of water stored in a ground-water reservoir depends on the capacity of the rocks of the aquifer for water, as ground water occupies only the interstices or voids in the rock. As in an ordinary reservoir, however, the rise and fall of the water table is an index to the quantity of water which has been added or withdrawn. When the capacity of the rocks to absorb water is known, the quantity of water represented by a rise or fall of the water table can be determined.

Over most of the floor of the San Luis Valley there occurs such a zone of saturation. The water that occurs in the zone of saturation in the shallow valley fill is known as unconfined or shallow water. Locally it is often referred to as the "sub."

When the upper surface of a zone of saturation is composed of an impermeable body the water is said to be confined. If the water is under sufficient pressure to rise above the zone of saturation it is called artesian water.[4] If the hydrostatic pressure is sufficient, the water may rise in a well to the land surface and may flow from the well. As the hydrostatic pressure in the water-bearing bed fluctuates, the water in the well will rise and fall accordingly. Unlike fluctuations of the water table, these fluctuations are not necessarily an index to additions or withdrawals of ground water. The water moving through such a confined water-bearing bed may be compared to water moving through a conduit, the water-bearing bed being really a large natural conduit filled with permeable material through which the water moves under pressure. If the cross-sectional area of the water-bearing bed, the hydraulic gradient of the water, and the coefficient of permeability of the material are known, the quantity of water passing through the bed can be determined for any period of time.

Such a body of ground water occurs in the valley fill at greater depths than the unconfined water in the shallow valley fill. This body of confined or artesian water also constitutes a ground-water reservoir.

These two bodies of ground water will be discussed in order of their occurrence beneath the land surface.

[3] Meinzer, O. E.: Outline of ground-water hydrology with definitions: U. S. Geol. Survey Water-Supply Paper 494, p. 32, 1923.
[4] Idem., p. 40.

Unconfined (or Shallow) Ground Water

Extent and Hydrologic Character of the Aquifer

Areal extent and thickness.—Valley fill is present over most of the San Luis Valley from Poncha Pass on the north to and beyond the New Mexico State line on the south. It is broken only by the San Luis Hills, which trend northeast from Antonito to Fort Garland and form an almost complete barrier across the southern end of the valley. The area to the south of the San Luis Hills is economically and socially a part of the San Luis Valley, although geologically and in part hydrologically it is distinct. The ground-water studies were confined to the part of the valley north of the San Luis Hills.

In this part of the valley, the shallow valley fill is limited on the west by the foothills of the Conejos, La Garita, and Saguache Mountains, on the north by the converging Saguache Mountains and the Sangre de Cristo Range, on the east by the Sangre de Cristo Range, and, as already pointed out, on the south by the San Luis Hills. In the central part of the valley the deposits above the confining beds are composed mainly of clays and sands with some gravel. Along the edge of the valley floor, bordering the foothills, the material is composed of coarse sand and gravel. Narrow tongues of alluvium and torrential wash extend up the valleys of the larger streams, especially those of the Rio Grande and Conejos Rivers.

The thickness of the shallow valley fill, considered as the depth to the first confining bed, ranges widely over the valley floor. At Moffat, in the trough of the valley, clay occurs at a depth of about 10 feet. In the vicinity of Swede Corner, 13 miles west of Moffat, it occurs at depths of 10 to 15 feet, and in the Nash well, about 5 miles east of Moffat, Siebenthal [5] reports yellow clay at a depth of 85 feet. On the Rio Grande alluvial fan 9 miles southwest of Center, the irrigation well of E. P. Long, in sec. 4, T. 39 N., R. 7 E., penetrated gravel and sand to a depth of 90 feet without encountering any clay beds. At the G. E. Oxley irrigation well, in sec. 13, T. 39 N., R. 8 E., about 9 miles east of south from Center, clay was reported at a depth of 50 feet. In the vicinity of Hooper, the first clay bed of consequence is reported from 80 to 90 feet. The depth to clay is reported as about 60 feet at Monte Vista, and about 50 feet at Parma, 6 miles southeast of Monte Vista. In the vicinity of Alamosa, clay beds have been encountered at depths ranging from 15 to 40 feet. In a well near the Bowen School, in sec. 34, T. 37 N., R. 8 E., a bed of blue clay was struck at a depth of 30 feet. About 2 miles southwest of the Bowen School, Siebenthal [6] reports hard clay at 60 feet. At the State fish hatchery, half a mile south of La Jara, clay was encountered at a depth of 30 feet. In the town of S clay was found at 32 feet, and at Romeo at a dep 17 feet. A test well in Antonito, near the apex of the Conejos alluvial fan, encountered lava rock at a depth of 50 feet. The foregoing figures give some idea as to the thickness of the shallow valley fill in various parts of the valley.

Relation to the artesian aquifer.—Beneath most of the valley plain the ground water in the shallow valley fill (shallow water) is separated from the ground water in the deep valley fill (artesian water) by beds of impermeable or only slightly permeable clay. Along the edge of the valley floor and opposite the canyon mouths, however, this clay parting feathers out, for wells drilled far up on the alluvial fans and along the edge of the valley floor do not pass through clay beds. Deep wells drilled farther from the edge of the valley and in the interior of the valley pass through one or more clay beds. The log of the well drilled by the Denver & Rio Grande Western Railroad at Villa Grove, on the alluvial fan of San Luis Creek, indicates that the well penetrated 960 feet of gravel and sand with no clay.[7] On the Rio Grande alluvial fan, a pumped irrigation well (No. 12J4G1) owned by E. P. Long penetrated 90 feet of sand and gravel. A dry hole in the southwest corner of sec. 6, T. 36 N., R. 8 E., on the alluvial fan of Creek, is reported to penetrate coarse gravel and to a depth of 163 feet.

Siebenthal [8] reports several wells along the eastern margin of the valley in which no clay beds were encountered, as follows:

> On the Baca grant, a mile and a quarter southwest of the village (Crestone) in the fork of North and South Crestone Creek, a bore went 410 feet in boulders. On Dead Man Creek a bore 1,100 feet deep was all in sand. At the Willie Hansen ranch 2 miles northwest of Baldy station, on the Denver & Rio Grande Railroad, a number of wells have been bored just about at the margin of the flowing-well area. One in the NE¼ sec. 17, T. 37 N., R. 12 E., is 500 feet deep, reported all in sand. Near the middle of the north side of sec. 10, T. 37 N., R. 12 E., a well is reported 300 feet all in sand. Near the middle of the west side of sec. 36, T. 38 N., R. 12 E., a well 300 feet deep is sand and gravel.

Although well logs are not available along the entire margin of the valley, it seems probable that there is a strip of the valley adjacent to the foothills that is underlain by little, if any, clay. In regard to this strip, Siebenthal [9] says:

> Though it is evident that the clay beds of the water-bearing series are replaced at about this point by sand and gravel, it is not likely that they terminate so abruptly. It is probable that small clay beds have been overlooked in the wells near the edge of the flowing-well area.

[5] Siebenthal, C. E., Geology and water resources of the San Luis Valley, Colo.: U. S. Geol. Survey Water-Supply Paper 240, p. 79, 1910.
[6] Idem., p. 97.
[7] Op. cit., p. 100, 1910.
[8] Idem, pp. 100–101.
[9] Op. cit., p. 101.

he ground water in this marginal strip is unconfined is the source for both the shallow and artesian water of the valley. From this common source, the ground water moves laterally toward the valley, part of it passing beneath the clay beds to become artesian water and part moving out into the permeable materials on top of the clay beds.

General character of the materials.—The material which forms the shallow valley fill ranges from silt to coarse gravel. The finest material is found in the trough of the valley, particularly in the closed basin area, whereas the coarsest material is found in the alluvial fans and outwash slopes along the edge of the valley. Large alluvial fans have been built by the streams entering the valley from the west side, the largest being that built up by the Rio Grande. Pronounced fans have also been built by Gato, Alamosa, and La Jara Creeks and by the Conejos River. Along the east side of the valley the alluvial fans are not large, but are so numerous that they coalesce along their lateral margins to form a steep, gravelly alluvial slope, skirting the foot of the mountains. The alluvial fans on the west side of the valley are much flatter and more extensive than those on the east side.

The difference in the shape and size of the alluvial on the east and west sides is due to the difference he character of the streams entering the valley. The streams entering from the west head far back in the mountains and receive the drainage from innumerable tributary streams and canyons that drain extensive areas of high altitude and heavy precipitation. These streams are much gentler in gradient than those entering the valley from the east, but they discharge floods of much greater volume and duration and consequently are capable of carrying large loads of detrital material. The detritus is not heaped about the mouths of the canyons but is spread widely, some of it being carried several miles into the valley.

Streams entering from the east side are steeper and shorter and do not receive much drainage from tributaries. Although they head high in the mountains they do not drain extensive areas, and the precipitation is not as heavy as in the drainage areas of the western tributaries. Consequently the floods are flashy, and most of the detritus is deposited near the mouths of the canyons to form steep alluvial fans.

The coarsest material, consisting almost entirely of poorly assorted gravel, is found at the apices of the alluvial fans. In general the material in the west-side fans is coarser than that in the east-side fans. In the upper part of the west-side fans it is not uncommon to gravel as large as 8 and 10 inches in diameter, eas in the east-side fans gravel of this size is not so common. Toward the lower end of the fans the gravel becomes progressively finer. In the central trough of the valley only small amounts of gravel are in evidence, by far the larger part of the valley fill being composed of sand, clay, and silt.

Some idea as to the character and distribution of the material that makes up the shallow valley fill is furnished by the following two tables of well logs, consisting entirely of wells that were bored to determine the depth to the shallow water.

TABLE 1.—*Logs of observation wells in the closed basin area*

[Logs of wells designated by 2 numbers as 9M8J1—(X-11) were furnished by the State engineer of New Mexico. For locations of the wells, see the map, pl. 5]

Well number and log	Thickness (feet)	Depth (feet)
5M32N1—(X-25):		
Clay and gumbo	4.9	4.9
Sand and clay	.4	5.3
Sand and gravel	1.4	6.7
6K14D1:		
Adobe	2.0	2.0
Sandy soil	1.5	3.5
Fine soil	.5	4.0
6K17D1:		
Black soil	2.0	2.0
Sandy soil	1.0	3.0
Gravel	1.0	4.0
6L1D1:		
Adobe soil with pebbles	6.3	6.3
Fine sand	.2	6.5
6L4B1:		
Sandy clay soil	17.0	17.0
Sand	1.0	18.0
Clay	(?)	(?)
6L4R1:		
Adobe soil	3.5	3.5
Fine sand	.5	4.0
6L19H1:		
Adobe soil	3.0	3.0
Soil and fine sand	2.1	5.1
Gravel, medium to course	1.6	6.7
6L28N1:		
Adobe, brown soil	2.0	2.0
Sandy soil	1.4	3.4
Gravel, medium to coarse	2.2	5.6
6M3B1:		
Adobe soil	5.0	5.0
Fine sand	.5	5.5
6M6R1—(X-24):		
Clay	4.0	4.0
Clay, some sand and gravel	.9	4.9
Sand and gravel	1.4	6.3
6M7R1—(X-23):		
Clay	4.0	4.0
Sand and clay	1.3	5.3
Sand and pea gravel	1.3	6.6
Sand	.7	7.3
6M19A1—(X-22):		
Clay	4.4	4.4
Sand and clay	.6	5.0
Sand	2.7	7.7
6M19R1—(X-21):		
Clay	4.6	4.6
Sand and clay	.4	5.0
Fine yellow gravel	1.7	6.7
Sand	.6	7.3
6M26M1:		
Sandy soil	2.0	2.0
Sand	2.0	4.0
Gravel	.5	4.5
6M30R1—(X-20):		
Clay	1.4	1.4
Sand and clay	2.9	4.3
Sand and pea gravel	2.9	7.2
6M31R1—(X-19):		
Clay and gumbo	2.6	2.6
Sandy clay	1.4	4.0
Sand	1.1	5.1
Sand and pea gravel	2.3	7.4
6N31D1:		
Sandy clay	3.0	3.0
Very fine sand	6.0	9.0
7K1N1—(E-9):		
Sandy clay	1.9	1.9
Clay	1.8	3.7
Clay, sand, and gravel	1.9	5.6
7K1R1—(E-8):		
Fine sand and clay loam	2.3	2.3
Fine sand and small gravel	1.7	4.0
Sand and gravel	2.7	6.7
7K3N1—(E-11):		
Hard clay	3.0	3.0
Clay, sand, and gravel	2.0	5.0
7K4N1—(E-12):		
Clay gumbo	1.6	1.6
Large gravel and sand	2.5	4.1
7K6N1—(E-14):		
Sand, loam, and gravel	8.2	8.2
Clay, gravel, stones	3.9	12.1
7K7A1—(E-13):		
Clay	2.8	2.8
Sand	1.4	4.2
Clay	1.3	5.5
Sand and clay	2.3	7.8
7K10A1—(E-10):		
Clay	2.6	2.6
Sand and gravel	3.6	6.2
7K18R1:		
Sandy soil	2.0	2.0
Fine sand	1.5	3.5
7K25A1:		
Adobe	2.5	2.5
Fine sand	2.0	4.5
Coarse sand	2.0	6.5
7K30D1:		
Sandy soil	2.5	2.5
7K33R1:		
Clay	1.0	1.0
Sandy clay	5.0	6.0
Fine sand	1.7	7.7
7L1R1—(E-2):		
Clay loam	1.1	1.1
Heavy clay	1.9	3.0
Clayey sand	1.4	4.4
Sand and pea gravel	2.1	6.5
7L2R1—(E-3):		
Fine sand and clay	1.3	1.3
Sand	4.5	5.8
Clay	.5	6.3
Fine sand	3.0	9.3
7L3R1—(E-4):		
Clay	1.2	1.2
Sandy clay	3.0	4.2
Coarse sand	2.2	6.4
Blue sand and pea gravel	3.6	10.0
7L4R1—(E-5):		
Clay	1.8	1.8
Sand	2.4	4.2
Sand and pea gravel	5.8	10.0
7L5R1—(E-6):		
Clay	2.4	2.4
Heavy black clay	.3	2.7
Clay, sand, and gravel	2.3	5.0
Sand and small gravel	2.2	7.2
7L7A1—(E-7):		
Sand and clay	2.4	2.4
Sand	1.2	3.6
Sand and gravel	4.4	8.0
7L22C1:		
Adobe	2.0	2.0
Fine sand	2.4	4.4
Gravel, medium	4.2	8.6

TABLE 1.—*Logs of observation wells in the closed basin area*—Continued

Well number and log	Thickness (feet)	Depth (feet)
7M5N1—(X-18=E-1=F-1):		
Blue clay	5.8	5.8
Sand and clay	.7	6.5
Fine sand	3.5	10.0
7M5R1—(F-2):		
Clay	3.2	3.2
Sand	1.6	4.8
Clay	.3	5.1
Sand	2.9	8.0
Sand and pea gravel	1.0	9.0
Sand	1.0	10.0
7M8N1—(X-17):		
Clay loam, light	1.5	1.5
Clay	2.5	4.0
Clayey sand	1.8	5.8
7M10D1—(F-3):		
Clay (adobe)	.7	.7
Fine sand	5.7	6.4
Silty blue clay	2.6	9.0
Silty clay	1.0	10.0
7M10H1—(F-4):		
Fine sand	3.3	3.3
Sand	.7	4.0
Clay, sandy	1.3	5.3
Fine blue sand	3.8	9.1
7M11H1—(F-5):		
Sand; varies (some clayish)	8.4	8.4
7M12A1—(F-6):		
Sand	3.9	3.9
Sand, some gravel	4.4	8.3
7M20C1—(X-16):		
Clay loam	1.4	1.4
Clay gumbo	2.2	3.6
Clay and sand	.7	4.3
Clay	.4	4.7
Fine sand	2.0	6.7
Clay	2.1	8.8
Sand	1.2	10.0
7M20P1—(X-15):		
Clay loam	2.0	2.0
Clay	1.0	3.0
Sand	3.9	6.9
Clay and sand	.6	7.5
Sand	2.5	10.0
7M29L1—(X-14):		
Fine sandy loam	3.6	3.6
Sand	3.6	7.2
Sand and clay	.3	7.5
Sand, some clay	2.5	10.0
7M27C1:		
Soil, brown	1.5	1.5
Fine sandy cla[illegible]	[illegible]	[illegible]
Fine sand	[illegible]	3.3
Medium sand, no gravel	.8	9.6
7N8N1—(F-7):		
Sand, some gravel	8.0	8.0
Sand	2.0	10.0
7N10R1:		
Adobe	2.0	2.0
Fine sand	2.0	4.0
9J1R1:		
Clay and thin layers of sand	7.5	7.5
Sand	.1	7.6
9J22C1:		
Soil, black sandy	3.0	3.0
Gravel, coarse	35.0	38.0
9J25A1:		
Clay soil	2.0	2.0
Gravel	2.8	4.8
9J34E1:		
Loam with pebbles	2.5	2.5
Gravel and boulders	15.0	17.5
9K12A1:		
Sandy soil	3.0	3.0
Sand, medium to coarse	4.0	7.0
9K21A1:		
Adobe	1.5	1.5
Fine sand	2.0	3.5
9K24H1:		
Brown silt loam	2.0	2.0
Fine brown sandy soil	3.1	5.1
Sand, medium to coarse	.4	5.5
9L10A1:		
Clay soil	2.5	2.5
Very fine sand, yellow	3.0	5.5
Fine sand	1.0	6.5
9L27A1:		
Sandy loam	2.5	2.5
Fine sand	1.5	4.0
9L33P1:		
Loam	2.0	2.0
Gravel, medium to coarse	1.5	3.5
9L336N1:		
Loam	2.5	2.5
Coarse sand	1.5	4.0
9M2C1:		
Sandy soil, brown	2.5	2.5
Fine sand	5.7	8.2
Dark green sand	.9	9.1
9M5B1—(X-13):		
Sandy clay, loam	1.2	1.2
Fine sand	5.8	7.0
Clay gumbo	1.7	8.7
Sand	3.7	12.4
9M5K1—(X-12):		
Sand clay loam	1.0	1.0
Sandy clay	4.2	5.2
Fine silty clay sand	2.8	8.0
Sand	3.9	11.9
9M8J1—(X-11):		
Sandy clay	1.7	1.7
Clay, sand	1.9	3.6
Fine sand and clay	2.0	5.6
Sand and clay	2.0	7.6
Sand and pea gravel	2.4	10.0
9M14H1:		
Sandy soil	1.9	1.9
Fine sand	5.4	7.3
Fine sandy clay	2.2	9.5
Gravel, medium	(?)	(?)
9M17J1—(X-10):		
Clay loam, some sand	.7	.7
Hard yellow sand and clay	2.3	3.0
Sand and pea gravel	2.4	5.4
Coarse sand	3.1	8.5
9M20J1—(X-9):		
Fine sand and a little clay	5.3	5.3
Coarse sand and pea gravel	3.7	9.0
Coarse blue sand and clay	1.0	10.0
9M32A1—(X-8):		
Clayey sand loam	2.4	2.4
Clay and sand	.5	2.9
Sand	.6	3.5
Coarse sand and pea gravel	[illegible]	4.3
Sand	[illegible]	[illegible]
9M32R1—(X-7):		
Sand and pea gravel	3.4	3.4
Sand	1.6	5.0
Coarse sand and pea gravel	5.0	10.0
9N8M1:		
Fine sand	5.0	5.0
Clay	1.3	6.3
Silt dark (some vegetable matter)	3.3	9.6
9N27Q1:		
Sandy soil	4.0	4.0
Fine dark gray sand	2.0	6.0
9N29P1:		
Sandy soil	3.0	3.0
Fine sand; yellow	2.0	5.0
Fine sand; dark gray	2.0	7.0
9Q30D1:		
Fine sand	10.0	10.0
10K3D1:		
Sandy soil	1.0	1.0
Adobe	1.0	2.0
Fine sand	2.0	4.0
10K6N1:		
Sandy soil	2.5	2.5
Gravel	2.0	4.5
10K12A1:		
Sandy soil	3.0	3.0
Fine sand	2.1	5.1
10K16A1:		
Loam soil, brown	3.0	3.0
Sand, fine to medium	1.6	4.6
10K19N1:		
Sandy soil with pebbles	1.0	1.0
Gravel	2.4	3.4
10K21R1—(D-12):		
Sand, clayey	3.5	3.5
Gravel	1.5	5.0

TABLE 1.—*Logs of observation wells in the closed basin area*—Continued

Well number and log	Thickness (feet)	Depth (feet)
10K23R1—(D-10):		
Sandy loam	.8	.8
Clay	2.0	2.8
Sand grading to pea gravel	2.9	5.7
10K27A1—(D-11):		
Sandy loam, some gravel	2.3	2.3
Sandy clay	1.3	3.6
Sand and small gravel	2.6	6.2
10L14D1:		
Sandy soil	1.0	1.0
Fine sand	2.0	3.0
Medium coarse gravel	1.0	4.0
10L20R1—(D-7):		
Fine sandy loam	.4	.4
Sand and gravel	1.6	2.0
Large gravel, sand	4.1	6.1
10L26A1—(D-4):		
Sand and gravel to walnut size	4.5	4.5
Sand and small gravel	2.9	7.4
10L27A1—(D-5):		
Sandy loam	1.2	1.2
Sand and small gravel	1.8	3.0
Sand and gravel	3.5	6.5
10L28A1—(D-6):		
Clayey sand and gravel	2.8	2.8
Sand and gravel	2.2	5.0
10L30A1—(D-8):		
Sandy loam	3.5	3.5
Sand	1.6	5.1
Sand and gravel	1.5	6.6
10L30D1—(D-9):		
Sandy loam	4.5	4.5
Sand	1.5	6.0
Sand and pea gravel	2.3	8.3
10L33R1:		
Sandy soil	3.0	3.0
Coarse gravel	1.8	4.8
10M2A1:		
Adobe soil, brown	2.0	2.0
Fine sand	2.1	4.1
Gravel, medium	1.8	5.9
Sandy clay, green	1.9	7.8
10M4N1—(X-6):		
Sandy loam	3.2	3.2
Sand, little gravel	2.8	6.0
Sand and gravel	3.1	9.1
10M16D1—(X-5):		
Sandy loam and small gravel	3.5	3.5
Sand and small gravel	[illegible]	[illegible]
10M18N1—(X-4):		
Sand and small gravel	2.9	2.9
Clayey sand	.9	3.8
Sand and pea gravel	4.0	7.8
10M20D1—(X-3=D-1):		
Sandy loam and small gravel	3.0	3.0
Sand and gravel	3.5	6.5
10M32A1—(X-2):		
Sand and loam and pea gravel	2.5	2.5
Sand and small gravel	1.7	4.2
Sand and pea gravel	3.7	7.9
10M32R1—(X-1=C-1):		
Sandy loam and pea gravel	5.4	5.4
Sand and clay	.6	6.0
Sand and pea gravel (occasionally)	5.5	11.5
10M33R2—(C-2):		
Sand	8.2	8.2
Clay	.3	8.5
10N31N1—(C-5):		
Fine sandy loam	1.0	1.0
Clay	.6	1.6
Sand	.5	2.1
Gravel and sand	3.1	5.2
11K4J1:		
Sandy soil	2.0	2.0
Gravel	2.7	4.7
11K6E1:		
Gravel	3.0	3.0
11K13R1:		
Sandy soil	1.5	1.5
Gravel	3.0	4.5
11K16R1:		
Sandy soil with pebbles	1.0	1.0
Coarse gravel	3.5	4.5
11K33A1:		
Gravel and soil	2.5	2.5
Gravel	2.0	4.5
11L6M1:		
Sandy soil	3.0	3.0
Sand	2.0	5.0
11L20A1:		
Sand soil	3.0	3.0
Gravel, medium to coarse	4.3	7.3
11L23D1:		
Sand and gravel	5.0	5.0
11L24A1:		
Sandy soil	1.5	1.5
Fine sand	4.3	5.8
11L30N1:		
Sandy soil	1.0	1.0
Gravel	3.0	4.0
11L33D1:		
Sandy soil	2.0	2.0
Coarse gravel	1.7	3.7
11L35D1:		
Sandy soil	2.8	2.8
Fine sand	2.0	4.8
Gravel, fine	1.5	6.3
11L36A1:		
Sandy soil	7.5	7.5
Fine sand	2.0	9.5
11M1D1—(C-4):		
Sand and some gravel	1.3	1.3
Clayey sand	1.6	2.9
Sand	1.5	4.4
Sand and small gravel	2.4	6.8
11M2D1—(C-3=Y-1):		
Sand loam, some gravel	3.6	3.6
Sand	6.0	9.6
11M6N1:		
Brown sandy soil	6.0	6.0
11M10A1—(Y-2):		
Sand loam and small gravel	3.5	
Sand and occasional pea gravel	2.5	
Sand	4.0	
11M13R1—(R-8):		
Silt and sand	2.0	2.0
Coarse sand	5.2	7.2
11M14D1—(Y-3):		
Sandy loam	3.0	3.0
Sand	7.0	10.0
11M21D1:		
Sandy soil	1.5	1.5
Fine sand	3.3	[illegible]
11M22R1—(Y-5):		
Sand and gravel (loam)	3.5	3.5
Sandy clay	1.2	4.7
Sand and gravel	2.5	7.2
11M23D1—(Y-4=R-10)		
Fine sandy loam and small gravel	2.7	2.7
Sand and gravel	.8	3.5
Sand and pea gravel	4.7	8.2
11M27R1—(Y-6):		
Fine sand loam and a little gravel	4.2	4.2
Sand and gravel	3.8	8.0
11M29R1:		
Sandy soil	1.0	1.0
Fine sand	6.4	7.4
11M34R1—(Y-7=A-1):		
Sand loam and small gravel	3.6	3.6
Sand and pea gravel	.8	4.4
Sand and gravel	4.7	9.1
11M36N1—(A-2):		
Sandy loam	2.0	2.0
Sand and pea gravel	4.0	6.0
Gravel	2.4	8.4
11M36R1—(A-3):		
Sand (sample)	6.6	6.6
Sand and gravel	.4	7.0
Sand	3.0	10.0
11N3R1—(C-9):		
Fine sand	4.0	4.0
Sand	3.8	7.8
11N4R1—(C-8):		
Fine sand	2.4	2.4
Sandy clay	1.2	3.6
Fine clayey sand, green	3.6	7.2
Coarse sand	2.8	10.0

TABLE 1.—*Logs of observation wells in the closed basin area*—Continued

Well number and log	Thickness (feet)	Depth (feet)
11N5N1—(C-6):		
Sand	1.5	1.5
Sandy clay	1.3	2.8
Sand, slightly clayey	1.4	4.2
Clay	.6	4.8
Coarse sand	2.6	7.4
11N9D2—(C-7):		
Clay	4.0	4.0
Clay, sandy	1.5	5.5
Sand	1.1	6.6
11N13D2—(C-11):		
Sand-loam, clayey	1.2	1.2
Sand clay	1.8	3.0
Sand; some clay	3.7	6.7
11N14D1—(C-10):		
Fine sand	4.0	4.0
Sand and clay	2.0	6.0
Clay	.6	6.6
Sand	3.4	10.0
11N17N1—(R-7):		
Sand	3.5	3.5
Coarse sand	3.5	7.0
11N22E1—(R-5):		
Clay	4.0	4.0
Clay, sandy	.5	4.5
11N26A1—(R-1 destroyed in 1934):		
Sand	1.5	1.5
Sandy clay	3.0	4.5
11N26B1—(R-2):		
Sandy	4.0	4.0
11N26D1—(R-3):		
Clayey sand	3.5	3.5
Sand	2.3	5.8
Limy hardpan	.5	6.3
Fine silty sand	.7	7.0
11N27B1—(R-4):		
Sand, some clay on top	3.5	3.5
Hardpan	.5	4.0
Fine sand	.5	4.5
11N33N1—(A-5):		
[illegible]nd	.9	.9
[illegible]	.9	1.8
[illegible]	3.9	5.7
[illegible]d and fine gravel	3.7	9.4
[illegible]33R1—(A-6):		
Clay loam	.5	.5
Clay	1.9	2.4
Sand and clay	.9	3.3
Sand	.7	4.0
Fine clayey sand	2.2	6.2
Sand	1.9	8.1
11N34R1—(A-7):		
Clay loam	[illegible]	[illegible]
Clay	[illegible]	[illegible]
Sand and some gravel	6.8	10.0
11N35L1—(S-1):		
Sand	4.0	4.0
11N35Q1—(S-2):		
Sand?	4.0?	4.0?
11Q7R1—(C-13):		
Sand	1.5	1.5
Sandy clay	1.5	3.0
Slightly clayey sand	4.0	7.0
Sand	3.0	10.0
11Q16H1—(C-15):		
Fine sand	3.5	3.5
Hardpan?	.1	3.6
Sand	4.0	7.6
11Q17G2—(C-14):		
Sandy clay	2.5	2.5
Sand	7.5	10.0
11Q18D1—(C-12):		
Fine sandy clay	2.8	2.8
Sand	1.0	3.8
Sandstone?	.1	3.9
Green sandy clay	3.1	7.0
Fine sand	1.1	8.1
11Q31N1—(A-9):		
Sandy clay	.5	.5
Clay	4.7	5.2
Sand clay	4.8	10.0
11Q32N1—(A-10):		
Sand, clayey	6.0	6.0
Silty sand	4.0	10.0
11Q33N1—(A-11):		
Sand	10.0	10.0
12K8A1:		
Sandy soil with pebbles	1.0	1.0
Coarse gravel	2.5	3.5
12K11A1—(B-12):		
[illegible]dy loam, small [illegible]vel	2.0	2.0
[illegible] and gravel	2.5	4.5
[illegible] and small [illegible]avel	.5	5.0
12K12A1—(B-11):		
Sandy loam	1.5	1.5
Large gravel	.4	1.9
Sand and a little gravel	2.7	4.6
Gravel and sand	2.4	7.0
12K13R1:		
Adobe	2.0	2.0
Sand, medium to coarse	1.8	3.8
12K15N1:		
Adobe soil with pebbles	2.0	2.0
Sandy adobe soil	1.0	3.0
Gravel	1.0	4.0
12L1R1—(B-5):		
Sandy loam, small gravel	4.8	4.8
Sand	2.6	7.4
Sand and gravel	1.3	8.7
12L2N1—(B-7):		
Sandy loam	2.5	2.5
Sand	2.5	5.0
Sand and fine gravel	3.0	8.0
12L2R1—(B-6):		
Sandy loam	1.0	1.0
Fine sand	2.0	3.0
Coarse sand	4.5	7.5
12L4R1—(B-8):		
Sandy loam and small gravel	1.5	1.5
Sand and pea gravel	4.2	5.7
Sand and gravel	1.9	7.6
12L5R1—(B-9):		
Sandy loam	3.5	3.5
Sand and gravel, small	3.8	7.3
Coarse sand and gravel	1.8	9.1
12L7A3—(B-10):		
Sand loam and small gravel	2.0	2.0
Sand and gravel	3.0	5.0
Sand and small gravel	2.2	7.2
12L15R1:		
Sandy soil	1.0	1.0
Fine sand	3.3	4.3
12L17R1:		
Adobe	2.0	2.0
Coarse sand	3.0	5.0
12L26N1:		
Adobe	2.0	2.0
Fine sand	[illegible]	[illegible]
Coarse sand	[illegible]	[illegible]
12L29R1:		
Sandy soil	1.0	1.0
Coarse gravel	3.0	4.0
12M3R1—(Y-8)—(B-1):		
Fine sand, occasional small gravel	5.5	5.5
Sand and gravel	1.0	6.5
Sand and some gravel	2.4	8.9
12M5N2—(B-4):		
Fine sandy loam	3.0	3.0
Sandy loam, some gravel	3.0	6.0
Sand and pea gravel	2.8	8.8
12M8A1—(B-3):		
Fine sandy loam	3.0	3.0
Sand	3.8	6.8
Sand and small gravel	1.8	8.6
12M9A2—(B-2):		
Fine sandy loam	2.5	2.5
Sandy loam	4.5	7.0
Sand and gravel	3.0	10.0
12M10R1—(Y-9):		
Sandy loam, small gravel	6.0	6.0
Sand, occasional gravel	4.0	10.0
12M13A1:		
Fine silt	5.4	5.4
12M14N1—(Y-10):		
Fine clayey sand	3.2	3.2
Sand and pea gravel	1.9	5.1
Sand and gravel	.7	5.8
Sand and small gravel	1.6	7.4
12M16N1:		
Sandy soil	4.8	4.8
Fine sand	1.9	6.7
Medium coarse gravel	2.3	9.0
12M19D1:		
Sandy silt	4.3	4.3
Medium gravel	2.0	6.3

TABLE 1.—*Logs of observation wells in the closed basin area*—Continued

Well number and log	Thickness (feet)	Depth (feet)
12M23N1—(Y-11):		
Sandy loam	1.5	1.5
Sand	4.4	5.9
Sand and small gravel	1.9	7.8
12M26N1—(Y-12):		
Sandy loam and pea gravel	3.6	3.6
Sand	5.2	8.8
12M29R1:		
Sandy clay soil	1.0	1.0
Fine sand	6.0	7.0
12M30N1:		
Adobe	4.0	4.0
Fine sand	2.5	6.5
12M35N1—(Y-13):		
Clay	2.8	2.8
Sand	2.2	5.0
Sand and occasional gravel	3.7	8.7
12N1D1—(A-8):		
Clay, some sand	6.7	6.7
Clayey sand	3.3	10.0
12N6A1—(A-4):		
Sandy loam	1.5	1.5
Sand	1.9	3.
Sand and clay	.4	3.[illegible]
Sand and fine gravel	4.4	8.[illegible]
12N23N1:		
Wind-blown soil	1.5	1.5
Fine sand, organic matter	1.9	3.4
Sand, rusty color	1.4	4.8
Sand and silt	1.5	6.3
12N31R1:		
Adobe	6.0	6.0
Fine sand	2.0	8.0
12Q6L2:		
Wind-blown sand	1.0	1.0
Sand with stiff clay	1.1	2.1
Medium fine sand	.9	3.0
Medium fine sand with iron oxide concretions	.5	3.5
Clay and sand	.5	4.0
Fine sand	4.0	(?)
12Q18D1:		
Clay	3.5	3.5
Fine sand	.5	4.0
13M6N1:		
Sandy soil	2.0	2.0
Gravel	[illegible]	[illegible]
13M11D1—(Y-14):		
Sandy clay	2.4	2.4
Fine sand, clayey	.7	3.1
Clay	.7	3.8
Sand	5.8	9.6
13M14A1—(Z-2):		
Sandy loam	1.4	1.4
Clayey sand	4.6	6.0
Sand	4.0	10.0
13M14D1—(Z-1=Y-15):		
Fine sandy loam	2.0	2.0
Clayey sand	1.2	3.2
Sand	6.8	10.0
13M15R1—(Y-16):		
Clay, loam	2.3	2.3
Sand and gravel	2.1	4.4
Sand and pea gravel	.9	5.3
13M17H1:		
Clay soil	3.0	3.0
Coarse gravel	1.8	4.8
13M22R1—(Y-17):		
Clay loam	1.8	1.8
Clay	1.8	3.6
Clayey sand	2.7	6.3
Sand	1.7	8.0
Sand and small gravel	2.0	10.0
13M35D1—(Y-18):		
Clay loam	2.0	2.0
Clay and pea gravel	2.0	4.0
Clay sand and gravel	1.5	5.5
Sand and gravel	1.5	7.0
13N2D1:		
Adobe	2.0	2.0
Very fine sand	5.0	7.0
Fine sand	1.5	8.5
13N7R1—(Z-4):		
Clay loam	1.3	1.3
Sand	2.0	3.3
Clayey sand	1.5	4.8
Clay	2.2	7.0
Sand and clay	2.0	9.0
Sand clay and small gravel	1.0	10.0
13N10R1—(Z-7):		
Sand and clay, varying degrees	6.3	6.3
Fine sand	3.9	10.2
Sandy clay	1.3	11.5
Sand	1.0	12.5
13N15D1—(Z-6):		
Clay loam	.5	.5
Clay	1.3	1.8
Sand	1.1	2.9
Clay	1.3	4.2
Sand	2.0	6.2
Sand	3.8	10.0
13N16D1—(Z-5):		
Sand and clay	3.3	3.3
Sand	3.2	6.5
Clay	.4	6.9
Sand	1.3	8.2
Sandy clay	3.8	12.0
13N18D1—(Z-3):		
Clay loam	1.5	1.5
Clay	1.9	3.4
Clayey sand	.6	4.0
Streaked clay and sand	[illegible]	[illegible]
Sand	2.8	9.0
13Q20N2:		
Wind-blown sand	.5	.5
Brown clay, hardly any sand	.7	1.2
Fine loose sand	1.5	2.7
Medium sand with clay matrix	2.8	5.5
14N9R1:		
Sand and silt	2.5	2.5
Clay, some sand	1.9	4.4
Gravel, medium to coarse	1.4	5.8

In order to study the character and distribution of the material of the shallow valley fill in the closed basin area, table 3 has been prepared, separating the material reported in the observation-well logs into four groups, as follows: (1) Clay or loam, (2) fine sand, (3) medium or coarse sand, and (4) gravel. This grouping represents only in a general way the distribution of the material, as the classification of the material depended largely upon the individual boring the well. However, it is a rough index of the material composing the upper part of the shallow valley fill. In the table the material of the groups is expressed as a percentage of the combined length of all the observation wells for which logs were available in a township. No computations were made where the material was represented by less than three well logs in a township. A final grouping was made of the area as a whole, using all available well logs. In this final summation, 186 well logs were used, representing 1,446 feet of hole.

None of the observation wells penetrated the entire thickness of the shallow valley fill but only 1 to 2 feet below the water table, usually to depths of only 10 feet or less. Thus the figures represent only the distribution of the material down to and a little below the water table.

The table shows quite clearly the preponderance of coarse material on the Rio Grande alluvial fan and along the edge of the valley floor. Similarly, it shows the large amount of fine material, as clay or loam and fine sand, in the central part of the valley. This is especially true in the trough of the valley, as, for example, T. 39 N., R. 11 E., lying immediately south of San Luis Lake. In this township 80.5 percent of the alluvium was classified as fine material—that is, clay, loam, or fine sand. In T. 39 N., R. 8 E., on the Rio Grande alluvial fan and 18 miles west of the township just described, only 39.0 percent of the material is fine, whereas 61.0 is coarse. For the area as a whole there is more fine material than coarse, the ratio being 54.5 percent fine and 45.5 percent coarse. This is to be expected, however, as the alluvial fans occupy considerably less than half of the valley floor.

Laboratory analysis of the materials.—In order to form some concrete conception of the physical and water-bearing properties of the material in the shallow valley fill. 22 samples were analyzed in the hydrologic laboratory of the Geological Survey, at Washington, D. C. These samples were taken from 12 wells located on the valley floor and distributed over the closed basin area. The results of the analysis, together with the field classification of the material are given in tables 4 and 5.

TABLE 2.—*Logs of observation wells in the Carmel-Bowen or central-southwest area*

[For locations of the wells, see the map, pl. 5]

Well number and log	Thickness (feet)	Depth (feet)
14K13N1:		
Brown soil	2.0	2.0
Medium to coarse gravel	2.5	4.5
14K15M1:		
Adobe brown	8.5	8.5
Adobe with scattered pebbles	.5	9.0
14K15R1:		
Adobe brown	1.5	1.5
Coarse pebbly gravel	2.5	4.0
Fine sandy clay	3.4	7.4
14K17H1:		
Adobe soil, gray	2.6	2.6
Coarse pebbly gravel	.4	3.0
14K18J1:		
Brown soil	1.5	1.5
Coarse pebbly gravel	1.5	3.0
14K18M1:		
Brown soil	1.7	1.7
Coarse pebbly gravel	1.9	3.6
14K21H1:		
Brown soil	1.5	1.5
Coarse pebbly gravel	1.9	3.4
14K21M1:		
Brown soil	1.5	1.5
Coarse gravel with many large scattered pebbles	1.9	3.4
14K23M1:		
Soil	1.5	1.5
Gravel, large pebbles	3.5	5.0

TABLE 2.—*Logs of observation wells in the closed basin area*—Continued

Well number and log	Thickness (feet)	Depth (feet)
14K24P1:		
Brown soil	2.0	2.0
Sandy clay	1.3	3.3
Gravel with coarse pebbles	1.0	4.3
14K25N1:		
Brown soil	2.4	2.4
Coarse gravel of boulders and pebbles	2.5	4.9
14K27R1:		
Sandy soil	2.6	2.6
Coarse gravel with scattered pebbles	1.9	4.5
14K28H1:		
Brown soil	1.4	1.4
Gravel with pebbles and small boulders	2.4	3.8
14K33A1:		
Brown soil	4.5	4.5
Coarse gravel with large pebbles	1.7	6.2
14L11R1:		
Adobe	2.0	2.0
Fine sand	1.0	3.0
Fine sand	2.5	5.5
14L15D1:		
Sandy soil	1.5	1.5
Fine gravel	7.0	8.5
Clay	2.0	10.5
14L18A1:		
Adobe soil	3.0	3.0
Coarse sand	1.7	4.7
Clay and sand	2.2	6.9
14L22R1:		
Adobe	3.0	3.0
Fine sand	1.5	4.5
14L28D1:		
Adobe	3.0	3.0
Fine sand	1.8	4.8
Sandy clay	1.3	6.1
14L31P1:		
Brown soil	1.5	1.5
Fine sandy soil	3.7	5.2
Gravel, medium to coarse	.4	5.6
14L34N1:		
Sandy soil	2.5	2.5
Gravel	1.5	4.0
14L35R1:		
Sand soil	2.0	2.0
Gravel	1.5	3.5
14M7R1:		
Clay soil	1.0	1.0
Sandy soil	2.0	3.0
Fine sand	4.0	7.0
14M16A1:		
Sandy soil	5.5	5.5
14M19N1:		
Sandy soil	3.0	3.0
Fine sand	2.0	5.0
Clay	3.0	8.0
14M21N1:		
Adobe	2.0	2.0
Fine gravel	1.0	3.0
14M24N1:		
Loam	3.0	3.0
Very fine sand	2.0	5.0
14M31R1:		
Adobe	3.0	3.0
Fine sand	1.5	4.5
Medium coarse sand	2.5	7.0
14N31M1:		
Adobe	1.5	1.5
Fine sand	1.0	2.5
Sand	3.0	5.5
15K1C1:		
Brown sandy soil	5.0	5.0
Gravel, medium to coarse	.4	5.4
15K1P1:		
Brown soil with scattered pebbles and boulders	2.5	2.5
Clay with boulders	2.5	5.0
Coarse gravel	.3	5.3
15K1P2:		
Brown soil with large scattered pebbles	4.0	4.0
Sticky clay with pebbles and cobbles	2.0	6.0
Gravel, coarse	2.0	8.0
15K3B1:		
Brown soil with large pebbles and small boulders	5.0	5.0
15K11D1:		
Brown soil with large scattered pebbles and small boulders	4.1	4.1
15K14A1:		
Light-brown clay with many scattered pebbles, cobblestones, and boulders	5.2	5.2
15L5N1:		
Brown adobe with scattered pebbles	1.6	1.6
Gravel, medium to coarse	.5	2.1
15L7C1:		
Loam, brown	3.2	3.2
Sandy adobe with scattered pebbles	1.9	5.1
15L7N1:		
Coarse sand and gravel	23.0	23.0
15L13A1:		
Adobe	2.0	2.0
Sand	.5	2.5
15L14D1:		
Adobe	2.0	2.0
Gravel	1.5	3.5
15L16D1:		
Brown soil	3.0	3.0
Gravel, medium to coarse	1.4	4.4
15L17D1:		
Brown soil	.9	.9
Coarse pebbles and small boulders	4.3	5.2
Gravel and boulders	1.8	7.0
15L19B1:		
Brown adobe soil with large pebbles and boulders scattered throughout	2.8	--
Gravel with large pebbles and cobbles	1.2	
15L25D1:		
Sandy adobe	3.8	
Gravel, medium to coarse	.5	4.3
15L27D1:		
Sandy adobe	(?)	(?)
Gravel, medium to coarse	(?)	4.7
15L30G1:		
Soil, brown	1.4	1.4
Coarse pebbly gravel	3.5	[illegible]
15L33R1:		
Brown soil and adobe	4.8	4.8
Sand clay, coarse in lower part	2.0	6.8
Gravel, medium to coarse	1.6	8.4
15L35R1:		
Brown adobe soil	5.0	5.0
Brown sandy soil (no gravel)	3.7	8.7
15M4R1:		
Adobe	3.0	3.0
Fine sand	2.0	5.0
Gravel	1.5	6.5
Sandy clay	.5	7.0
15M16R1:		
Adobe (no gravel)	5.4	5.4
15M28R1:		
Adobe, black	5.5	5.5
15M29M1:		
Adobe	4.0	4.0
15M36R1:		
Sandy soil	1.0	1.0
Gravel	2.0	3.0
15N7N1:		
Adobe	5.0	5.0
Fine sand	.7	5.7
15N27C1:		
Adobe, black	3.0	3.0
Coarse sand	1.5	4.5
16L5D1:		
Adobe soil, brown	3.9	3.9
Fine sand	2.6	6.5
Gravel, medium to coarse	.6	7.1
16M6H1:		
Adobe	6.5	6.5
16M9A1:		
Adobe	5.0	--
Fine sand	1.5	

TABLE 3.—*Composition of material in the shallow valley fill of the closed basin area, based on percentage of total footage in logs of observation wells in the several townships*

Coordinate number	Township and range	Number of well logs	Clay or loam	Sand: Fine	Sand: Medium or coarse	Gravel
6L	T. 44 N., R. 9 E.	5	55.5	32.5	2.5	9.5
6M	T. 44 N., R. 10 E.	8	55.0	20.0	12.0	13.0
7K	T. 43 N., R. 8 E.	11	47.0	24.0	11.0	18.0
7L	T. 43 N., R. 9 E.	7	30.0	13.0	34.0	23.0
7M	T. 43 N., R. 10 E.	11	33.5	33.5	32.0	1.0
9J	T. 42 N., R. 7 E.	4	15.5	6.5		78.0
9K	T. 42 N., R. 8 E.	3	31.0	41.0	28.0	
9L	T. 42 N., R. 9 E.	4	47.0	36.0	8.5	8.5
9M	T. 42 N., R. 10 E.	9	23.0	38.0	26.0	13.0
9N	T. 1 S., R. 1 W.[1]	3	36.0	64.0		
10K	T. 41 N., R. 8 E.	8	36.5	32.0	11.0	20.5
10L	T. 41 N., R. 9 E.	8	22.0	16.0	29.0	33.0
10M	T. 41 N., R. 10 E.	8	19.0	14.5	40.5	26.0
11K	T. 40 N., R. 8 E.	5	16.5	9.5		74.0
11L	T. 40 N., R. 9 E.	8	23.5	39.0	9.5	28.0
11M	T. 40 N., R. 10 E.	14	15.5	24.5	46.5	13.5
11N	T. 40 N., R. 11 E.	16	26.0	28.0	41.0	5.0
11Q	T. 40 N., R. 12 E.	7	25.5	26.5	48.0	
12K	T. 39 N., R. 8 E.	5	28.0	11.0	20.0	41.0
12L	T. 39 N., R. 9 E.	10	20.5	20.5	38.5	20.5
12M	T. 39 N., R. 10 E.	14	29.0	31.5	27.0	12.5
12N	T. 39 N., R. 11 E.	4	43.0	37.5	12.5	7.0
13M	T. 38 N., R. 10 E.	8	29.0	20.0	34.0	17.0
13N	T. 38 N., R. 11 E.	6	34.5	45.5	19.0	1.0
	Total area	186	28.5	26.0	28.5	17.0

[1] Baca Grant.

Permeability of the materials.—The hydraulic permeability of a rock is its capacity for transmitting water under pressure.[10] A measure of this capacity, as used by the United States Geological Survey, is called the "coefficient of permeability", which is defined as the rate of flow, in gallons a day, through a square foot of cross section under a hydraulic gradient of 100 percent, at a temperature of 60° F. The coefficient of permeability can also be defined as the quantity of water, in gallons a day, that is conducted laterally through each mile of the water-bearing bed under investigation (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot per mile of hydraulic gradient.[11]

The coefficients of permeability of water-bearing materials range widely. Materials tested in the hydrologic laboratory of the United States Geological Survey at Washington, D. C. were found to have coefficients of permeability ranging from 0.001 to 90,000[12]—that is, the greatest permeability was 90,000,000 times the least. As is shown in the preceding tables, the material in the shallow valley fill ranges of the San Luis Valley widely from silt to coarse gravel, and there is likewise a wide range in the permeability of the material.

The transmissibility of an aquifer, as defined by Theis,[13] is the average coefficient of permeability, multiplied by the thickness of the aquifer.

In addition to the laboratory determinations shown in the table, the coefficient of permeability was determined in one locality in the field by methods developed by Thiem[14] and by Theis.[15]

The Thiem method for determining permeability of water-bearing materials consists of pumping a well and observing the decline of the water table in nearby observation wells. Thiem's formula for computing the

[10] Meinzer, O. E., The occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, p. ?, 1923.

[11] Stearns, N. D., Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596, p. 148, 1927.

[12] Meinzer, O. E., Movements of ground water: Am. Assoc. Petroleum Geologists Bull., vol. 20, no. 6, p. 710, 1936.

[13] Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys Union Trans., p. 520, 1935.

[14] Thiem, G., Hydrologische Methoden, Leipzig, 1906.

[15] Op. cit., p. 522.

TABLE 4.—*Physical properties of material from the shallow valley fill in the closed basin area, San Luis Valley, Colorado*

Well no.	Depth (feet)	Field classification of material	Apparent specific gravity	Porosity (percent)	Moisture equivalent (percent by volume)	Specific[1] retention (percent by volume)	Specific yield (porosity minus specific retention by volume)	Permeability
9M2C1	0-4.5	Clay, slightly sandy	1.39	48.7	17.5	16.4	32.3	30
	4.5-5.3	Sand	1.44	47.0	10.6	10.8	36.2	90
10K12A1	0-3.0	Sandy loam	1.44	46.5	15.3	14.7	31.8	20
	3.0-4.5	Sand and gravel	1.55	40.4	8.5	9.0	31.4	650
10M2A1	0-2.2	Clay, slightly sandy	1.31	50.9	43.7	41.6	9.3	(²)
	2.2-5.0	Coarse sand	1.39	40.2	36.9	32.4	7.8	(²)
	5.0-5.8	Very coarse sand	1.52	41.9	6.6	7.3	34.6	900
11L23D1	3.0	Coarse sand and gravel	1.87	(³)	(³)			1,500
11M1D1	0-5.0	Sandy gravel	1.65	36.9	12.2	12.4	24.5	20
11M36R1	5.0-5.7	Sand, some gravel	1.74	34.3	9.4	10.1	24.2	85
11N3R1	0-2.5	Sand	1.37	48.0	12.3	12.2	35.8	180
	2.5-4.0	Adobe, slightly sandy	1.43	47.8	91.2			(²)
	4.0	Sand, little clay	1.49	43.7	18.0	17.0	26.7	80
12K14A1	4.0-4.5	Sand and gravel	1.75	(³)	(³)			600
12N23N1	3.4-4.8	Fine sand	1.38	47.9	18.2	16.8	31.1	25
	4.8-6.6	Sand and silt	1.58	39.3	9.6	10.1	29.2	45
12Q6L2	1.0-2.1	Sand and clay	1.20	55.3	25.7	22.5	32.8	(²)
	2.1-3.0	Fine sand	1.43	46.8	27.7	24.3	22.5	65
13M14D1	2.2-2.8	Adobe	1.25	53.4	25.8	22.6	30.8	(²)
	2.8-4.5	Sand	1.40	46.6	9.7	9.9	36.7	60
13Q20N2	1.5-2.2	Fine sand	1.35	48.8	26.9	23.6	25.2	(²)
	2.7-3.5	Sand and clay	1.45	46.3	23.2	20.9	25.4	1

[1] Based on relation of moisture equivalent to specific retention after 400 days' drainage. Piper, A. M., Thomas, H. E., and Robinson, T. W. Ground-water hydrology of Mokelumne area, California (U. S. Geol. Survey typewritten report, Oct. 30, 1935).
[2] Less than 1.
[3] Too coarse to determine porosity and moisture equivalent.

coefficient of permeability as expressed by Wenzel [16] is written in the following form:

$$P=\frac{527.7q \log_{10} (a_1/a)}{m\ (s-s_1)}$$

in which P=the coefficient of permeability;
q=rate of pumping, in gallons a minute;
a and a_1=distances of two observation wells from the pumping well, in feet;
m=average vertical thickness (at a_1 and a) of the saturated part of the water-bearing bed, in feet;
s and s_1=draw-downs at the two observation wells, in feet.

A pumping test was made near Monte Vista, Colo., during the summer of 1936, on an irrigation well owned by G. E. Oxley, about 6⅝ miles northeast of Monte Vista, in the NW¼ sec. 13, T. 39 N., R. 8 E. This well, no. 12K13D1, is located on the south side and well toward the base of the Rio Grande alluvial fan. There were four other irrigation wells within a mile of the pumped well, but none of them were operated during the period of the test or for several days before the test was begun.

The pumped well is about half a mile south of an east-west irrigation canal (the Prairie ditch). As water was flowing in the canal for several months preceding and also during the period of the test it is believed that any seepage from the canal did not affect conditions during the test. The slope of the water table was, from west to east—that is, from well 12K14A1 to well 12K13D3.

The pumped well was drilled in 1934 to a depth of 54 feet and is 20 inches in diameter. Concrete to a depth of 2 feet had been placed as a seal in the bottom of the hole, thus reducing the effective depth to 52 feet. The measured depth at the time of the test was 49 feet, indicating that 3 feet of the hole had filled in. The well was cased with 17 joints of galvanized-iron casing, perforated from 19 feet to the bottom, and gravel packed on the outside from top to bottom. Mr. Oxley reported that in drilling the well, coarse sand and gravel were penetrated to a depth of 50 feet, where clay was struck. While sinking the observation wells, it was noted that the sand and gravel became coarser with depth.

Four observation wells were sunk in the vicinity of the pumped well, two on an east-west line, and two on a north-south line through the well and on opposite sides. All the observation wells were 1 inch in diameter and three of them were fitted with 24-inch screen drive points. These wells were driven into the saturated sand and gravel to such depth that the water table during pumping would not drop below the bottoms of the wells. Each of the observation wells was developed by pumping with a pitcher pump until the water discharged was clear, indicating that the ground wat[er] had free access to the well and that the water level in t[he] well showed the level of the water table. Definite points were established at each well from which measurements of the depth to the water level could be made. In order to determine the relative differences in altitude of the measuring point of the wells, instrumental levels were run from an assumed datum of 100 feet at the measuring point of the pumped well to all of the observation wells.

[16] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 679-A, p. 10, 1935.

TABLE 5.—*Mechanical analysis of material from the shallo[w] valley fill in the closed basin area, San Luis Valley, Colo.*

[Size in millimeters; percent by weight]

Well no.	Depth (feet)	Larger than 1.0	1.0–0.50	0.50–0.25	0.25–0.125	0.125–0.062	Less than 0.062
9M2C1	0–4.5	....	2.4	21.3	42.4	24.1	9.5
	4.5–5.3	0.4	2.9	14.7	44.3	29.1	9.2
10K12A1	0–3.0	35.5	26.1	25.1	7.6	2.2	3.1
	3.0–4.5	53.0	25.4	13.2	5.9	2.0	.9
10M2A1	0–2.2	5.6	23.0	26.2	19.0	13.0	13.2
	2.2–5.0	10.9	23.3	32.3	18.9	10.6	4.8
	5.0–5.8	28.5	45.4	15.9	7.2	2.9	.9
11L23D1	3.0	75.7	9.0	9.5	4.6	.8	.4
11M1D1	0–5.0	20.2	17.9	28.3	17.9	9.3	6.6
11M36R1	5.0–5.7	34.5	16.3	25.0	14.2	6.8	3.3
11N3R1	0–2.5	1.1	3.8	40.1	40.6	10.0	5.0
	2.5–4.0	3.4	8.8	28.2	29.6	14.2	15.4
	4.0	7.6	19.6	25.9	24.1	14.7	7.6
12K14A1	4.0–4.5	60.7	13.6	18.3	6.2	.8	.5
12N23N1	3.4–4.8	2.5	20.6	30.8	24.5	17.6	4.3
	4.8–6.6	3.2	17.2	32.8	21.2	19.6	6.3
12Q6L2	1.0–2.1	7.3	14.2	30.0	31.7	13.3	4.5
	2.1–3.0	2.8	3.2	23.2	36.4	26.6	6.8
13M14D1	2.2–2.8	8.8	27.0	27.8	17.0	8.0	12.2
	2.8–4.5	6.1	26.2	49.4	15.2	1.9	1.3
13Q20N2	1.6–2.2	7.5	11.6	14.0	29.7	25.6	11.4
	2.7–5.5	10.1	15.8	27.7	24.9	15.4	6.6

TABLE 6.—*Number, depth, altitude, and location of wells used in pumping test*

Well no.	Depth of well below measuring point (feet)	Distance of measuring point above (+) or below (−) land surface (feet)	Altitude of measuring point; assumed datum 100 feet at measuring point of pumped well (feet)	Distance in feet and direction from pumped well
12K13D1	49.3	+0.3	100.00	
12K13D2	15.2	+1.3	101.00	100 north.
12K13D3	8.9	+.1	99.80	140 east.
12K13D4	13.5	+.4	100.06	40 south.
12K14A1	11.9	−.2	99.94	60 west.

The test was started at 9:27 on the morning of September 3. During the 3 days preceding the test, measurements were made of depth to water in all of the wells in order to determine the static level of th[e] water table, and a round of measurements was mad[e] few minutes before the pump started. All measur[e]ments were made with a steel tape, graduated to

TABLE 7.—*Location and depth to water levels, in feet, below measuring points, in observation wells used in the pumping tests*

12K13D1 Pumped well		12K13D2 100 feet north of pumped well		12K13D3 140 feet east of pumped well		12K13D4 40 feet south of pumped well		12K14A1 60 feet west of pumped well	
Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)
AUGUST 31									
	4.81		5.81		4.76		4.85		4.64
SEPTEMBER 1									
	4.78		5.77		4.72		4.75	11:32 a. m.	4.59
	4.78		5.77		4.71		4.79	3:34 p. m.	4.59
SEPTEMBER 2									
11:12 a. m.	4.78	11:07 a. m.	5.77	11:09 a. m.	4.72	11:14 a. m.	4.80	11:05 a. m.	4.60
SEPTEMBER 3									
8:02 a. m.	4.79	7:58 a. m.	5.77	8:05 a. m.	4.81	8:00 a. m.	4.13	7:53 a. m.	4.61
9:27 a. m.	(1)	10:02 a. m.	6.34	10:04 a. m.	5.23	10:05 a. m.	5.86	9:59 a. m.	5.03
9:40 a. m.	17.84	10:26 a. m.	6.44	10:27 a. m.	5.35	10:29 a. m.	6.06	10:24 a. m.	5.16
9:42 a. m.	17.82	10:49 a. m.	6.53	10:50 a. m.	5.46	10:52 a. m.	6.22	10:47 a. m.	5.28
9:43 a. m.	17.86	11:12 a. m.	6.59	11:15 a. m.	5.56	11:15 a. m.	6.34	11:10 a. m.	5.39
10:08 a. m.	17.95	11:34 a. m.	6.66	11:35 a. m.	5.62	11:37 a. m.	6.47	11:31 a. m.	5.48
10:32 a. m.	17.93	12:00 m.	6.74	12:01 p. m.	5.70	12:03 p. m.	6.58	11:58 a. m.	5.59
10:54 a. m.	18.09	12:31 p. m.	6.82	12:33 p. m.	5.82	12:34 p. m.	6.69	12:29 p. m.	5.69
11:16 a. m.	18.15	1:09 p. m.	6.94	1:10 p. m.	5.91	1:12 p. m.	6.80	1:07 p. m.	5.81
11:19 a. m.	18.26	1:35 p. m.	6.97	1:36 p. m.	5.98	1:38 p. m.	6.89	1:33 p. m.	5.85
12:05 p. m.	18.27	2:25 p. m.	7.09	2:26 p. m.	6.09	2:28 p. m.	7.02	2:22 p. m.	5.97
12:36 p. m.	18.23	3:03 p. m.	7.15	3:05 p. m.	6.16	3:06 p. m.	7.09	3:01 p. m.	6.07
1:14 p. m.	18.45	3:36 p. m.	7.21	3:38 p. m.	6.22	3:39 p. m.	7.16	3:34 p. m.	6.13
1:41 p. m.	18.41	4:19 p. m.	7.27	4:21 p. m.	6.28	4:22 p. m.	7.23	4:17 p. m.	6.20
2:32 p. m.	18.63	5:01 p. m.	7.33	5:03 p. m.	6.32	5:05 p. m.	7.30	5:00 p. m.	6.28
3:09 p. m.	18.59	5:33 p. m.	7.36	5:34 p. m.	6.37	5:36 p. m.	7.34	5:31 p. m.	6.32
3:46 p. m.	18.78	6:03 p. m.	7.41	6:05 p. m.	6.42	6:07 p. m.	7.36	6:01 p. m.	6.36
[illegible] p. m.	18.7								
[illegible] m.	18.77								
[illegible] m.	18.7								
[illegible] m.	18.79								
[illegible] p. m.	18.76								
SEPTEMBER 4									
8:20 a. m.	19.52	8:02 a. m.	7.77	8:05 a. m.	6.71	8:07 a. m.	7.67	8:00 a. m.	6.75
9:37 a. m.	19.31	8:54 a. m.	7.80	9:56 a. m.	6.78	8:59 a. m.	7.77	8:53 a. m.	[illegible]
9:41 a. m.	19.15	9:56 a. m.	[illegible]	9:58 a. m.	[illegible]	10:00 a. m.	[illegible]	9:52 a. m.	[illegible]
[illegible] a. m.	19.32	10:54 a. m.	7.93	10:56 a. m.	6.88	10:58 a. m.	7.93	10:52 a. m.	6.97
10:03 a. m.	19.33	11:55 a. m.	7.96	11:57 a. m.	6.91	11:59 a. m.	7.97	11:53 a. m.	7.01
11:01 a. m.	19.44	12:55 p. m.	8.00	12:57 p. m.	6.94	12:59 p. m.	8.01	12:52 p. m.	7.05
12:02 p. m.	19.49	1:53 p. m.	8.02	1:55 p. m.	6.98	1:57 p. m.	8.04	1:51 p. m.	7.08
1:01 p. m.	19.48	2:54 p. m.	8.07	2:56 p. m.	7.01	2:58 p. m.	8.07	2:52 p. m.	7.13
2:00 p. m.	19.53	3:54 p. m.	8.08	3:56 p. m.	7.03	3:57 p. m.	8.10	3:52 p. m.	7.15
2:59 p. m.	19.58	4:53 p. m.	8.12	4:55 p. m.	7.06	4:57 p. m.	8.13	4:51 p. m.	7.19
4:00 p. m.	19.61	5:54 p. m.	8.14	5:56 p. m.	7.08	5:58 p. m.	8.14	5:52 p. m.	7.21
4:59 p. m.	19.58								
6:01 p. m.	19.31								
SEPTEMBER 5									
6:24 a. m.	19.60	6:16 a. m.	8.29	6:19 a. m.	7.20	6:21 a. m.	8.24	6:13 a. m.	7.38
6:51 a. m.	19.59	6:45 a. m.	8.30	6:47 a. m.	7.22	6:49 a. m.	8.25	6:43 a. m.	7.39
6:59 a. m.	(2)	7:33 a. m.	7.75	7:34 a. m.	6.73	7:37 a. m.	7.47	7:32 a. m.	7.04
7:00 a. m.	8.56	8:03 a. m.	7.61	8:04 a. m.	6.56	8:07 a. m.	7.23	8:01 a. m.	6.90
7:01 a. m.	7.24								
7:02 a. m.	7.03								
7:03 a. m.	6.99								
7:04 a. m.	6.97								
7:06 a. m.	6.94								
7:07 a. m.	6.90								
7:08 a. m.	6.87								
7:09 a. m.	6.86								
7:10 a. m.	6.84								
7:15 a. m.	6.78								
7:20 a. m.	6.71								
7:25 a. m.	6.67								
7:30 a. m.	6.64								
7:35 a. m.	6.60								
7:40 a. m.	6.57								
7:45 a. m.	6.54								
7:50 a. m.	6.51								
7:55 a. m.	6.48								
8:00 a. m.	6.46								
[illegible] a. m.	6.44								
[illegible] m.	6.42								
[illegible]	6.40								
[illegible] m.	6.38								
[illegible] m.	6.36								

[1] Pump started.

[2] Pump stopped.

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TABLE 7.—*Location and depth to water levels, in feet, below measuring points, in observation wells used in the pumping tests*—Contin-

SEPTEMBER 5—Continued

12K13D1 Pumped well		12K13D2 100 feet north of pumped well		12K13D3 140 feet east of pumped well		12K13D4 40 feet south of pumped well		12K14A1 60 feet west of pumped well	
Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)	Time	Depth to water (feet)
8:30 a. m.	6.34	8:34 a. m.	7.50	8:37 a. m.	6.38	8:38 a. m.	7.02	8:32 a. m.	6.76
8:35 a. m.	6.32	9:04 a. m.	7.40	9:07 a. m.	6.27	9:06 a. m.	6.82	9:03 a. m.	6.62
8:40 a. m.	6.30	9:35 a. m.	7.27	9:42 a. m.	6.15	9:46 a. m.	6.59	9:33 a. m.	6.53
8:45 a. m.	6.28	10:06 a. m.	7.24	10:09 a. m.	6.09	10:17 a. m.	6.47	10:03 a. m.	6.42
8:50 a. m.	6.26	10:37 a. m.	7.17	10:39 a. m.	6.01	10:43 a. m.	6.36	10:34 a. m.	6.32
8:55 a. m.	6.24	11:06 a. m.	7.11	11:08 a. m.	5.94	11:12 a. m.	6.26	11:03 a. m.	6.26
9:00 a. m.	6.23	11:36 a. m.	7.04	11:39 a. m.	5.89	11:41 a. m.	6.17	11:33 a. m.	6.17
9:05 a. m.	6.22	12:05 p. m.	6.99	12:08 p. m.	5.84	12:10 p. m.	6.08	12:01 p. m.	6.09
9:10 a. m.	6.20	1:07 p. m.	6.87	1:09 p. m.	5.77	1:11 p. m.	5.96	1:04 p. m.	5.94
9:15 a. m.	6.19	2:04 p. m.	6.80		5.69		5.82	2:01 p. m.	5.84
9:20 a. m.	6.18	3:07 p. m.	6.74	3:10 p. m.	5.62	3:13 p. m.	5.72	3:04 p. m.	5.73
9:25 a. m.	6.16	4:07 p. m.	6.67	4:10 p. m.	5.57	4:12 p. m.	5.64	4:04 p. m.	5.61
9:30 a. m.	6.15	5:03 p. m.	6.64	5:06 p. m.	5.51	5:09 p. m.	5.61	5:01 p. m.	5.58
9:35 a. m.	6.14								
9:40 a. m.	6.12								
9:45 a. m.	6.11								
9:50 a. m.	6.10								
9:55 a. m.	6.08								
10:00 a. m.	6.07								
10:10 a. m.	6.06								
10:20 a. m.	6.04								
10:30 a. m.	6.02								
10:40 a. m.	6.00								
10:50 a. m.	5.98								
11:00 a. m.	5.96								
11:10 a. m.	5.94								
11:20 a. m.	5.93								
11:30 a. m.	5.92								
11:40 a. m.	5.90								
11:50 a. m.	5.88								
12:00 m.	5.87								
12:15 p. m.	5.85								
12:30 p. m.	5.83								
12:45 p. m.	5.81								
1:00 p. m.	5.80								
1:15 p. m.	5.78								
1:30 p. m.	5.76								
1:45 p. m.	5.74								
2:00 p. m.	5.73								
2:15 p. m.	5.72								
2:30 p. m.	5.69								
2:45 p. m.	5.68								
3:00 p. m.	5.66								
3:15 p. m.	5.65								
3:30 p. m.	5.64								
3:45 p. m.	5.63								
4:00 p. m.	5.62								
4:15 p. m.	5.61								
4:30 p. m.	5.60								
4:45 p. m.	5.58								
5:00 p. m.	5.57								
5:15 p. m.	5.56								
7:01 p. m.	5.49								
8:10 p. m.	5.47								
SEPTEMBER 6									
6:00 a. m.	5.25			6:09 a. m.	5.19	6:06 a. m.	5.18	6:04 a. m.	5.12
7:14 a. m.	5.23			7:01 a. m.	5.20	7:11 a. m.	5.17	7:08 a. m.	5.10
8:11 a. m.	5.25			8:19 a. m.	5.19	8:14 a. m.	5.15	8:08 a. m.	5.08

hundredths of a foot. The pump was operated continuously for a period of 45.5 hours, with the exception of a 45-minute stop between 4:15 and 5 a. m. on September 4, pumping at an average rate of 900 gallons a minute. A 1-foot Cipolletti weir and a hook gage, located about 150 feet south of the well, were used to measure the rate of discharge from the pump. The water pumped was conducted through a small irrigation ditch to a potato field about half a mile south of the well. Measurements of the depth to water in all the wells were made during the daylight hours of the test, but none were made at night. After the completion of the pumping period, measurements were continued for about 25 hours, so that the recovery of the water table could be determined. The measurements of depth to water made during the test are given in table 7.

Thiem's equation requires the draw-down at 2 points on the cone of depression for computing the coefficient of permeability. During the early part of a pumping period, before the cone of depression has developed extensively, the difference in draw-down in two observation wells at different distances from the pumped well will change because considerable water is still being removed from storage in the vicinity of the wells. As the pumping progresses, the cone of depression develo- and approaches an equilibrium condition with result that the difference in draw-down approaches constant value. Thus, the closest value to the actual coefficient of permeability will be obtained by using draw-downs at the end of the pumping period. As none of the observation wells penetrated to the bottom of the aquifer, the vertical thickness of the saturated part of the water-bearing bed is known only from reports. This is taken as 45.5 feet.

The coefficients of permeability computed from the test ranged rather widely. A study of the test data gives some clues with which to explain this difference in the coefficients. The inconsistent draw-down in the observation wells may be due largely to the heterogeneous character of the water-bearing material, which may not have allowed changes in water pressure to be freely transmitted to the observation wells. Lack of data as to the average thickness of the saturated part of the water-bearing bed at the observation wells also affects the computations of permeability.

Another factor influencing the computations of permeability was the stopping of the pump for about 45 minutes on the morning of September 4. Wenzel [17] found in his second pumping test in Nebraska, that the shape of the cone of depression altered considerably once the pump was stopped. Also, it was found that when pumping was started again, the cone of depression did not regain the form it possessed before pumping stopped, at least during the period of observations.

After a critical study of the data it was concluded that the coefficient of permeability of the material was between 3,000 and 5,000. The coefficient of permeability determined in the laboratory for a sample taken just above the water table at a depth of 4.0 to 4.5 feet at the observation well 12K14A1 (table 4) is 600. As the sand and gravel become coarser with depth, this sample is not representative of the saturated part of the aquifer.

Upon completion of the period of pumping, measurements of depth to water were made at intervals for a period of about 25 hours in the four observation wells and in the pumped well in order to observe the rate of recovery and to apply thereto the equation developed by Theis. (See table 7.) This equation is written in the following form:

$$T=\frac{264F}{V'}\log_{10}\frac{t}{t'}$$

in which T=the coefficient of transmissibility.

F=rate of pumping in gallons a minute.

V'=residual draw-down—that is, the distance the water level stands below its equilibrium position, in feet.

t=time since pumping started.

t'=time since pumping stopped.

[17] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 679-A, pp. 33-34, 1936.

It will be noted from figure 53, that all of the measurements from about 10:30 a. m., on September 5, 3.5 hours after pumping stopped, to the last measurement 25 hours after pumping stopped, give consistent results, but the measurements prior to 10:30 a. m. do not. Using only the results obtained after 10:30, the coefficient of transmissibility is 216,000; and with a thickness of water-bearing material of 45.5 feet the coefficient of permeability is computed to be about 4,800.

Specific yield of the materials.—The specific yield of a rock or soil has been defined as "the ratio of (1) the volume of water which, after being saturated, it will yield by gravity, to (2) its own volume. This ratio is stated as a percentage and may be expressed by the formula $Y=100\left(\frac{y}{v}\right)$, in which Y is the specific yield, y is the volume of water in the rock or soil, and V is the volume of the rock or soil." [18] The specific yield of a rock or soil is difficult to determine experimentally, requiring a large expenditure of time and equipment. No attempt was made during the present investigation to determine directly the specific yield of the water-bearing material in the valley. It is possible, however, to arrive at a value for the specific yield indirectly, based on its relation to other physical properties of water-bearing material.

The specific yield is equal to the porosity minus the specific retention. If, as is sometimes done, the moisture equivalent is used roughly for specific retention, the difference between porosity and moisture equivalent is an approximate measure of the specific yield. Both porosity and moisture equivalent may be determined in the laboratory with relative ease. Recently Piper [19] has shown by experiments covering periods of drainage up to 400 days, the relation between moisture equivalent and specific retention. In table 4, the specific retention is shown as computed from the curve developed by Piper, and the specific yield is shown as the difference between the porosity and the specific retention. The specific yield of 19 samples thus determined ranged from 7.8 to 36.7 percent and averaged 28.9 percent.

Yield of water to wells.—As has already been pointed out, the materials of the shallow fill of San Luis Valley range widely from clays to coarse gravel. As a result, the yield of wells that penetrate the sediments also ranges widely. Coarse sand and gravel yield water readily, whereas fine sands, silt, and clay yield water slowly. With the exception of the observation wells, bored by different agencies to observe water levels,

[18] Meinzer, O. E., Outline of ground-water hydrology: U. S. Geol. Survey Water-Supply Paper 494, p. 28, 1923.

[19] Piper, A. M., Notes on the relation between the moisture equivalent and the specific yield of water-bearing materials: Am. Geophys. Union Trans., 1933, pp. 481-487.

Piper, A. M., Thomas, H. E., and Robinson, T. W., Ground-water hydrology of the Mokelumne area, Calif.: U. S. Geol. Survey typewritten report, Oct. 30, 1935.

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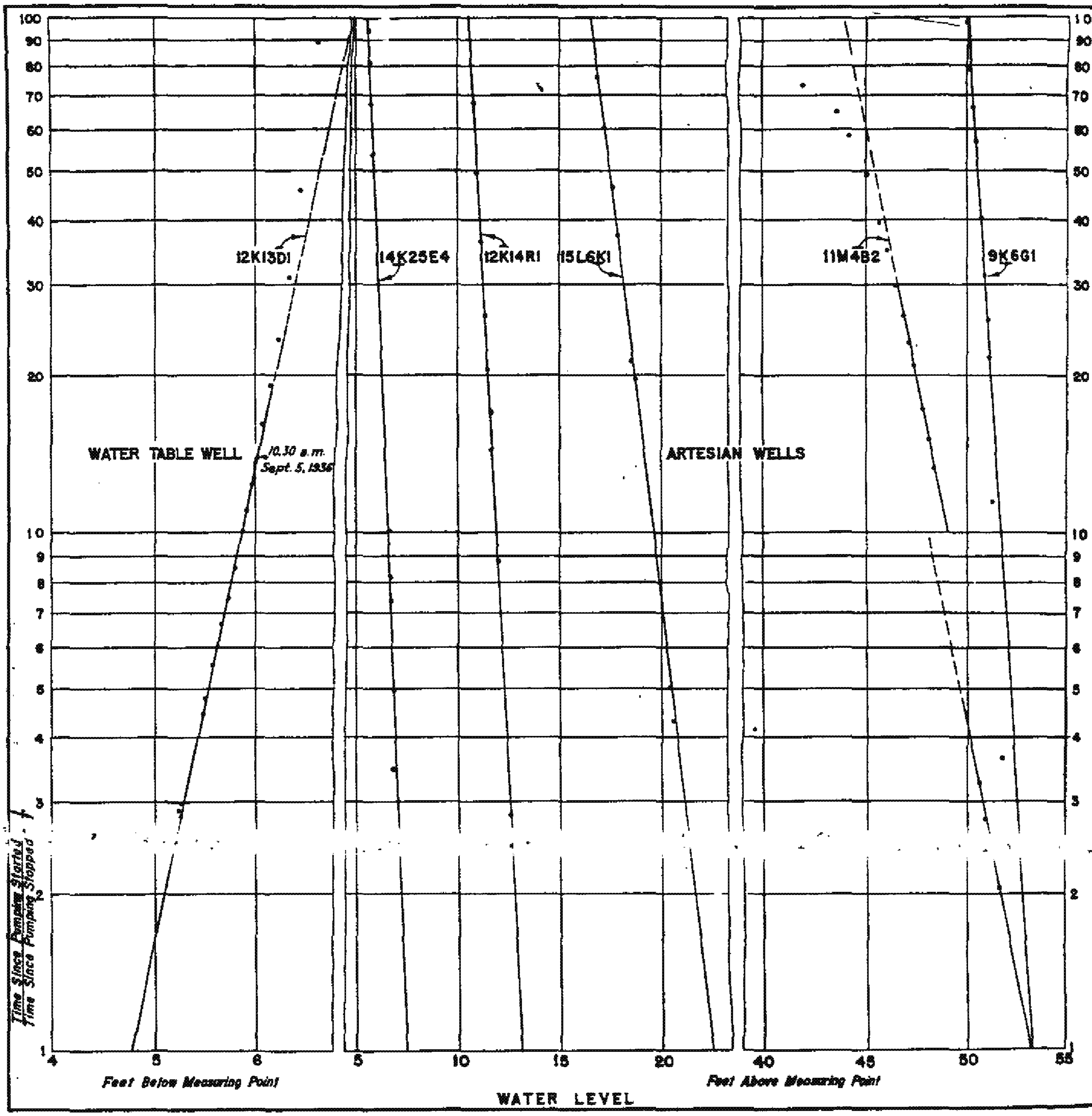

FIGURE 53.—Recovery curves of wells used for transmissibility determinations.

nearly all the wells in the shallow valley fill have been sunk to provide water for irrigation. As artesian water can be obtained at moderate depths over most of the valley floor, virtually no shallow wells have been put down for domestic or stock use. The water-yielding capacity of the sediments is best shown by studying the locations and yields of wells that have been sunk in order to pump water for irrigation.

Irrigation wells have been sunk in nearly every part of the valley, but in only a few localities have they been successful. These localities are all on the west side of the valley, on or adjacent to the alluvial fans. The locations of irrigation wells are shown on the map of the valley, plate 11. (Map vol.) The greatest concentration of irrigation wells is on the Rio Grande alluvial fan, another group is located east of the Monte Vista canal in the Carmel-Bowen drainage district, and a few are scattered on either side of the Rio Grande in the vicinity of Parma. With the exception of a few failures due to methods of construction, all the irrigation wells in these areas are successful. The average yield of the wells is about 850 gallons a minute (p. 248), although some wells were reported to yield as high as 1,600 gallons a minute (table 12). Some of the irrigation plants pump only a few hundred gallons a minute, but in these the yield is limited by the capacity of the pumping plant and not by the capacity of the well. The wells with the highest yields are located on the Rio Grande alluvial fan. It is apparent that in these localities the sediments yield water to wells readily. Doubtless with further development the areas of pumped wells will be expanded to the north and south, but not much to the east.

In the central and eastern parts of the valley, practically all attempts to pump for irrigation have been failures, mostly because of the inability of the sediments to yield water readily.

About 1913, tests were made in sec. 1, T. 44 N., R. 9 E., about 6 miles north of Moffat, to determine the feasibility of irrigating by pumping from wells. A report by F. H. Whiting,[20] consulting engineer, describes the tests as follows:

> The first well sunk was carried to a depth of 60 feet, but proved to be in material yielding little or no water. The adjacent four wells put in after this one proved to yield three-fourths of a second-foot per well. * * *
>
> Four additional wells were drilled in sec. 26, T. 44 N., R. 8 E. These wells under ordinary pumping have yielded 1 second-foot each.

This last group of wells was located about 8 miles southwest of the first group, where the sediments are coarser.

Well No. 11L14E1, belonging to John Achaz, located about 5 miles southeast of Hooper, was dug for an irrigation well. It had to be abandoned for this purpose, as it did not yield sufficient water. An inspection of the spoil pile showed that the water-bearing material was composed mainly of fine sand with a few scattered pebbles.

An abandoned irrigation well owned by E. T. Dow is located in the NW¼ sec. 14, T. 38 N., R. 12 E., about 13 miles northeast of Alamosa. This well, originally dug 10 feet in diameter and 15 feet deep, was, according to the owner, exhausted in 28 minutes when pumped at the rate of 600 gallons a minute. Examination of the water-bearing material was difficult, as the well had not been in use for several years, though indications were that it was rather fine and would not yield water readily.

An attempt was made about 1934 by the city of Alamosa to supplement its water supply from the shallow ground water. A well of large diameter was sunk and tested from time to time at different depths, but it did not yield sufficient water and was finally abandoned. The driller reported the material penetrated as alternating strata of clay and fine sand.

[20] Whiting, F. H., Preliminary report upon the Moffat Irrigation District (manuscript copy), p. 32, Saguache, Colo., 1913.

From the foregoing discussion, it is apparent that the sediments in the central and eastern parts of the valley yield water to wells with difficulty, but on the west side the coarse gravel and sands yield water readily.

The Water Table

Location and description of observation wells.—In order to determine the nature and fluctuation of the water table, the depth to the water level was measured periodically in observation wells distributed over the valley floor. The observation wells are divided into two groups—one group located north and the other group south of the Rio Grande. In the group north of the river, located in the closed basin area and on the Rio Grande alluvial fan, there are 245 wells. In the south group, located in the Bowen, Carmel, Morgan, and Waverly drainage districts, and on the alluvial fan of Gato and Alamosa Creeks, there are 74 wells. The locations of the observation wells are shown on plate 5.

Except on the two alluvial fans, there are very few wells in the shallow valley fill in the entire valley. Therefore, it was necessary to bore most of the observation wells. Considerable difficulty was experienced in boring the wells, especially on the west side of the valley, because of the coarse sand and gravel that were encountered. This material slumped and caved so badly that many holes had to be abandoned. In these places 1-inch pipes, pointed on the end and perforated for a foot above the points, were driven into the ground far enough so that the points were well below the water table. In the trough of the valley north of the river, some trouble was experienced with fine sand filling up the wells from the bottom. None of the wells bored were over 12 feet in depth and nearly all were 10 feet or less in depth, 2 inches in diameter, and cased with galvanized iron casing to the bottom.

In the period 1931 to 1933, engineers from the States of Colorado and New Mexico bored about 250 wells in the closed basin area in order to observe the groundwater level. Measurements of depth of water were made by the Colorado engineers in their wells at intervals through the spring, summer, and fall of 1931 and 1932. Measurements were continued by the New Mexico engineers in their wells at frequent intervals until the fall of 1935. In order to continue the record of water-level measurements all except 1 of the 126 New Mexico wells were recovered and measured during the present investigation. However, only 24 of the Colorado wells were measured. A few of them could not be found, a large number were either destroyed or in such bad condition that they were useless as observation wells, and many were situated so near to New Mexico wells that measurements on them would be a duplication of work.

Levels had been run by engineers from both Colorado and New Mexico to the wells established by them, and these level data were made available for use in the present investigation. Levels were also run to about 65 of the wells that were put down in 1936, based on the 1929 general adjustment of the first-order level net. The levels run by the Colorado and New Mexico engineers were based on the earlier adjustment of the first-order level net. In order that all of the altitudes, determined by the three sets of level lines, would be comparable, the altitudes determined by the Colorado and New Mexico engineers were reduced and adjusted to the 1929 general adjustment.

Different systems of numbering were used by the Colorado and New Mexico engineers to designate their wells. In order to incorporate the wells in one numbering system for the present report, a rectangular coordinate system for numbering all the wells was used, based on the General Land Office subdivisions. The townships were assigned numbers and the ranges letters. Thus the first two characters of the well number designate the township and range in which the well is located. The next one or two numbers designate the section in which the well is located. The section was further divided into sixteen 40-acre tracts, each of which was assigned a letter as shown by the accompanying diagram. The letters I and O were omitted so that they would not be confused with 1 and zero. The first

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

well recorded in a 40-acre tract is numbered 1, the second 2, and so forth. The townships were numbered from north to south and the ranges from west to east. The numbers assigned to the township and the letters assigned to ranges are shown on plate 5. Thus, for example, a well located in the NE¼NE¼ sec. 16, T. 39 N., R. 9 E., would be numbered 12L16A1. A second well in this same 40-acre tract would be numbered 12L16A2. Such a system of numbering serves a double purpose, that of designating a well and also locating it, once the key number and letter are known.

Form of the water table.—The form of the water table in the closed basin area in October 1936 is shown by ground-water contours on the map (pl. 5), wherever there are sufficient data. Because of the steep slope of the water table on the Rio Grande alluvial fan and the very gentle slope in the trough of the valley, three contour intervals are used to show the form of the water table—a 5-foot interval below 7,530 feet; a 10-foot interval between 7,530 and 7,540 feet; and a 20-foot interval above 7,540 feet. No ground-water contours are shown south of the Rio Grande, as the altitude of the measuring points was not determined for a sufficient number of wells.

The water table closely resembles in form the general land surface. A comparison of the water-table map with Siebenthal's [21] topographic map of the valley shows a striking similarity. In general, the water table slopes from the west, north, and east sides toward the trough of the valley. The trough of the water table follows closely the trough of the valley floor, which extends from north to south along the old channel of San Luis Creek. Like the land surface, the water table is characterized by a relatively gentle slope from the west side to the trough of the valley, and a relatively sharp slope from the east. An example of this is best seen by examining the profile along the township line common to Tps. 39 and 40 N. In a distance of 24 miles from well 12J1H1, in the northeast corner of range 8, to well 11Q31N1, in the southwest corner of range 12, the water table descends 157.3 feet, or an average of about 6.5 feet to the mile; whereas, in a distance of 2 miles between well 11Q33N1 and well 11Q31N1, the water table descends 24.9 feet, or an average of about 12.4 feet to the mile. The slope of the water table on the west side of the valley, however, is not uniform, but becomes progressively flatter toward the east. As an example, in the profile just mentioned, the average slope for a distance of 12 miles east of well 12J1H1 is 9.1 feet to the mile, but for the remaining 12 miles it is only 4.0 feet to the mile.

Beginning about 9 miles south of Saguache, in the vicinity of Russel Lakes, the contours indicate a broad shallow depression of the water table, extending east toward the main depression of the trough. The lowest part of the water table is a closed depression in the vicinity of well 13N1A1, about 6 miles south of San Luis Lake, which is indicated by the closed 7,510- and 7,515-foot contours. South of this depression the trough of the water table continues toward the Rio Grande but is much constricted.

Direction of movement of the ground water as indicated by the water table.—The movement of ground water is in the direction of the maximum hydraulic gradient, at right angles to the contours of the water table. The shape of the contours indicates that on the Rio Grande alluvial fan, which is the principal area of recharge on the west side of the valley, the ground water is moving radially outward toward the northeast, east, and southeast. The contours show that the water in the shallow valley fill is moving from the foothills toward the trough of the valley, except along the south side of the Rio

[21] Siebenthal, C. E., Geology and water resources of the San Luis Valley, Colo.: U. S. Geol. Survey Water-Supply Paper 240, pl. 1, 1910.

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Grande fan north of the river between Monte Vista and Alamosa, where they indicate that the ground water is deflected somewhat toward the Rio Grande. With this one exception, the water table contours indicate that for October 1936 none of the water in the shallow valley fill of the closed basin area was moving out of the area. In the trough of the valley the ground water is moving from north to south toward the closed depression south of San Luis Lake. However, between San Luis Lake and the closed depression the water table is quite flat, indicating slow movement. Here large amounts of the ground water inflow are dissipated by evaporation and transpiration. The closed depression is probably due to heavy discharge by transpiration and evaporation.

Depth to the water table.—Over most of the valley floor the depth to water rarely exceeds 10 feet. Only on the steep alluvial slopes and alluvial fans is the depth to water great, in places amounting to 100 feet, or more. The depth to water varies from place to place over the valley, and to some extent from month to month in the same place, as is shown by depth to water measurements. As shown on the map (pl. 5), the depth to water in the closed basin area is less than 5 feet over approximately 70 percent of the area and from 5 to 8 feet over approximately 20 percent of the area. In only two localities in the closed basin area does the depth to water exceed 8 feet. These lie just to the west of the valley trough, one a few miles south of Moffat, and the other about 8 miles southeast of Mosca.

Over most of the area south of the Rio Grande, in the Carmel-Bowen drainage district and the general area east to the river, the depth to water is less than 5 feet. To the west, where the topography of the alluvial fan of Gato and Alamosa Creeks begins to develop, the depth to water increases, and farther west and higher up on the fan the depth to water is greater than 100 feet.

Influence of drains on the water table.—Since about 1910 numerous drainage systems have been constructed in the San Luis Valley, principally along the west side. The development of the drainage systems was a piecemeal process, as a rule each being constructed independently. They consist of both buried and open drains, the buried drains usually discharging into the open drains. They have been quite effective in lowering the water level wherever the water level was excessively high and the land had become "water logged." At present there is a network of drains over most of the agricultural lands on the west side of the valley.

It is not believed that these drainage systems in the closed basin area have changed materially the general form of the water table. Their general effect has been to lower the water table a few feet and to maintain it at a more or less uniform depth over the drained area. There is not sufficient information available to show the local effects of individual drains. It is to be expected that adjacent to the drains the water table is relatively low and that the distance through which the water table is lowered depends upon the permeability of the water-bearing material.

Fluctuations of the water table.—Seasonal Fluctuations.—A condition of approximate equilibrium exists between the amount of water annually replenishing the ground-water supply and the amount annually discharged. This balance is maintained through the changing conditions by fluctuations of the ground-water level. When the amount of recharge exceeds the amount of discharge the water table rises, and conversely when the discharge exceeds the recharge the water table is lowered. In the San Luis Valley fluctuations of the water table follow closely the seasons, but the seasonal fluctuations vary from place to place.

The common method of irrigation in the valley is by subirrigation—that is, by raising the water table and maintaining it or the overlying capillary fringe within the root zone of the plants during the growing season. The result of this practice is a very sharp and pronounced rise of the water table in the irrigated area with the beginning of the irrigation season, usually about the first of April. The two principal areas in which irrigation is practiced are on the Rio Grande alluvial fan and in the area south of Monte Vista that is served by the Monte Vista and the Empire canals. At the end of the irrigation season, the water level gradually declines until the next season. An example of this seasonal rise and decline on the Rio Grande alluvial fan is shown by the measurements of depth to water in well 12J10K1, owned by E. L. Neff. In this well the water level rose 10.5 feet between April 2 and June 8, 1936, then declined, so that on December 17 it stood 3.77 feet below its position on June 8. Because of a shortage of irrigation water early in July, the "sub" could not be maintained, and consequently the water level declined sharply. However, a supply of water became available in August that partly restored the water table to its June level.

In the northern, central, and eastern parts of the closed basin area the agricultural lands give way to meadow and brush lands. Irrigation water is usually applied to the meadowlands but not to the brushlands. The vegetation on both types of land is for the most part composed of plants that habitually feed on ground water. The brush cover is locally referred to as "chico", but it is made up chiefly of two dominant plant species, greasewood and rabbitbrush, with greasewood the more prominent. The meadow lands are largely covered with salt grass, which discharge large quantities of ground water by transpiration, resulting in a decline of the water level until the end of the growing season. When the transpiration draught ceases or becomes light the water level starts to rise, and it generally continues to rise slowly through the winter. With the advent of warm weather, the ground thaws and allows the melted snow water and rainfall to percolate downward to the water table, resulting in a sharp rise of the water level. The water level then remains high until the transpiration draught is resumed. This condition is shown by the records of depth to water obtained prior to 1936 in the New Mexico wells located in the transpiration area. During the latter part of July and first part of August 1936, unusually heavy rains produced a pronounced rise of the ground water levels. Thus the effect of transpiration on the lowering of the water table is not so pronounced for the 1936 season as for some previous seasons, although the trend is indicated by the June and July measurements.

Diurnal Fluctuations.—In order to obtain a record of diurnal fluctuations of the water table, three wells in the closed basin area were equipped with automatic water-stage recorders. These wells, 11L23D1, 12Q6L2, and 13Q20N2, are in the general area where the conditions are favorable for the transpiration of large quantities of water. Well 13Q20N2 is located about 10 miles east and north of Alamosa, well 12Q6L2 about 1½ miles southeast of San Luis Lake, and well 11L23D1 about 6½ miles northwest of Mosca. These wells are 18 inches square and were dug especially to accomodate the recorders. The recorders were Stevens 8-day type L, which operate on a time scale of 1 inch to 10½ hours and a 1 to 1 or natural water-height scale. The records obtained on these wells are shown in figure 54.

All the wells were located in extensive areas of greasewood, rabbitbrush, and salt grass. In the vicinity of well 11L23D1, the growth was much thicker and more vigorous and luxuriant than at either of the other two wells, and the hydrograph of this well shows large diurnal fluctuations. No diurnal fluctuation was observed in well 13Q20N2 and only faint fluctuations in well 12Q6L2. It is not clear why the diurnal fluctuations were not more pronounced in these two wells, but the reason may lie in part in the difference in the density and growth of the vegetation and in part in difference in the texture of the soil. However, it will be noted that in all of the wells there was a net decline in the water level from day to day except during and immediately following periods of heavy rain. This decline is

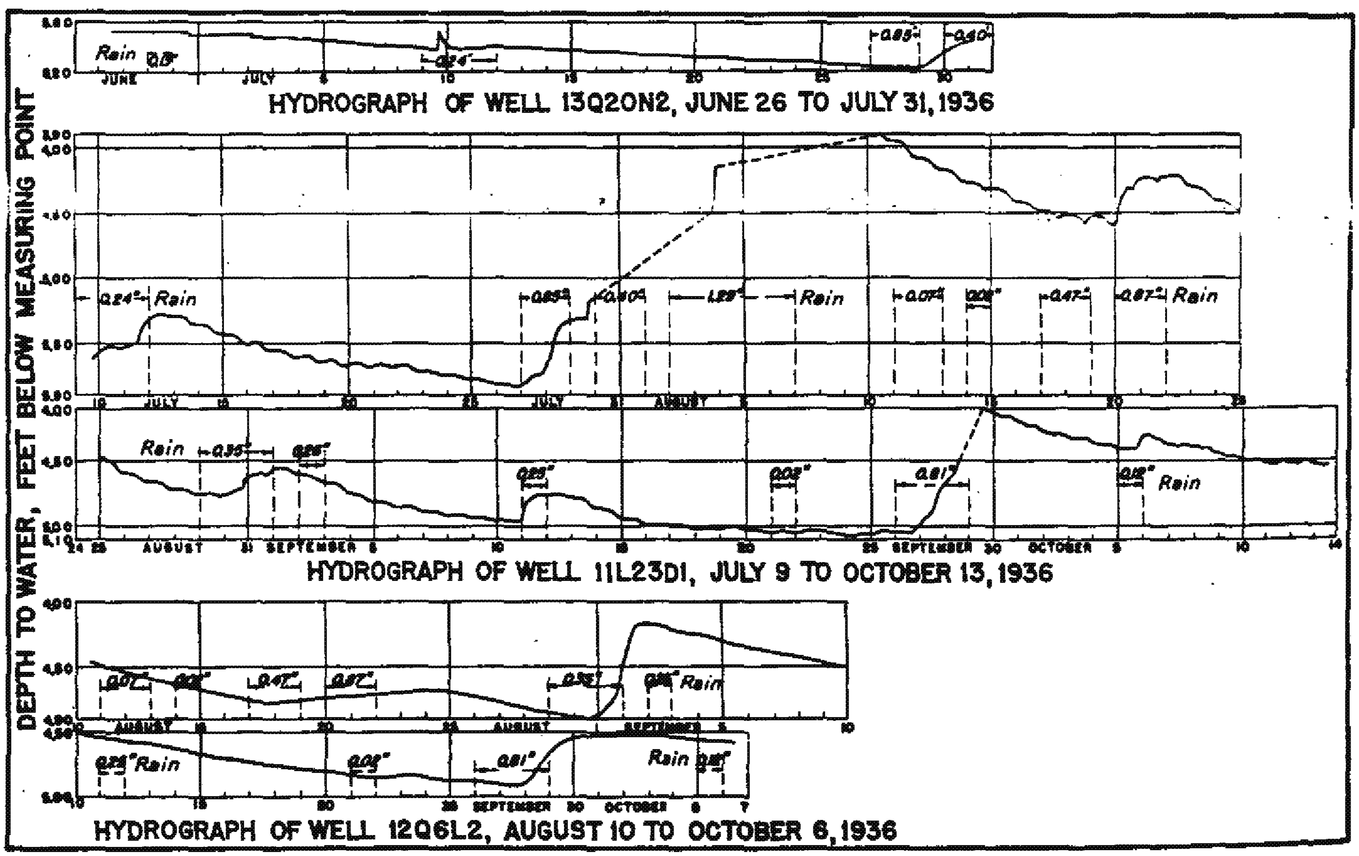

Figure 54.—Hydrographs of shallow wells equipped with recorders.

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the result of draft by transpiration and probably in small part by soil evaporation.

The hydrograph of well 11L23D1 shows that the water table goes down during the daytime when transpiration is rapid, and rises at night when transpiration is low. Usually the water starts downward about 10 a. m., reaching its low stage between 7 and 8 p. m. Between about 9 and 11 p. m., the water begins to rise perceptibly, and it continues to rise until about 9 the next morning. The maximum daily fluctuation observed during the period in which the recorder was in operation amounted to about 1 inch. During and immediately following periods of rain the diurnal fluctuations are replaced by rapid rise of the water table. For a short period after the period of rise, the water level remains practically stationary and then it declines rapidly. During the period of decline the diurnal fluctuations are superimposed on a rapidly declining water level, and hence the amount of the daily rise is reduced and that of the daily decline is increased.

Beginning about September 30 a different type of diurnal fluctuation is shown by the hydrograph of well 11L23D1. The water level began to rise about 11 a. m. and continued to rise until about 4 p. m., which is the opposite of the daytime decline caused by transpiration. Beginning on the afternoon of September 26, rain started falling, and the rain was followed by several inches of snow on September 27. After the storm the temperature dropped below the freezing point each night, thus definitely ending the growing season and the transpiration draft. The daytime rise of the water table was evidently due to water from the melting snow and ice percolating downward to the water table.

Fluctuations Caused by Rainfall Penetration.—Fluctuations of the water table due to rainfall penetration are indicated by the monthly measurements of depth to water and are shown definitely by the hydrographs of the three recorder wells, 11L23D1, 12Q6L2, and 13Q20N2. The measurements in nearly every well in the closed basin area show that the water level stood higher in August and September 1936 than in July 1936. The records of the United States Weather Bureau station at Garnett, Colo., located in about the center of the closed basin area, show that the precipitation was only 0.68 inch in June, but that it was 1.49 inches in July, 3.07 inches in August, and 1.34 inches in September. The heavy rains in July occurred after the monthly round of measurements had been made, and hence their effect on the water table was not apparent until the August round of measurements.

The response to rainfall was much faster and of greater magnitude at well 11L23D1 than at either of the other two recorder wells. This was no doubt due to the greater permeability of the material in the vicinity of this well. Here the material consisted of coarse sand and gravel from the surface down to the water table, whereas at wells 12Q6L2 and 13Q20N2 the logs show a mixture of fine sand and clay. The permeability of the material in the zone of fluctuation (table 4, p. 233) was 1,500 at well 11L23D1, 65 at well 12Q6L2; and only 1 at well 13Q20N2.

The water table responded much more to heavy rains than to light rains. For rains of 0.10 inch or less the response was very slight. The greatest response was recorded in well 11L23D1 for the period July 27 to August 6, when 2.54 inches was recorded at Garnett. The exact rise of the water table is not known, as the recording pencil was forced off the chart. However, measurement on August 10, 4 days after the rain stopped, indicated a rise in excess of 1.85 feet. A rise is also shown on the hydrograph of well 13Q20N2 up to the afternoon of July 30, when the recorder ceased to function. Measurements in this well on July 20 and August 13, before and after the rainstorm, show that the water level rose 1.84 feet. The rain and snow storm of September 26 to 28, in which the total precipitation amounted to 0.81 inch at Garnett, produced a rise in excess of 0.90 foot at well 11L23D1 (here again the pencil was forced off the chart) and a rise of 0.40 foot at well 12Q6L2. The stairstep effect, in the hydrograph of well 13Q20N2, is due to the mechanical operation of the recorder in overcoming the frictional resistance of the recording device. On the same hydrograph the sharp vertical rise, amounting to 0.15 foot on July 8, was due to rain water entering the well at the surface, and not, as might be supposed, to rainfall penetration.

It must be borne in mind that the rainfall at the recorder wells may have differed considerably from the rainfall recorded at the United States Weather Bureau station at Garnett, but a comparison of the rainfall at this station and the hydrographs of the recorder wells makes it evident that a causal relationship exists. The hydrographs and the records of other observation wells also indicate that the rise of the water table differed from place to place over the valley floor, these differences probably being due to differences both in the texture of the shallow valley fill and in the amount of rainfall.

Fluctuations Caused by Pumping.—Within the last 5 years many farmers in the agricultural area on the west side of the valley have drilled wells and equipped them with pumping plants. The wells are usually of large diameter and penetrate only the shallow or unconfined water (table of irrigation wells, pp. 250 and 251). These irrigation wells are used only when there is a shortage of irrigation water. Such a shortage occurred during the season of 1936, beginning early in July.

As a result, there was much pumping activity during July and August and well into September. This pumping draft, combined with a shortage of the surface water for irrigation, produced a lowering of the water table, especially on the Rio Grande alluvial fan and in the Carmel-Bowen drainage district, which are the two areas of heavy pumping draft. (See the hydrographs of wells 11J9D1, 11J26P1, and 11K6N1 (fig. 55), located on the Rio Grande alluvial fan.) In these parts of the valley the water level began to decline sometime after the June round of water level measurements and did not begin to recover appreciably until after the September round of measurements. The rise in October was due to the cessation of pumping and some late irrigation with surface water.

Source of the Ground Water

Streams.—All the streams that enter the San Luis Valley flow across the alluvial slopes bordering the valley floor. As already pointed out (pp. 229–232), the material forming the alluvial slopes is coarse in texture and therefore the water percolates through it readily and the streams have large seepage losses. It is common knowledge that the flow of the minor streams dwindles noticeably after they reach the alluvial slopes, particularly the streams flowing from the Sangre de Cristo Range, only a few of which flow beyond the base of the alluvial slopes. Several of the streams flowing from the mountains on the west side of the valley are larger and are able to withstand heavy losses in flowing across the alluvial slopes, but the losses from the minor west-side streams are readily noticeable wherever the water has not been diverted for irrigation.

Prior to the time of any irrigation development on the Rio Grande and the Conejos River, these streams were undoubtedly large contributors to the ground water. This was especially true during flood periods, when the water spread out to inundate the flood plain. With the advent of irrigation development and consequent diversions, the flow in the river channels soon after emerging from their rock canyons was greatly reduced. At the present time nearly the entire flow of the Rio Grande is diverted in the upper part of its alluvial fan for irrigation. Thus with the changed regimen of the streams, the opportunity for ground-water recharge by stream losses was reduced.

The following table from a report by Carpenter[22] shows the seepage losses for sections of the Rio Grande between the Del Norte and Monte Vista gaging stations, for the period 1896 to 1903. There was considerable irrigation at that time but it was not so extensive as at present.

TABLE 8.—*Gains (+) and losses (−) from seepage on the Rio Grande between the old Del Norte gaging station*[1] *and Monte Vista*

[In cubic feet per second]

Section	Distance in miles	1896	1897	1898	1899	1900, August	1900, September	1900, November	1903, July–August
Del Norte gaging station to Off's[2]	8	−107.03	−72.09	−49.85	−57.43	−4.26	−79.07	−19.54	−56.20
Off's to Monte Vista	10	+54.32	+6.61	+6.26	+2.46	−13.29	+19.11	+18.47	+1.17
Del Norte gaging station to Monte Vista	18	−52.71	−65.48	−43.59	−54.97	−17.55	−59.96	−1.07	−55.03

[1] About 3 miles above Del Norte. [2] About 5 miles below Del Norte.

Presumably this table of seepage loss or gain was compiled from special seepage measurements for short periods and is not the average for any 1 year or month. Results of the stream gaging in 1936 at the Del Norte and Monte Vista gaging stations (tables 10 and 11) do not show as great losses as those shown in the table for several years earlier. The highest loss in 1936 occurred during March and April, and amounted to 2,345 acre-feet, or an average of about 19.2 cubic feet per second. The stream losses shown by the above table, except in August 1900, occurred in the 8-mile section of the stream below the Del Norte gaging station, which is about at the apex of the Rio Grande alluvial fan. Thus it is apparent that nearly all of the stream loss takes place on the upper part of the fan. No measurements of discharge from this 8-mile section of the river are available for 1936, but as there has been little if any increase in the quantity of water diverted from it for irrigation since 1903, it is safe to assume that it still has appreciable seepage losses.

Carpenter[22a] also shows a similar set of seepage determinations for the Conejos River. Between the San Juan Bridge (at Mogote) and the Conejos Bridge (at Conejos), a distance of about 4 miles, there was a loss of 22.12 cubic feet per second in August 1900, and 4.66 cubic feet per second in October 1900, but a gain of 7.92 cubic feet per second in July 1903. This section of the river is well up on the alluvial fan and corresponds to the section between the Del Norte gaging station and Off's on the Rio Grande. No stream measurements are available from which to compute seepage losses in this section of the stream in 1936, but the conditions are favorable for contributions to the ground water by seepage losses.

Irrigation water.—During the irrigation season practically the entire flow of the Rio Grande is diverted for irrigation. In the calendar year 1936 these diversions amounted to 480,674 acre-feet. (See tables 10 and 11.) Most of this water is used on the Rio Grande alluvial fan and on the gravelly soil forming the base of the

[22] Carpenter, L. G., Seepage and return waters: Colo. Agr. Coll. Bull. 180, Part 1, p. 42, 1916.

[22a] Op. cit., p. 49.

alluvial fans of Gato and Alamosa Creeks. Because of the method of irrigation and the type of soil the opportunity for ground-water recharge in these areas is great. As has been stated previously, the common method of irrigation is by raising the ground-water level and maintaining it about up to the root zone. As the soils are coarse and permeable, such a system of irrigation becomes a very effective method of ground-water recharge. It is essentially the same as water spreading for ground-water recharge. A similar condition of irrigation diversion and "subbing" exists for most of the streams entering the valley from the west side.

On the east side of the valley irrigation is not practiced extensively, chiefly because of a lack of water supply and because attempts to divert water on the alluvial slopes have failed on account of heavy ditch losses. Lining the ditches or fluming the water has apparently not been economically feasible. Any water from those streams that flow across the alluvial slopes is used to irrigate native hay meadows on the valley floor. In these meadows there is undoubtedly some ground-water recharge.

As a result of irrigation, there is without doubt much larger total recharge to the ground water in the valley now than before irrigation was practiced, evidence of which is furnished by the extensive system of drains that has been constructed to lower the water level and carry away excess ground water.

Artesian wells.—According to the artesian-well inventory (table 20), there are in the valley 6,074 wells, and these wells have an aggregate annual discharge of about 119,000 acre-feet. The flow of these wells is a potential source of water for recharge of the shallow ground-water supply. A small part of the total flow is used for domestic, industrial, and stock use; the remainder, being used for irrigation, is allowed to discharge directly on the land, where it is dissipated by evaporation and downward percolation. As the land surface in the area of artesian flow is relatively flat, most of the artesian water not used for irrigation disappears within a few hundred feet of the well. Of the artesian water used for irrigation a certain amount is lost by transpiration and evaporation. The cities of Monte Vista and Alamosa use artesian water and discharge some of it into the Rio Grande in the form of sewage, but the stream is diverted below both cities for irrigation. Thus, very little of the flow from the artesian wells passes out of the valley as stream flow, and the amount of artesian water available for ground-water recharge is essentially equal to the total flow of the wells less the artesian water lost by evaporation and transpiration.

Recharge of the shallow aquifer also takes place by underground leakage out of the artesian wells. In the early period of artesian development, many wells were cased only sufficiently to prevent the top of the hole from caving. The common practice was to use only one "stick" of casing, usually from 18 to 22 feet in length, and in some wells no casing was used. The casing was not long enough to be seated even on the first confining bed, thus allowing part of the water to come up on the outside of the casing and to enter the shallow aquifer. Proof that water from these inadequately cased wells is entering the shallow aquifer is shown by the increase in flow after a well has been recased and the casing has been properly seated. Thus drillers report that after recasing, the flow of the well is likely to increase two or three times.

Rainfall penetration.—It has already been shown (p. 243) that the water table fluctuates in response to rainfall. The hydrographs from wells equipped with automatic water-stage recorders show a material rise of the water level following periods of moderate to heavy rain, thus indicating recharge of the ground-water supply by rainfall penetration. These hydrographs further indicate that the amount of rainfall penetration varies from place to place. Doubtless on the coarse material of the alluvial slopes and fans a large part of the rainfall percolates to the water table, whereas on the finer material in the central part of the valley the amount of rainfall reaching the water table is less. A rough measure of the quantity of rainfall reaching the water table in the central part of the closed basin area is afforded by the rise of the water table in wells 9M2C1, 10M2A1, 11M1D1, 11N3R1, 12N23N1, 13M14D1, and 13Q20N2, which are located outside the influence of recharge from irrigation. The rise of the water level in these wells in the period of heavy rains from July 20 to October 15, averaged 0.94 foot, or 11.3 inches. In this period the precipitation, as recorded at the United States Weather Bureau station at Garnett was 5.78 inches. As the capillary fringe reaches virtually to the surface over most of the valley floor, capillary water occupies part of the pore space, and so the effective porosity of the material above the water table and therefore its capacity to absorb additional water is reduced. For this reason the figures for specific yield which are shown in table 4 cannot be used to compute the quantity of rainfall penetration from a known rise of the water table.

Precipitation in the valley during the rainy season is very irregularly distributed. Individual showers of varying intensity sweep across the valley in an easterly direction, covering strips only a few miles in width, outside of which the ground is often perfectly dry. Thus, for June 1936 the rainfall at Garnett was only half that at Alamosa, 20 miles south, while for July 1936 the rainfall at Garnett was one and one-half times that at Alamosa. As the texture of the soil and the amount and intensity of the rainfall range widely throughout the valley, it follows that the amount of rainfall penetration also ranges widely. The small depth to the water table below the land surface is favorable to recharge by rainfall penetration, and the data presented show that the recharge from this source is a substantial quantity.

Disposal of the Ground Water

Processes.—The ground water in the shallow valley fill is discharged by soil evaporation and plant transpiration, underflow, artificial drainage, and pumping from wells. There are no known springs on the valley floor that discharge shallow ground water, but the several lakes are essentially outcrops of the water table. At the foot of the alluvial slopes there are springs such as Little Spring and Big Spring, east of the Medano Ranch, which discharge water that was lost by the streams farther up the alluvial slopes.

Evaporation and transpiration.—Wherever the water table stands close to the land surface, the ground water moves upward through the soil by capillary rise to be disposed of by evaporation, and in general the closer it is the greater is the amount of ground water evaporated. In a somewhat similar manner water is discharged by the plants where the water table stands within reach of the root zone. In the San Luis Valley the conditions are favorable for the disposal of large quantities of ground water by both evaporation and transpiration.

As shown on plate 11, there are in the valley extensive uncultivated areas occupied by native vegetation, which is composed almost entirely of plants that habitually feed on ground water, such as greasewood, rabbitbrush, and saltgrass. In the cultivated areas the practice of maintaining the ground-water level up to the root zone of the plants allows these plants to feed on ground water, even though they may not be habitual users of ground water. The map (pl. 5) shows that in July 1936 the water table in about 70 percent of the closed basin area stood less than 5 feet below the land surface, and that in only about 10 percent of the area was it more than 8 feet below the surface. Thus in all except a small part of the area the water table is within reach of the roots of ground-water plants. Much of the decline of the water table in the summer of 1936 was due to transpiration, and specific evidence of the disposal of ground water by transpiration is furnished by the diurnal fluctuations of the water table, as recorded by the automatic water-stage recorders (p. 242).

The rate of disposal of ground water by evaporation from the soil undoubtedly varies from place to place over the valley floor, with the depth of the water table below the land surface and the height of the capillary fringe, which in turn is governed by the texture of the soil. Undoubtedly there are areas in the floor of the valley where there is little or no soil evaporation, because of unfavorable combinations of depth to water and soil texture. There are, however, extensive areas, both bare and with vegetal cover, where soil evaporation is known to occur. Here the alkali salts left behind by evaporation have collected as a crust on the surface of the soil or appear as efflorescences. These alkali deposits were observed in nearly all parts of the valley but especially in the central trough.

No experiments were conducted during the present investigation to determine the rate of ground-water discharge by evaporation and transpiration, but some data are available from experiments conducted in the valley during 1930, and additional data are available from the work of others in areas comparable to the San Luis Valley.

During the growing season of 1930, Tipton and Hart [33] conducted experiments on soil evaporation in the San Luis Valley, in four soil tanks, each 3 feet in diameter and 4 feet deep, and with the water level at different depths. The results obtained are shown in the following table:

TABLE 9.—*Evaporation,*[1] *May to October, inclusive, 1930*

[Results of experiments by R. J. Tipton and F. C. Hart in the San Luis Valley, Colo.]

	Tank no. 1	Tank no. 2	Tank no. 3	Tank no. 4
	Vegetal cover			
	Saltgrass sod	Saltgrass sod	Saltgrass sod	Bare
Mean depth of water surface (feet)	0.33	0.80	1.93	0.02
Water loss (feet)	2.26	[illegible]	[illegible]	[illegible]

[1] Believed to include transpiration losses for tanks 1, 2, and 3.

These experiments, however, are applicable only to areas of saltgrass where the depth to water is less than 2 feet, or to bare land with the water table at the surface.

The rates of evaporation and transpiration discharge determined by White [34] in the Escalante Valley, Utah, are believed to be more or less applicable to the San Luis Valley. The Escalante Valley, though lower in altitude, is comparable to the San Luis Valley in many respects, such as topographic situation, climate, rainfall, and vegetative cover. White's results were based on experiments covering three growing seasons. In estimating the ground-water discharge, he classified the lands according to vegetative cover and according to depth to water. Thus in the lowland areas occupied by saltgrass associated with greasewood, rabbitbrush,

[33] Tipton, R. J., and Hart, F. C., Field investigations, 1930; Consumptive use determination, evaporation experiments, drainage measurements: Manuscript copy in files of the State Engineers Office, Denver, Colo., March 1931.

[34] White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil; Results of investigations in Escalante Valley, Utah: U. S. Geol. Survey Water-Supply Paper 659-A, pp. 87, 88, 1932

and pickleweed, with saltgrass dominant, where the depth to water was from 0 to 3 feet in the spring and 3 to 5 feet in the fall, 1 acre-foot per acre was taken as the probable ground-water discharge by evaporation and transpiration. In the area where the chief ground-water plants were greasewood, rabbitbrush, and shadscale, with a light growth of saltgrass, and the depth to water was from 0 to 5 feet in the spring and from 3 to 8 feet in the fall, 5 acre-inches per acre was used as the probable ground-water discharge by evaporation and transpiration. On somewhat higher lands occupied by greasewood, rabbitbrush, and shadscale, where the depth to water was from 8 to 30 feet, 2 acre-inches per acre was used as the discharge by transpiration, with no loss by evaporation.

Lee [3] in Owens Valley, Calif., conducted tank experiments to determine the loss of shallow ground water by evaporation and transpiration, and from the results of these experiments he estimated the amount of ground water evaporated and transpired annually.

Thus, knowing the depth to water and the kind and amount of vegetation, it is possible to estimate the annual discharge of ground-water by evaporation and transpiration. Such an estimate (p. 249), based on White's figures was made for the trough of the valley in the closed basin area, but no attempt has been made to estimate the discharge for the entire valley.

Underflow.—The statement is made on page 241 that the ground-water contours indicate movement of water toward the Rio Grande, especially along its alluvial fan. Such movement is indicated by the stream-flow records at Del Norte and Alamosa. Tables 10 and 11 show the seepage gain of the river by months for the calendar year 1936, between the Del Norte and Monte Vista gaging stations and the Monte Vista and Alamosa gaging stations.

These tables show that in all months in 1936 except January and November there was a net seepage gain in the river between Del Norte and Alamosa. This seepage gain amounted to a continuous flow for the year of about 72 second-feet. The two stretches of the river between the gaging stations are about equal in length, yet the seepage gain in the lower stretch is about twice that of the upper stretch. This is to be expected, as the seepage water, which is no doubt largely water diverted and used for irrigation, must move laterally a considerable distance from its point of application before it enters the river as underflow. That the seepage gain is largely irrigation water is shown by the facts that the largest gains occurred during the irrigation period, from April to October, and that in general during the late fall and early winter the seepage gain was small or there was a seepage loss from the stream. There are no data available to show from which side of the river the underflow is the greatest, but it probably comes largely from the north side. South of the river, a part of the underflow is probably intercepted by Rock Creek, which parallels the Rio Grande from Monte Vista to Alamosa.

It seems probable that prior to any irrigation development, the Rio Grande may have been a losing stream part of the time and a gaining stream part of the time—losing while in flood, when the water spread over its flood plain, and gaining after the flood water had receded. Under its present regimen, however, no floods of any consequence pass across the valley floor,

[3] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 294, 1912.

TABLE 10.—*Monthly summation of inflow and diversions on the Rio Grande between the Del Norte and Monte Vista gaging stations to show seepage gain or loss*

[All quantities in acre-feet]

1936	January	February	March	April	May	June	July	August	September	October	November	December	Total
Rio Grande at Del Norte	9,320	9,970	13,880	67,330	141,200	89,150	39,550	37,570	27,100	15,130	12,930	9,710	472,840
Inflow (visible)	700	700	1,500	2,500	3,000	1,400	550	1,200	600	700	700	700	14,250
Total flow	10,020	10,670	15,380	69,830	144,200	90,550	40,100	38,770	27,700	15,830	13,630	10,410	487,090
Diversions	0	665	9,195	51,440	104,975	71,340	34,520	38,230	28,060	15,945	1,545	0	355,915
Difference	10,020	10,005	6,185	18,390	39,225	19,210	5,580	540	−360	−115	12,085	10,410	131,175
Rio Grande at Monte Vista	9,290	11,120	4,970	17,260	42,270	21,000	6,490	5,350	3,920	3,430	11,740	11,520	148,360
Seepage gain (+) or loss (−)	−730	+1,115	−1,215	−1,130	+3,045	+1,790	+910	+4,810	+4,280	+3,545	−345	+1,110	+17,185

TABLE 11.—*Monthly summation of inflow and diversions on the Rio Grande between the Monte Vista and Alamosa gaging stations to show seepage gain or loss*

[All quantities in acre-feet]

1936	January	February	March	April	May	June	July	August	September	October	November	December	Total
Rio Grande at Monte Vista	9,290	11,120	4,970	17,260	42,270	21,000	6,490	5,350	3,920	3,430	11,740	11,520	148,360
Inflow (visible)[1]	200	400	900	900	900	900	900	900	900	900	900	900	9,600
Total flow	9,490	11,520	5,870	18,160	43,170	21,900	7,390	6,250	4,820	4,330	12,640	12,420	157,960
Diversions	0	0	4,585	20,240	44,080	25,945	7,830	8,220	6,685	5,115	2,105	0	124,755
Difference	9,490	11,520	1,285	−2,080	−910	−4,045	−440	−1,970	−1,865	−785	10,535	12,420	33,205
Rio Grande at Alamosa	9,380	11,680	4,880	2,860	5,000	2,870	2,630	3,260	1,470	1,660	10,860	12,160	68,710
Seepage gain (+) or loss (−)	−110	+160	+3,595	+4,940	+5,910	+6,915	+3,070	+5,230	+3,335	+2,445	+325	−260	+35,505

[1] Partly estimated.

as the water is diverted for irrigation. Siebenthal [26] mentions a seepage loss of 75 second-feet between Del Norte and Monte Vista, indicating that in the early days of irrigation development, the stream on the upper part of its alluvial fan may have been a losing stream. However, no such loss is indicated by the stream measurements of 1936. Even for March, the month of greatest loss between Del Norte and Monte Vista, the amount is only 1,215 acre-feet, or an average flow of about 19.6 second-feet.

Artificial drainage.—A considerable quantity of shallow ground water is disposed of by means of the network of drains in the valley, but no systematic measurements have ever been made of this discharge. A part of the drain water is reused for irrigation and the rest is usually discharged into some stream. Practically the entire visible inflow between Monte Vista and Alamosa is drain water. As shown by table 12, this amounted to about 9,600 acre-feet during 1936. The amount undoubtedly varies from year to year, depending upon the available irrigation water. It was noted that during the shortage of irrigation water in July and August 1936, some of the drains were barely flowing, while in others the flow was greatly reduced.

Pumping.—During periods when there is a deficiency in irrigation water, the stand-by irrigation pumps are put in operation. As stated previously (pp. 243 and 244) this practice has only become general within the last 5 years. The location of the pumping plants is shown on plate 11, and a brief description of each is given in table 12.

The quantity of water pumped is variable, depending upon the available supply of surface water. On account of the permeable nature of the soils, a large part of the water pumped no doubt percolates back to the water table, but at points farther down the slopes. Thus only a part of the water pumped is permanently removed from the shallow aquifer.

A reconnaissance during the summer of 1936 showed that there were 176 pumping plants in the valley. Many of these had been installed since 1931, and some were just being installed. No measurements of discharge were made, but a reported discharge by the owner or operator was obtained for 99 of the plants. These reported discharges ranged from 100 to 1,600 gallons a minute, with an average of 850 gallons a minute. On this basis the total capacity of all the plants, pumping continuously, would be about 660 acre-feet per day, or about 330 second-feet.

Most of the pumping plants were operated with farm tractors or old automobile engines, a few were electrically operated, and some were operated by stationary gasoline engines. As the plants are used only for standby purposes, the power units were for the most part only temporary and were moved away as soon as the pumping period was over.

[26] Siebenthal, C. E., Geology and water resources of the San Luis Valley, Colo.: U. S. Geol. Water-Supply Paper 240, p. 55, 1910.

General Conclusions

Because of the limitation of time, the present investigation was necessarily qualitative in nature rather than quantitative, and the data were collected with the view of studying the nature and behavior of the water in the shallow valley fill rather than the quantity. Thus, although the processes by which water is added to and discharged from the shallow ground water have been discussed, no estimates have been made of the quantities involved. Quantitative studies based on work during only one season are not as a rule applicable over a period of years. It is possible, however, from the available data to make some statements as to the magnitude of the quantities involved.

As shown on pages 244 and 245, the principal area of recharge in the closed basin area is on the Rio Grande alluvial fan, as the result of irrigation. Using the coefficient of transmissibility of 216,000, determined from the pumping test on well 12K13D1 (see p. 237), and the hydraulic gradient of the water table as shown by the map (pl. 5), a rough estimate can be made of the quantity of water moving radially outward from the fan. In general the toe of the fan corresponds to the position of the 7,600-foot contour of the water table, above which most of the irrigation and hence recharge takes place. The average hydraulic gradient along the 7,600-foot contour is about 8 feet to the mile. Thus the available data indicate that for each mile along this contour, water is moving out of the fan at the rate of about 1,900 acre-feet a year. The distance along the contour from the Gunbarrel Road (line common to Rs. 7 and 8 E.) to the Rio Grande is about 24 miles. On this basis, the movement of water out of the fan would amount to about 45,000 acre-feet annually.

This water moving out of the fan into the lower part of the valley is disposed of by several processes. A large part undoubtedly is discharged by evaporation and transpiration in adjacent areas where the water table stands close to the land surface. Of the remaining part, some is intercepted by drainage ditches to be reused for irrigation or discharged into the Rio Grande, some percolates into the Rio Grande as underflow, and some percolates farther eastward into the trough of the valley and is there discharged by evaporation and transpiration. This lateral percolation from the west into the trough of the valley is believed to be relatively small.

Nine samples of the water-bearing material taken at or immediately above the water table, from wells located along and just west of the valley trough (wells 9M2C1, 10M2A1, 11M1D1, 11M36R1, 11N3R1, 12N23N1, 12Q6L2, 13M14D1, and 13Q20N2), were tested in the hydrologic laboratory of the Geological Survey at Washington, D. C., for permeability. One sample was nearly impermeable and one had a coefficient of permeability of 900. The coefficients of permeability at the other wells ranged from 20 to 180 (table 4, p. 233). The average for the nine samples was approximately 150. The thickness of the shallow valley fill along the trough of the valley from the vicinity of Moffat south to Washington Springs, based on all available well logs and information received from local well drillers, ranges from 24 feet to 185 feet, and averages about 90 feet. On this basis the average coefficient of transmissibility in the trough of the valley was computed to be about 13,500.

An inspection of the water-table map (pl. 5) shows that the 7,540-foot contour of the water table encloses practically all of the valley trough from 2¼ miles south of Moffat south to Washington Springs. The average hydraulic gradient at this contour is about 7 feet to the mile. Roughly the gradient on the east side of the trough is about twice that on the west wide, indicating that, transmissibility being equal, twice as much water percolates into the trough from the east than from the west. However, it seems probable that the transmissibility is somewhat greater on the east side. None of the samples tested for permeability were taken east of the valley trough. Here the water-bearing material is derived from the nearby steep slope of the Sangre de Cristo Mountains, and would tend to be coarser and hence have greater permeability than the material transported across the valley from the west. Using the data for transmissibility and the hydraulic gradient, the lateral percolation per mile past the 7,540-foot contour was computed to be about 105 acre-feet a year. The length of the 7,540-foot contour in its loop around the trough of the valley, from the vicinity of Alamosa north nearly to Moffat and then south to the vicinity of Washington Springs, is about 75 miles. On this basis, the lateral percolation into the trough of the valley was computed to be about 8,000 acre-feet annually. However, the water-bearing material on the east side of the valley is probably more permeable than that on the west side, and to this extent the actual ground-water inflow may be somewhat greater than the computed inflow. As already indicated, only about one-third of this inflow is from the west.

In addition to underflow there is recharge by rainfall penetration, by artesian-well discharge, and possibly upward percolation of artesian water, and by surface water in the form of water applied in irrigation, waste drainage water, and stream flow. Discharge of the ground water is principally by evaporation and transpiration as the contours of the water table indicate little if any outward percolation. There is no known diversion of surface water out of the area.

As indicated on pages 245 and 246, recharge to the water table by rainfall penetration is a substantial quantity. As the capacity of the water-bearing material to absorb additional water where the capillary fringe reaches virtually to the surface is not known and as the texture of the soil and the amount and intensity of the rainfall range widely, it is not possible with the data available to estimate the amount of rainfall penetration. It is possible, however, to estimate roughly the quantity available for recharge by rainfall. The area enclosed by the 7,540-foot contour is approximately 160,000 acres. By assuming that the rainfall at Garnett, which was 7.93 inches in the calendar year of 1936, is representative of the rainfall within this area, the amount of rainfall was slightly more than 100,000 acre-feet.

In 1936 the discharge of artesian wells within the 7,540-foot contour, based on the artesian inventory was about 6,000 acre-feet. In addition there was leakage of the artesian wells underground and possibly upward percolation from the artesian aquifer. A part of this artesian water is undoubtedly disposed of by evaporation and transpiration, but a part of it produces recharge to the water table.

By using the evaporation and transpiration rate determined by White[27] for the Escalante Valley, Utah (p. 246)—that is, 2 acre-inches per acre where the depth to water is greater than 8 feet, 5 acre-inches per acre where it is from 5 to 8 feet, and 1 acre-foot per acre where it is less than 5 feet, it is possible to arrive at an estimate of the ground-water discharge. In July 1936 the depth to the water table was greater than 8 feet in about 18,000 acres, from 5 to 8 feet in about 69,000 acres and less than 5 feet in about 74,000 acres (pl. 5). On this basis the annual discharge of the ground water within the 7,540-foot contour would be about 100,000 acre-feet.

A recapitulation of the quantities involved in the recharge and discharge of the ground-water in the trough of the closed basin area shows that the recharge which can be attributed to percolation of unconfined water into the area and to water discharged by the flowing wells in the area is equal to only a small part, apparently less than one-fifth, of the ground-water discharge from the area.

It therefore appears that most of the recharge is due to rainfall penetration and inflow of surface water.

[27] White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil; Results of investigations in Escalante Valley, Utah: U. S. Geol. Survey Water-Supply Paper 659-A, pp. 87, 88, 1932.

TABLE 12.—*Pumping plants on wells in the San Luis Valley, Colo.*

No.	Owner	Year completed	Diameter (inches)	Depth (feet)	Size (inches) and type of pump [1]	Kind and amount of power [2]	Reported discharge (gallons a minute)	Remarks
9J34J1	C. D. Wadsworth	1936	16		14 T	D 35		
10H36L1	Frank Bennington	1931	16	32	6 H	G 6	300	
10H36N1	do	1936	16		6 H	— —		Pumping plant not installed.
10J35Q1	Jake Bennington		16	32	4 H	G —	450	
10K3N2	Unknown				6 H	— —		
10K22E1	do	1936			6 H	G —		
10K25G1	Fred Henry	1936	22	30-30	5 H	— —	600	2 wells connected.
10K25Q1	Ella Welty	1936	22	28-31	5 H	G —	700	Do.
10K32Q1	Lee Bassett	1931	14	41	4 H	G —	600	
10K35N1	Forrest Nelson estate	1935	16	45-45	8 H	G —	1,150	
11H2Q1	W. E. Gardner		36		— T	G —		
11J1G1	L. F. Kramer	1936	22		5 H	G —		
11J2B1	A. K. Dietrich	1931	16	28	4 H	G 4		
11J12G1	Roy McConnell	1934	20	50	8 T	G 20	450	
11J13E1	John Hynds		24	60	— V	G 20		
11J13N1	J. W. Davis	1934	20	60	9 T	G —	950	
11J14Q1	E. S. David	1934	20	60	9 T	G —	1,100	
11J20G1	Ethel Wright Scheel	1931	20	60	6 T	G 20	1,150	
11J21M1	Norman Chapman	1931	16	55	8 T	G 27	1,050	
11J21N1	J. C. Pepper	1932	20	65	8 T	G —		
11J22E1	Elmer Davis		20		— —	— —		Pumping plant not installed.
11J22M1	Abner Farrow		16		6 T	G 20		
11J24D1	Howard Macy	1936	24	56	— T	— —		Do.
11J24G1	do	1934			10 T	G 30	1,600	
11J24N1	Unknown		16		8 T	— —		
11J25E1	J. W. Schafer	1936	20	54	— —	G —		
11J25G1	Henry Hoagland	1934	20		6 H	G 27	500	
11J25K1	Roy McConnell	1933	20	56	8 T	G 30	1,400	
11J26E1	C. F. Monter	1936	16		— T	— —		Pumping plant not installed.
11J27E1	Unknown	1936	20		— T	G —		
11J27G1	do		20		6 H	G —		
11J28M1	Union Central Life Ins. Co.		18	37	— T	G 20		
11J29E1	Chester Mathias		16		5 H	G —	300	
11J30A1	Unknown	1936	22		— —	— —		Pumping plant not installed.
11J30G1	Chester Mathias		16		5 H	— —		Do.
11J32N1	Anna B. Wright		20-16	55	8 T	G —	600	2 wells connected.
11J35G1	Stanley Sanderson	1936	20		— —	— —		Pumping plant not installed.
11J35M1	John Hynds	1933	24		— T	G —	1,400	
11J35P1	do	1936	16	24	3 H	E —		
11J36G1	Creighton Sanderson	1931	30	55	10 T	G 40	1,350	
11K2G1	Clyde Kehler	1936	16	40	— —	— —		
11K2Q1	Max Selters	1936	16	40	6 T	G —		
11K3G2	Vern Bowsher	1934	16		8 H	G —	1,300	4 wells connected.
11K3N3	Opal N. King	1931	16	30	6 H	G —		2 wells connected.
11K4G1	Ed. E. Oliver	1936	16	30	— T	G —		Do.
11K7G1	O. V. Gromer		20	40	6 H	G 20	700	
11K8E1	J. F. Whitmer	1936	22	40	6 V	G —	700	
11K8G1	Geo. Bennington		16		6 H	— —		Pumping plant not installed.
11K8Q1	Al Goehl	1936	20		5 H	G —		2 wells connected.
11K9E2	Henry Selters	1936	20	51	8 H	G —		
11K9Q1	Jim Burns	1936	30	50	— T	G —		
11K10D1	Nell Newmeyer		20		6 H	G —		
11K11G2	Z. J. Fort		20	36	5 H	— —		Pumping plant not installed.
11K11X2	Frank Patterson		22	30	4 H	G —		
11K12Q1	A. B. Hughes		16		3 H	G —		2 wells connected.
11K13B1	Olin Perdew		16		8 H	G —		Do.
11K15E1	Jim P. Burns	1933	20		8 T	G —		
11K15M2	Vern Bowsher		20		— T	G 36		
11K16E1	Herman Goehl		16		8 H	G —	1,150	Do.
11K16G1	Cephus Bowsher		20		— T	E 20		
11K16N1	J. J. Smalley	1932	16	40	6 H	G —		Do.
11K16N2	do	1932	20		6 H	G —		
11K18M1	G. C. Hoffman	1931	20	40	— H	G —	450	
11K19E2	Jonathin Smith	1934	20	40	8 H	G —	900	
11K19G1	Henry Selters	1931	16	40	8 H	G —	1,300	Do.
11K19M1	Wright and James estate		20		— H	G —		
11K20E1	Sam Holland	1934	16	30	8 H	G —	950	Do.
11K20M1	Jim Wilson	1934	16	30	8 H	G 27	1,150	Do.
11K21E1	Joe Selters	1936	20	54	14 T	G 15	1,000	Do.
11K21G1	Leto Kehler		20	51	8 T	G —	700	
11K21M1	Mrs. Boyd	1936	20	32	6 H	— —		Do.
11K24G1	G. W. Keyes	1934	16	33	8 H	G —	900	Do.
11K24K1	C. F. James estate	1936	20		6 H	G —	250	
11K27M2	Unknown				— —	T —		
11K28M1	Chris Selters	1931	16	32	8 H	E 15	1,100	4 wells connected.
11K29E1	Harry Corlett	1936	22		— —	— —		Pumping plant not installed.
11K29K1	Joe Selters	1936	20	54	8 H	G —	850	
11K29M2	Chas. Dorney	1934	20	60	14 T	G —	1,050	
11K30E1	H. Grear		30	40	6 H	G —	350	
11K30G1	Mrs. E. G. Wright	1936	16		6 H	G —	600	
11K31E1	Felix Kayser	1934	24		— T	G —	600	
11K31G1	Joe Shown	1936	20	50	10 T	G —	750	
11K31M2	Ray Mets	1934	24	63	— T	G —	950	
11K32E1	H. C. Henry estate		20	50	14 T	G —	1,150	
11K32M1	Mr. Clark	1936	16		6 H	G —	1,150	2 wells connected.
11K36E1	Ella Welty		16		6 H	G —		Do.
11K36K1	Jim Nesley	1931	20		— T	E —		
11K36Q1	Mr. Solman	1931	16	30	6 H	G —	950	4 wells connected.
11L6E1	William Myers	1935	20	40	8 H	G —	1,200	2 wells connected.
11L7E3	Walker Myers	1935	20	40	8 H	G —	1,200	
11L17N2	John Heiman	1936	22	30	7 H	G —		Do.
11L29N2	F. E. Frye	1934	22	30	6 H	G —		
11L31B2	B. M. Gibson	1932	-16		6 H	G —		Do.
11L31E2	Jim Nesley	1934	16	35-35	6 H	G —		Do.
11L31N1	O. M. Wolfe	1931	16	35	6 H	E 10	1,050	Do.
11M17N2	do	1931	16	35	6 H	G —	800	Do.

[1] All pumps are centrifugal; H, horizontal; T, turbine; V, vertical.
[2] E, electric; G, gasoline; D, distillate.

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TABLE 12.—*Pumping plants on wells in the San Luis Valley, Colo.*—Continued

No.	Owner	Year completed	Diameter (inches)	Depth (feet)	Size (inches) and type of pump	Kind and amount of power	Reported discharge (gallons a minute)	Remarks
12J2K1	R. Sumner Long	1934	20		— T	G —	1,400	
12J2K2	do	1931	20		— —	— —		
12J3B1	H. L. Clark	1936	20	69	— —	— —		Pumping plant removed.
12J3K1	A. O. Miner	1936	20		— T	G —	650	
12J3M1	George Groutt	1936	20		— —	— —		Pumping plant not installed.
12J4G1	E. P. Long	1934	20	90	— T	G 27	1,500	
12J10B1	Marvin Metz	1936	20		— T	G —		
12J10K1	E. L. Neff	1934	16	44	— T	G 30		
12J11D1	Lester Hawkins		20	66	— T	G —	590	
12J11M1	do	1931	16		— T	G 30	1,300	
12J12B1	Minnie Wright	1934	16	35	— T	G—	1,300	
12J12D1	W. J. and Vern Sanderson		20		6 H	G —	450	
12J12M1	Lyman Wright	1931	20		8 T	G —	900	
12J14D1	Unknown				— T	G —	1,300	
12K2E1	George Hawkins		16		— V	G —		
12K4B1	P. E. Harney	1934	20		8 H	G —	1,050	
12K4K1	John Vinson	1936	16		8 H	G —		
12K5K1	Fred Scheel	1934	18		— T	G —		
12K5N1	W. I. Gilbreath	1936	20		8 H	G —	1,200	2 wells connected.
12K6E1	Unknown				8 H	G —	1,300	
12K6G1	Bishop Estate	1936	20	68	— T	G —	600	
12K6M1	Roy David		16	63	10 T	G —		
12K6M2	do	1936	20	26	8 H	G —	700	
12K7D1	Fred Scheel		16		8 H	G —	900	Do.
12K8D1	Warren Reynolds	1934	16		6 V	G —	600	
12K9K1	Anna B. Wright	1933	16	34	6 H	G —	800	Do.
12K9M1	Mr. Rawlins	1934	22		6 H	G —		Do.
12K10N1	Frank Ashcraft	1936	20	33	6 H	G —		
12K11D1	R. E. Johns	1934	16	33	8 H	G —		
12K11N1	W. D. Groat	1936	16	32	6 H	— —		Do.
12K11Q1	T. J. Bahr	1931	16		6 H	G —		
12K12B1	C. E. Coker	1936		32	6 H	G 30		
12K12M1	Clem Sydenstricker	1934	16		6 H	— —		Pumping plant not installed.
12K13D1	G. E. Oxley	1934	20	49	6 H	G —	800	
12K14D1	Theo. Schwarzbeck	1934	30		8 T	G —	1,100	
12K15B1	J. S. Campbell ranch		16		16 T	G 30	1,300	
					8 H	G —	1,350	2 wells connected.
12K15D1	William Mahl		16		6 H	G —		2 wells connected.
12K16M1	Fred Wright		16		8 H	G —	1,200	Do.
12K17Q1	Mr. Van Ostrand		16		8 H	G —	1,200	
12K18E1	Ella Welty	1936	20	42	8 T	G 30		
12K19D1	Unknown		16		6 H	G —	650	
12K22E1	A. G. Robertson		16	23	6 H	— —	900	
12L5Q1	B. J. Terhorst	1936	16		6 H	G —		
12L6D1	Joe Selters	1936	16	32	6 H	G —		Do.
12L6K1	Fred Dunker	1931	16		6 H	G —	960	Do.
12L6M1	W. C. Gilmore	1931	16	30	6 H	E 7½		Do.
12L7A1	Jack Owsley	1932	15	30	6 H	G —	960	Do.
12L7E1	Warren Clark	1932	18	30	6 H	E 10	650	Do.
12L7J1	Pete Entz	1931	16	36	6 H	G —	750	
12L7K1	William Entz	1931	15	33	6 H	G —	750	
12L7M1	Fred Schaak		30		5 H	G —		
12L8B1	Mrs. E. Farnsworth	1932	16		8 H	G —	1,100	Do.
12L8M1	Jess Montgomery	1932	16		5 H	G —		Do.
12L9D1	Frank Drake	1936	16		[illegible] H	G —	750	Do.
12L10D1	Henry Stahl	1933	16–18	23–33	8 H	G —	550	Do.
12L17B1	Clyde Funk	1936	16		5 H	G —	600	
12L18D1	Mr. Keck		16		6 H	G —		
12L19E1	R. G. Bohannon	1934	22	33	5 H	G —	650	
12L19B1	W. G. Beiriger		22	32	8 H	G —	900	Do.
12L19M1	Carl Saathoff	1934	22	33	8 H	G —	950	Do.
12L19K1	W. M. Entz	1932	16	30	— —	— —	900	Pumping plant removed.
12L30D1	Herbert M. Bailey	1936	22		6 H	— —		Pumping plant not installed.
12L30N1	C. F. Covey	1934	22	24	6 H	G —	700	
13K10D1	C. G. Wright				6 H	G —		
13K10K1	W. R. Riggenbach		22	40	6 H	G —	700	
13L18E1	Claud Thompson	1936	22	28	5 H	G 15		
13L19A1	Unknown		16		6 H	G —	350	
14K14D1	H. O. Wagner			20	6 H	G —		
14K15E1	W. J. Widger	1936	25	16	— H	G —	100	
14K22K1	G. Schneider		25		— H	G —	300	
14K26L1	R. W. White		28		— —	G —	100	
14K34G1	Whittier		40		— H	G —	550	
15K2L1	Herbert Winner		20	120	— —	G —	325	
15K12E1	Ed. Knapp		13	48	— —	G —	200	
15K12N1	D. O. Meister		20		— —	G —	120	
15K13Q1	W. W. McElhiney		25	106	— H	G —	300	
15K24G1	J. H. Kelley		55		6 V	G —	900	
15L7N1	D. E. Ryker	1934	23	10½	— H	G —	675	Well and buried drain connected.
15L18N3	J. K. Edmund		30		— —	G —	470	6 wells connected.
15L19E1	Forrest Kelley		48					

Confined or Artesian Water

Outline of Geologic and Artesian-water Conditions

General conditions.—The San Luis Valley is in the northern portion of the Rio Grande depression, described by Bryan in Section 1. The main part of the valley, north of the San Luis Hills, occupies an asymmetric structural basin in which has been deposited a large body of valley fill, with depositional contacts on the west side and a strong depression to the east and southeast on faults that are now concealed but are easily inferred. The lower part of the valley fill is considered to belong to the Santa Fe formation or its approximate equivalents of Pliocene age.

The name Santa Fe formation, used in this area by Siebenthal, is retained in the present description in order to give unity to the discussion of the older valley fill throughout the Rio Grande depression. The deposits in Colorado referred to as Santa Fe by Siebenthal and in this report are now mapped as the Hinsdale formation, which includes the Los Pinos member of dominantly sedimentary origin (see p. 208). The distinction probably has no hydrologic significance.

Resting unconformably on this older valley fill is the Alamosa formation, regarded by Siebenthal [28] as either late Pliocene or early Pleistocene. The Alamosa formation lies at the surface over almost the entire valley, and in its uppermost part consists largely of sand and gravel, which contain the shallow ground water under water-table conditions that have already been described. At greater depths, however, this formation consists chiefly of alternating strata of sand and clay, the sand strata containing large quantities of water under artesian pressure. In the portion of the valley lying north of the San Luis Hills flowing wells can be obtained over an area of about 1,430 square miles, the greatest length of the area of artesian flow, from north to south, being about 66 miles and its greatest width about 32 miles (pl. 5). The numerous streams that enter the valley from the mountainous borders have built alluvial fans that coalesce along their margins and extend toward the interior of the valley, which is characterized by extreme flatness. The fans, especially in their upper parts, are underlain largely by gravel, but toward the interior of the valley the coarse material gives way largely to sand and clay.

Santa Fe formation.—The Santa Fe formation is exposed in basalt-capped mesas in the vicinity of Fort Garland and in a series of low hills extending from Trinchera Creek to San Pedro Mesa. On the west side of the valley the formation is represented by red sand and gravel about 300 feet thick with overlying basalt dipping gently eastward under the valley.[29] As seen in these exposures the Santa Fe formation consists of irregularly bedded sediments and associated lava flows. Its gravel beds are less regular and more cemented than those of the overlying Alamosa formation, and its clay beds are less continuous. It has undergone more deformation and hence its dips are more erratic.

In the southern part of the valley, where the top of the Santa Fe formation lies at or near the surface, several wells penetrated lava that is believed to be associated with this formation.

The Santa Fe formation probably underlies most of the valley and attains considerable thickness. In the trough of the valley, however, the Alamosa formation reaches its greatest thickness, and only a few wells have been drilled deep enough to possibly enter the Santa Fe formation. A test well,[30] 4½ miles east of Mosca, in the SW¼SE¼ sec. 5, T. 39 N., R. 11 E., was drilled in search of oil to a depth of 1,283 feet, apparently without reaching the bottom of the Alamosa formation. However, two other oil tests—one near Hooper and one near Mosca—may have passed through the Alamosa formation. These encountered flows of hot water below a depth of 2,100 feet, possibly in the Santa Fe formation. In these wells definite interpretation of the strata penetrated is not possible, because of lack of detail with which the different strata were reported.

The oil-test well, 10M27A1, located about 2 miles northeast of Hooper, was drilled to a depth of 4,308 feet, and a strong flow of hot water was encountered at a depth reported to be between 2,100 and 2,600 feet. This water has a temperature between 115 and 120 degrees. A similar discharge of hot water resulted from the test well 8 miles east of Mosca, in sec. 11, T. 39 N., R. 11 E., which was drilled in 1915 to a depth of 2,655 feet. According to the log, the well originally flowed 350 gallons a minute, from a depth between 2,200 and 2,655 feet, with a temperature of about 140 degrees.

The character of the formation at its outcrops indicates that the Santa Fe formation would probably not yield water as readily as the Alamosa formation. Sufficient evidence, however, has not yet been presented to entirely condemn it as a potential producer of water. Future prospecting for flowing wells outside of the present area of artesian flow may serve to clarify some of the questions that have arisen concerning possible artesian aquifers in the Santa Fe formation.

Alamosa formation.—The Alamosa formation forms a continuous blanket of sediments that mantle almost the entire valley. In the interior of the valley it consists of alternating beds of water-bearing sand and dense blue clays, but near the borders of the valley these beds are in part replaced by materials of coarser texture in the alluvial fans. The formation is best known from the logs of artesian wells.

The exact manner in which the sediments were deposited is not fully known. Siebenthal [31] believed that shore features were indicated by coarse material near the edges of the fans and that the preponderance of fine material in the interior of the valley, together with the persistence and continuity of these thin beds of sand and clay, were proofs of deposition in a relatively deep lake. He pointed out that wells in the interior of the valley show heavy clay beds and relatively few aquifers, whereas wells nearer the margin of the valley show thinner clay beds and more aquifers. Bryan has, however, reviewed the problem and has concluded that the

[28] Siebenthal, C. E., op. cit., p. 46.
[29] Siebenthal, C. E., op. cit., pp. 30-31.
[30] Siebenthal, C. E., op. cit., p. 43.
[31] Siebenthal, C. E., op. cit., pp. 44-46.

sediments are chiefly stream and wind deposits and that the valley has not been occupied by any deep permanent lake. He infers that the valley floor was lowered coincident with deposition, and that the beds were deposited on alluvial plains similar to those of the present on which temporary lakes may have existed. (See p. 217.)

The Alamosa formation consists largely of alternating beds of water-bearing sand and relatively impermeable clay that confines the water within the sand aquifers. Along the margins of the valley the strata are inclined toward the interior, and thus the water received in the higher parts of the alluvial slopes, largely from the mountains, is transmitted through the aquifers to lower parts of the valley. When the confining beds are penetrated by wells on the valley floor, water is encountered under sufficient hydrostatic pressure to produce flowing wells.

The number of beds of water-bearing sand encountered in the Alamosa formation differs from place to place. The sand strata range in general from about 1 to 20 feet in thickness, and are separated from one another by layers of blue clay ranging from a few feet to as much as a few hundred feet in thickness. As a general rule, the greatest number of water-bearing sands may be expected in the interior of the valley, where the sediments presumably reach their maximum thickness. Thus, a 3-inch well, drilled in 1931 at the Adams State Teachers College, in Alamosa, to a depth of 897 feet, was reported by Mr. Ray Wells, the driller, to have encountered 10 different flows; Siebenthal [32] records the log of a well in the southwest corner of the NE¼ sec. 9, T. 37 N., R. 9 E., 482 feet in depth, which encountered eight flows; and several other logs were recorded which encountered as many as 7 flows.

There is little regularity in the number of flows reported for wells that are drilled even in the same neighborhood. Since the use of rotary drilling equipment is almost universal in the valley, there is little doubt that many of the weaker flows are not reported in the logs. Thus, it is probable that in some logs every change in material is recorded, where in others only the stronger flows are recorded. On account of this lack of uniformity, any correlation of flows between wells is practically impossible, with the exception, perhaps of the first flow encountered.

Evidence has been presented to show that the shallow ground water and the artesian water have a common source. Along the edges of the valley and especially opposite the mouths of the canyons, the confining clay beds give way to sand and gravel, and this marginal strip, outside of the area of artesian flow, is the area of artesian recharge.

[32] Siebenthal, C. E., op. cit., p. 63.

Source of the Artesian Water

On account of the very nature of an artesian system the artesian supply must come from water entering the higher portions of the system. All the requisites of an ideal artesian basin are present in the San Luis Valley. Water derived from mountain streams flows across the alluvial slopes bordering the valley, enters the alluvial fan deposits, and thence passes into the sand strata, which are overlain by the gently upturned confining clay beds. Some of the streams coming from the mountains to the east never get as far as the valley floor, while the volume of others is greatly reduced in flowing across the alluvial slopes. Some of the streams entering the valley from the west side are much larger than any of the east-side streams, and they also suffer losses in passing across the gravelly stretches of the alluvial slopes. Perennial streams, such as the Rio Grande and the Conejos, contribute substantial amounts of water to the artesian aquifers, either directly or by seepage of irrigation water. Much of the run-off carried by the minor streams on the west side is likewise available for artesian recharge, as the streams also lose water by seepage where they cross the coarse-textured material comprising the alluvial slopes.

By far the largest contributions to the supply of artesian water in recent years have come from seepage of the surface water that is used for irrigation, and the aggregate seepage loss is now much greater than it was under natural conditions before the water from the streams was diverted for irrigation. The resulting increase in the artesian head is explained on pages 260–261. Recharge of any artesian stratum is, however, confined to a belt along the margin of the valley that is not underlain by the confining bed of that stratum, and all artesian recharge is limited to the general marginal belt outside of the somewhat indefinite edge of the uppermost confining bed. In contrast, recharge of the shallow aquifer may occur by percolation to the water table in any part of the valley where the surficial material is at all permeable.

Water that falls as rain or snow on any part of the marginal belt of artesian intake may contribute to the artesian aquifers by penetrating to the water table. This process is closely allied to the building up of the water table by seepage from the streams and seepage of surface water after it has been diverted for irrigation. Owing to the complex nature of the several sources and the combination of effects governing the flow in the artesian aquifers, it is not practicable to isolate any one source from the others.

The available information indicates that under present conditions the water table is held at a high level in those parts of the artesian intake belt that are supplied by irrigation seepage and that this seepage is the principal present source of artesian recharge; however, it also indicates that there is also substantial recharge of the artesian intake belt by seepage directly from the streams and by direct penetration of the rain and snow water.

Upper Confining Bed

The first artesian flow occurs at about 100 feet near Monte Vista, at about 175 feet near Parma, at about 250 feet in Alamosa, at about 125 feet in Blanca, at about 155 feet in Center, at about 175 feet in Garnett, at about 200 feet in Hooper and Mosca, and at about 115 feet in the vicinity of Swede Corners. Along the entire distance between Center and Hooper the first confining bed is struck between 80 and 90 feet. The railroad well at Moffat is reported to have encountered its first flow at 365 feet. The Nash well, in the SE¼NE¼ sec. 7, T. 43 N., R. 11 E., 6 miles due east of Moffat, had a reported depth of 520 feet to the first sand that produced a flow at the surface, but other sands with water under artesian pressure were probably encountered at higher levels. A group of wells at the State fish hatchery, half a mile south of La Jara, encountered the first flow at depths of 40 to 50 feet below the surface, the depth to the top of the clay being only about 30 feet. A well 2¼ miles north of Manassa, in the NW¼NW¼ sec. 1, T. 34 N., R. 9 E., encountered its first flow at a depth of 60 feet.

Probably the most impressive evidence of the continuity and effectiveness of the upper confining bed is in the fact that nearly everywhere in the valley the water in the underlying aquifer is under sufficient head to rise above the level of the unconfined shallow water. The pattern of the confining bed may, however, be lenticular in character with the impermeable lenses overlapping and interlacing to the extent that any upward movement of the water is greatly impeded although not entirely prevented. Siebenthal[33] believed that the persistence of the upper confining bed is further demonstrated by the absence in the first underlying aquifer of alkaline water, such as the shallow ground water. However, as the water in this aquifer is under artesian head, it tends to move upward, thereby making downward percolation of alkaline water impossible, even if the confining bed is not entirely impermeable.

Insofar as is known, the only natural rupture in the confining bed in the central part of the valley discernible at the surface is at the Washington Springs, just north of the Denver & Rio Grande Western R. R., 7 miles east of Alamosa, in the northeast corner of sec 15, T. 37 N., R. 11 E. In 1906, Siebenthal[34] estimated a flow of about 10 gallons a minute from the base of Hansen Bluff on the north side of the railroad and observed a pool on the top of one of the mounds that constitute the continuation of Hansen Bluff. No such discharge was visible in 1936, although vegetation adjacent to the bluff gave evidence that there was a small discharge of ground water at that point.

The failure of the flow of the Washington Springs was recognized by White[35] when he visited them in 1916. He attributed the failure of the springs to the well development that had been undertaken in the central and western parts of the adjacent townships in the 3 or 4 years previous to 1916, and mentioned the fact that the Hansen wells, located a few hundred feet from these springs, had almost ceased flowing. During the present investigation it was learned that the drilling of wells on the higher land east of Hansen Bluff materially diminished the flow of other wells and of Washington Springs. Conversely, when wells were plugged on the lower bench in the vicinity of Hansen Bluff, the wells upon the higher land became respectively stronger. The mutual interference between the flowing wells and the Washington Springs indicates that these springs are essentially artesian in origin. Siebenthal[36] mentions a spring mound on the lower land south of the railroad and in the same section as Washington Springs. When visited in the spring of 1936 the mound presented a hummocky surface with small round pools of standing water, but in the summer of 1936 there was no longer any water in the depressions, and it was necessary to dig a small hole in the mound to obtain a sample of water for analysis.

Permeability and Transmissibility of the Artesian Aquifers

In the present investigation tests were made by the method developed by Theis (p. 237) to determine the transmissibility of the artesian aquifers at five representative points in the valley. Although more such tests would have been desirable, the data obtained aided materially in making estimates of the rate at which water is transmitted by the aquifers. The tests were made on flowing wells already in existence. The procedure was as follows: (1) the static head of the water after the well had been closed for some time was measured, (2) the well was opened and allowed to flow for several days, and the discharge was measured as accurately as possible from time to time as a check on the uniformity of flow, (3) the well was again closed, and measurements of head were made periodically until it approached the original static head at the beginning of the test.

The equipment used in these tests was comparatively simple. Expanding soil plugs were used to close the

[33] Siebenthal, C. E., op. cit., p. 44.
[34] Siebenthal, C. E., op. cit., p. 103.
[35] White, W. N., The San Luis Valley, Colorado; Irrigation from artesian wells and general irrigation and drainage problems involved in land classification: p. 10, manuscript in files of U. S. Geological Survey, Conservation Branch, 1916.
[36] Siebenthal, C. E., op. cit., p. 103.

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wells. A mercury-manometer pressure gage, developed by G. H. Taylor, of the United States Geological Survey, was connected to the end of the soil plug, and was used to measure the artesian head. The flow of all wells was small enough so that volumetric measurements could be made of their discharges by simply using a 5-gallon bucket and a stopwatch.

The essential data for each of the five wells that were used for transmissibility tests are presented in tables 13 and 14.

TABLE 13.—*Location and description of the artesian wells used for transmissibility determinations*

Well No.	Location	Diameter (inches)	Depth (feet)	Average discharge (gallons per minute)	Highest static head above land surface (feet)	Distance of measuring point above land surface (feet)	Period of test
9K6G1	11½ miles south of Saguache	3	[1] 218.9	53.3	54.0	2.4	Oct. 6-10, 1936.
11M4B2	In town of Hooper [2]	4½	740	36.0	47.6	1.0	Oct. 22-28, 1936.
12K14R1	6 miles northeast of Monte Vista	2	[1] 172.6	18	15.1	1.5	Sept. 8-12, 1936.
14K25E4	2¼ miles northwest of 15L6K1	4½	[1] 118.2	28	7.4	.5	Sept. 9-25, 1936.
15L6K1	11 miles southwest of Alamosa	3	[1] 120.3	60	22.2	.5	Sept. 9-15, 1936.

[1] Measured depth, 1936.
[2] Garrison Mill & Elevator Co., well, U. S. Geol. Survey Water-Supply Paper 240, p. 85, 1910.

TABLE 14.—*Record of the static head of 5 artesian wells during the period of tests to determine transmissibility of the artesian aquifer*

9K6G1 Time	Head (feet)
Oct. 6:	
4:33 p. m.	51.50
4:38 p. m.	51.50
4:48 p. m.	(1)
Oct. 9:	
10:49 a. m.	(2)
10:54 a. m.	47.00
10:56 a. m.	47.75
10:58 a. m.	48.15
11:00 a. m.	48.40
11:03 a. m.	48.80
11:06 a. m.	48.95
11:09 a. m.	49.10
11:12 a. m.	49.30
11:15 a. m.	49.40
11:20 a. m.	49.60
11:25 a. m.	49.70
11:30 a. m.	49.85
11:35 a. m.	49.95
11:40 a. m.	50.05
11:45 a. m.	50.15
11:50 a. m.	50.25
11:55 a. m.	50.35
12:00 M.	50.40
12:10 p. m.	50.50
12:20 p. m.	50.60
12:30 p. m.	50.70
12:45 p. m.	50.80
1:00 p. m.	50.90
1:15 p. m.	51.00
1:30 p. m.	51.05
1:45 p. m.	51.10
2:00 p. m.	51.15
4:58 p. m.	51.25
5:05 p. m.	51.30
Oct. 10:	
11:20 a. m.	51.60
11:26 a. m.	51.60

11M4B2 Time	Head (feet)
Oct. 23:	
12:48 p. m.	44.35
12:54 p. m.	(1)
Oct. 26:	
1:42¼ p. m.	(2)
1:43¼ p. m.	36.10
1:44 p. m.	36.60
1:45 p. m.	37.00
1:46 p. m.	37.55
1:47 p. m.	37.80
1:48 p. m.	38.15
1:49 p. m.	38.35
1:50 p. m.	38.60
1:51 p. m.	38.70
1:52 p. m.	38.80
1:53 p. m.	38.95
1:54 p. m.	39.10
1:55 p. m.	39.20
1:57 p. m.	39.45
1:59 p. m.	39.70
2:01 p. m.	39.80
2:03 p. m.	39.90
2:05 p. m.	40.10
2:08 p. m.	40.15
2:11 p. m.	40.20
2:14 p. m.	40.35
2:17 p. m.	40.55
2:20 p. m.	40.65
2:23 p. m.	40.80
2:26 p. m.	40.90
2:30 p. m.	41.10
2:35 p. m.	41.25
2:40 p. m.	41.40
2:45 p. m.	41.50
2:50 p. m.	41.65
2:55 p. m.	41.80
3:00 p. m.	41.90
3:05 p. m.	42.00
3:10 p. m.	42.10
3:15 p. m.	42.25
3:20 p. m.	42.30
3:25 p. m.	42.40
3:30 p. m.	42.45
3:40 p. m.	42.60
3:50 p. m.	42.70
4:00 p. m.	42.90
4:15 p. m.	43.05
4:30 p. m.	43.20
4:45 p. m.	43.30
5:00 p. m.	43.40
Oct. 27:	
10:23 a. m.	45.70
10:30 a. m.	45.70
4:04 p. m.	46.00
4:10 p. m.	46.00
Oct. 28:	
11:22 a. m.	46.55
11:31 a. m.	46.65

12K14R1 Time	Time (feet)
Sept. 8:	
3:19 p. m.	13.6
3:25 p. m.	13.6
3:27 p. m.	(1)
Sept. 11:	
10:46 a. m.	(2)
10:48 a. m.	8.60
10:49 a. m.	8.90
10:50 a. m.	9.10
10:51 a. m.	9.30
10:52 a. m.	9.40
10:53 a. m.	9.50
10:54 a. m.	9.60
10:55 a. m.	9.70
10:56 a. m.	9.90
10:57 a. m.	9.95
10:58 a. m.	10.00
10:59 a. m.	10.05
11:00 a. m.	10.10
11:05 a. m.	10.35
11:10 a. m.	10.50
11:15 a. m.	10.60
11:20 a. m.	10.75
11:25 a. m.	10.90
11:30 a. m.	10.90
11:35 a. m.	11.00
11:40 a. m.	11.00
11:45 a. m.	11.05
11:50 a. m.	11.10
11:55 a. m.	11.00
12:00 M.	11.20
12:15 p. m.	11.30
12:30 p. m.	11.40
12:45 p. m.	11.45
1:00 p. m.	11.55
1:15 p. m.	11.60
1:30 p. m.	11.70
1:45 p. m.	11.75
2:00 p. m.	11.75
4:20 p. m.	12.10
4:25 p. m.	12.10
4:30 p. m.	12.10
Sept. 12:	
10:26 a. m.	12.55
10:30 a. m.	12.55
10:35 a. m.	12.60
4:19 p. m.	12.60
4:25 p. m.	12.60

14K25E4 Time	Head (feet)
Sept. 14:	
2:44 p. m.	6.90
2:54 p. m.	6.95
3:01 p. m.	(1)
Sept. 22:	
1:37 p. m.	(2)
1:39 p. m.	3.90
1:41 p. m.	4.15
1:43 p. m.	4.25
1:45 p. m.	4.40
1:47 p. m.	4.50
1:49 p. m.	4.55
1:51 p. m.	4.60
1:54 p. m.	4.75
1:57 p. m.	4.80
2:00 p. m.	4.85
2:03 p. m.	4.90
2:06 p. m.	4.95
2:10 p. m.	5.05
2:15 p. m.	5.10
2:20 p. m.	5.15
2:25 p. m.	5.20
2:30 p. m.	5.25
2:40 p. m.	5.35
2:50 p. m.	5.45
3:00 p. m.	5.50
3:10 p. m.	5.55
3:20 p. m.	5.60
3:30 p. m.	5.65
3:40 p. m.	5.70
3:50 p. m.	5.75
4:00 p. m.	5.75
4:15 p. m.	5.75
4:30 p. m.	5.80
4:45 p. m.	5.85
5:00 p. m.	5.90
5:15 p. m.	5.90
Sept. 23:	
10:53 a. m.	6.45
11:00 a. m.	6.50
11:05 a. m.	6.50
2:12 p. m.	6.53
2:17 p. m.	6.55
5:31 p. m.	6.55
5:36 p. m.	6.60
Sept. 24:	
12:07 p. m.	6.70
12:15 p. m.	6.70
Sept. 25:	
4:54 p. m.	6.95
5:00 p. m.	7.00

15L6K1 Time	Head (feet)
Sept. 10:	
11:26 a. m.	21.70
11:40 a. m.	21.70
12:04 p. m.	(1)
Sept. 14:	
11:24 a. m.	(2)
11:31 a. m.	13.95
11:33 a. m.	14.05
11:34 a. m.	14.[illegible]
11:36 a. m.	14.[illegible]
11:37 a. m.	14.5[illegible]
11:38 a. m.	14.65
11:39 a. m.	14.75
11:40 a. m.	14.80
11:41 a. m.	14.95
11:42 a. m.	15.00
11:43 a. m.	15.05
11:44 a. m.	15.15
11:45 a. m.	15.25
11:46 a. m.	15.30
11:47 a. m.	15.35
11:49 a. m.	15.45
11:51 a. m.	15.55
11:54 a. m.	15.70
11:57 a. m.	15.85
12:00 M.	15.95
12:05 p. m.	16.10
12:10 p. m.	16.35
12:15 p. m.	16.45
12:20 p. m.	16.55
12:25 p. m.	16.65
12:30 p. m.	16.85
12:35 p. m.	16.90
12:40 p. m.	17.00
12:45 p. m.	17.10
12:50 p. m.	17.20
12:55 p. m.	17.25
1:00 p. m.	17.30
1:10 p. m.	17.45
1:20 p. m.	17.60
1:30 p. m.	17.70
1:40 p. m.	17.80
1:50 p. m.	17.85
2:00 p. m.	17.95
4:05 p. m.	18.65
4:10 p. m.	18.70
4:15 p. m.	18.75
4:20 p. m.	18.75
4:25 p. m.	18.75
4:30 p. m.	18.80
Sept. 15:	
10:45 a. m.	20.35
10:50 a. m.	20.35
10:55 a. m.	20.35
11:00 a. m.	20.35
4:06 p. m.	20.55
4:10 p. m.	20.55
4:15 p. m.	20.55

[1] Well opened.
[2] Well closed.

The recovery equation of the Theis method involves only two variables—that of $\log_{10} (t/t')$ and v'. From the form of the equation the data for these two variables should plot as a straight line on semilog paper. It will be noted from figure 53 that, with the exception of well 11M4B2, all the points fall very close to a straight line. Measurements on this well, for the first few hours of recovery, fall to the left of the straight line determined from later measurements. It will also be noted that the line is not continuous—the portion determined by measurements near the end of the test lying parallel to but on the left of the line for earlier measurements. It is not clear why all the points for this curve do not plot closer to a straight line, similar to the other curves. A possible explanation may be had from the performance of the well prior to shutting it for the recovery measurements.

The well had been closed in for about 6 months before the test. When the well was opened a large amount of fine sand and a small amount of clay were discharged with the water. The water also carried considerable inflammable gas. It was also noted, during this period of flow, that there was a definite surge of the discharge occurring at irregular intervals. The discharge of sand and clay may have increased the permeability of the material in the aquifer immediately surrounding the well. The static head, determined at the end of the test, was greater than that at the beginning of the test. These factors may have exerted some influence, whose effect is shown by the failure of the measurements to plot as a straight line.

As the head of an artesian well rises and falls in response to changes in barometric pressure (p. 261), all the measurements of head were corrected to a constant barometric pressure before plotting the recovery curve. In making the correction, it was assumed that the well was 100 percent efficient as a water barometer. The maximum water-level correction for barometric changes in pressure was only 0.23 feet, and most of the corrections were less than 0.10 foot.

Computations for the coefficient of transmissibility are simplified by using as v', the difference, from the curve, between the abscissas at the points where t/t' equals 1 and where t/t' equals 10. By doing this, the last term of the equation becomes equal to 1. The coefficients of transmissibility for the wells, computed on this basis are as follows: 9K6G1, 11,500; 11M4B2, between 1,800 and 2,300; 12K14R1, 3,800; 14K25E4, 7,800; 15L6K1, 5,300.

The average depth of the four wells (9K6G1, 12K14R1, 14K25E4, and 15L6K1) located on the west side of the valley, is about 160 feet, and their average coefficient of transmissibility is about 7,000. The four wells penetrate an average of 125 feet below the top of the first confining bed. On the basis of a thickness of 125 feet, the computed average permeability is 56, including the confining as well as the productive beds.

Head of the Artesian Water With Reference to the Land Surface

The pressure head of water at a given point in an aquifer is its hydrostatic pressure expressed as the height of a column of water that can be supported by the pressure. It is the height that a column of water rises in a tightly cased well that has no discharge.[37] During the course of the present investigation the heads of only a few wells were measured, partly because only a limited amount of time was apportioned for this phase of the work and partly because it was difficult to get permission from the well owner to close the wells on account of the possibility of injuring them. As most of the wells in the valley, except the city wells, are only partly cased, it is generally feared that any sudden changes produced by closing or opening the wells might cause the wells to cave, and thus to reduce their flow. No ill effects were noticeable after closing and opening the wells in the valley on which measurements of head were made.

During the investigation monthly measurements were made on 22 artesian wells. Of this number, 14 are on the Rio Grande alluvial fan, 6 are in the vicinity of Diamond Springs, in the southwestern part of the valley, and 2 are abandoned artesian wells in the closed basin area.

The wells on the Rio Grande alluvial fan either lacked sufficient head to flow at the surface or were intermittent, that is, flowing during only a part of the year. Three of the wells in the vicinity of Diamond Springs flowed, and these were shut in long enough to obtain measurements of head. The other three wells did not have sufficient head to flow, and hence their water levels were measured from the tops of the casings.

Tables 15 and 16 show all measurements that were made on artesian wells during 1936.

TABLE 15.—*Records of water levels in artesian wells of San Luis Valley*

10J27A1.—Unknown. Domestic and stock well, 2 inches in diameter, drilled 128 feet deep. Measuring point, top of casing 0.2 foot above land surface.

Date	Depth to water (feet) [1]	Date	Depth to water (feet) [1]
Apr. 7, 1936	0.31	Dec. 18, 1936	+1.18
June 8, 1936	+1.30		

10J28A1.—L. M. Gardner estate. Stock well, 2 inches in diameter, drilled 135 feet deep. Measuring point, top of lower valve seat 0.6 foot above land surface.

Date	Depth to water (feet) [1]	Date	Depth to water (feet) [1]
Apr. 17, 1936	9.41	Aug. 18, 1936	7.30
May 5, 1936	8.03	Sept. 18, 1936	7.13
June 8, 1936	7.34	Oct. 14, 1936	6.93
July 22, 1936	7.23	Dec. 18, 1936	7.73

[1] Plus sign preceding measurement indicates water level above measuring point.

[37] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U. S. Geol Survey Water-Supply Paper 494, p. 37, 1923.

TABLE 15.—*Records of water levels in artesian wells of San Luis Valley*—Continued

11J2A1.—A. K. Dietrich. Domestic and stock well, 2 inches in diameter, drilled 180 feet deep. Measuring point, top of casing, 0.2 foot above land surface.

Date	Depth of water (inches) [1]	Date	Depth to water (feet) [1]
Apr. 2, 1936	0.26	June 8, 1936	+1.39
Apr. 20, 1936	(2)	Dec. 18, 1936	+.34

11J13C1.—Mrs. J. C. Hynds. Domestic well, 2 inches in diameter, drilled 150 feet deep. Measuring point, top of casing 0.1 foot above land surface, altitude 7,682.70 feet.

Date	Depth to water (feet) [1]	Date	Depth to water (feet) [1]
Apr. 7, 1936	1.67	Sept. 18, 1936	0.26
June 5, 1936	(2)	Oct. 19, 1936	.06
July 10, 1936	(2)	Nov. 16, 1936	.31
July 20, 1936	.41	Dec. 17, 1936	.99
Aug. 18, 1936	.52		

11J13R1.—Howard Macy. Stock well, 2 inches in diameter, bored 123 feet deep. Measuring point, top of casing 2.2 feet above land surface, altitude 7,680.68 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 18, 1936	5.75	Sept. 18, 1936	4.50
May 5, 1936	3.72	Oct. 14, 1936	4.29
June 8, 1936	3.05	Nov. 16, 1936	4.55
July 20, 1936	4.33	Dec. 17, 1936	5.15
Aug. 18, 1936	4.68		

11J13R2.—Howard Macy. Stock well, 2 inches in diameter, bored 173 feet, deep. Measuring point, ½-inch reducer plug, top of casing 2.9 feet above land surface, altitude 7,681.43 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 18, 1936	2.74	Sept. 18, 1936	[illegible].57
May [illegible], 1936	2.11	Oct. 14, 1936	[illegible].41
June 8, 1936	1.23	Nov. 16, 1936	1.63
July 20, 1936	1.77	Dec. 17, 1936	1.98
Aug. 18, 1936	1.89		

11J14P1.—J. H. Boats. Domestic well, 2 inches in diameter, bored 145 feet deep. Measuring point, top of lower valve seat of suction pump 2.0 feet above land surface.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 18, 1936	9.40	Sept. 18, 1936	7.12
May 5, 1936	8.11	Oct. 4, 1936	7.12
June 8, 1936	6.50	Nov. 16, 1936	7.48
July 20, 1936	7.09	Dec. 17, 1936	8.19
Aug. 18, 1936	7.32		

11J23H1.—Mrs. Anna McCormick. Domestic well, 4 inches in diameter, drilled 150¼ feet deep. Measuring point, top of lower valve seat of suction pump 2.5 feet above land surface.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 18, 1936	8.11	Sept. 18, 1936	6.22
May 5, 1936	7.10	Oct. 14, 1936	6.19
June 8, 1936	5.72	Nov. 16, 1936	6.50
July 20, 1936	6.31	Dec. 17, 1936	7.02
Aug. 18, 1936	6.45		

[1] Plus sign preceding measurement indicates water level above measuring point.
[2] Reported by owner or tenant.

TABLE 15.—*Records of water levels in artesian wells of San Luis Valley*—Continued

11J25R1.—Roy McConnell. Domestic well, 2 inches in diameter, drilled 207 deep. Measuring point, top of 2-inch union in the period Apr. 7 to July 19; on and after July 20 top of casing 0.14 foot below top of 2-inch union and 2.0 feet above land surface, altitude 7,682.81 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 7, 1936	2.60	Aug. 18, 1936	1.05
May 5, 1936	1.78	Oct. 14, 1936	.94
June 8, 1936	.91	Nov. 16, 1936	1.20
July 20, 1936	[3] 1.35		

11N32R1.—Unknown. Abandoned well, 2 inches in diameter. Measuring point, top of casing 1.0 feet above land surface.

Date	Depth to water (feet)	Date	Depth to water (feet)
Mar. 17, 1936	2.27	Aug. 14, 1937	0
Apr. 16, 1936	2.29	Sept. 15, 1936	0
May 15, 1936	0	Oct. 13, 1936	0
June 13, 1936	0	Dec. 11, 1936	(4)
July 16, 1936	0		

12J12P1.—Lyman Wright. Stock well, 2 inches in diameter, drilled 138 feet deep. Measuring point, top of casing 0.2 foot above land surface, altitude, 7,681.74 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
Mar. 30, 1936	1.78	Aug. 17, 1936	0.12
Apr. 3, 1936	2.00	Sept. 17, 1936	.01
Apr. 17, 1936	1.70	Oct. 14, 1936	0
May 5, 1936	1.23	Nov. 16, 1936	.41
June 8, 1936	.02	Dec. 17, 1937	.81
July 17, 1937	.30		

12J13C1.—H. A. Mathias. Stock well, 2 inches in diameter, drilled 159 feet dee. Measuring point, top of casing at land surface, altitude 7,680.36 feet.

Date	Depth to water (feet) [1]
Apr. [illegible], 1936	[illegible].81
July 17, 1936	+.85

12J26D1.—Frank C. Seyfried. Domestic well, 2 inches in diameter, drilled 168 feet deep. Measuring point, top of casing 0.5 foot above land surface.

Date	Depth to water (feet) [1]	Date	Depth to water (feet)
Apr. 10, 1936	2.90	Sept. 17, 1936	0.38
May 5, 1936	1.68	Oct. 14, 1936	.79
June 8, 1937	+.17	Nov. 16, 1936	1.43
Aug. 17, 1936	.04		

12K6C1.—Van Ostrand. Stock well, 2 inches in diameter, drilled 150 feet deep. Measuring point, top of 8-inch galvanized iron extension to 2-inch casing 5.5 feet above land surface, altitude 7,677.89 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
July 10, 1936	[5] 1.46	Aug. 25, 1936	1.50
July 21, 1936	1.75	Sept. 1, 1936	1.47
July 24, 1936	1.82	Sept. 8, 1936	1.33
July 27, 1936	1.90	Sept. 15, 1936	1.28
July 28, 1936	1.91	Sept. 22, 1936	1.22
Aug. 3, 1936	1.81	Sept. 29, 1936	1.15
Aug. 10, 1936	1.61	Oct. 6, 1936	1.14
Aug. 17, 1936	1.77	Oct. 13, 1936	[6] 1.23

[1] Plus sign preceding measurement indicates water level above measuring point.
[3] New masuring point, see description.
[4] No measurement, ice in well.
[5] Water-stage recorder installed.
[6] Water-stage recorder removed.

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TABLE 15.—*Records of water levels in artesian wells of San Luis Valley*—Continued

12K6D1.—Van Ostrand. Domestic and stock well, 2 inches in diameter, bored 175.8 feet deep. Measuring point, top of Tee on casing, 0.9 foot above land surface, altitude 7,680.06 feet.

Date	Depth to water (feet)	Date	Depth to water (feet)
July 10, 1936	0.46	Sept. 22, 1936	0.38
July 21, 1936	.81	Sept. 29, 1936	.32
Aug. 10, 1936	.67	Oct. 6, 1936	.31
Aug. 17, 1936	.83	Oct. 13, 1936	.37
Sept. 1, 1936	.57	Oct. 20, 1936	.40
Sept. 8, 1936	.47	Nov. 16, 1936	.67
Sept. 15, 1936	.43	Nov. 17, 1936	1.69

13Q28B1.—Unknown. Abandoned well, 3 inches in diameter, drilled 103 feet deep. Measuring point, top of casing 2.1 feet above land surface.

Apr. 15, 1936	1.64	Sept. 12, 1936	1.71
May 14, 1936	1.59	Oct. 12, 1936	1.64
June 11, 1936	1.65	Nov. 10, 1936	1.59
July 13, 1936	1.77	Dec. 10, 1936	1.48
Aug. 13, 1936	1.75		

16K13A1.—Mrs. F. M. Wilson. Unused well 8 inches in diameter, drilled 200 feet, measured 136 feet. Measuring point, top of casing 0.8 foot above land surface.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 14, 1936	4.85	July 23, 1936	4.98
May 14, 1936	4.46	Aug. 19, 1936	5.82
June 10, 1936	4.39		

16L18R1.—O. O. Kenton. Unused well 2 inches in diameter, drilled 75 feet deep. Measuring point, top of casing level with land surface.

June 6, 1936	1.47	Sept. 21, 1936	1.63
June 10, 1936	1.41	Oct. 15, 1936	1.58
July 23, 1936	1.45	Nov. 18, 1936	1.69
Aug. 19, 1936	1.54	Dec. 16, 1936	1.70

16L31A1.—Tennis Smith. Stock well, 2 inches in diameter. Measuring point, top of highest part of casing, west side, 0.5 foot above land surface.

July 23, 1936	+7.6	Oct. 15, 1936	+7.33
Aug. 19, 1936	+7.7	Nov. 18, 1936	[illegible]
Sept. 21, 1936	+7.35	Dec. 16, 1936	[illegible]

16L32P1.—Frank Morgan. Domestic and stock well, 2 inches in diameter, 61 feet deep. Measuring point, top of casing 0.5 foot above land surface for the period Apr. 13 to Oct. 15; on and after Oct. 15, top of casing.

Date	Depth to water (feet)	Date	Depth to water (feet)
Apr. 13, 1936	4.29	Sept. 21, 1936	2.88
May 6, 1936	3.66	Oct. 15, 1936	[2] 2.99
June 10, 1936	2.56	Nov. 18, 1936	2.91
July 23, 1936	2.66	Dec. 16, 1936	3.40
Aug. 19, 1936	2.24		

17L10D1.—B. Bake. Domestic well, 2 inches in diameter, drilled 68 feet deep. Measuring point, top of casing 0.6 foot above land surface.

Apr. 13, 1936	0.88	Sept. 21, 1936	0.40
June 10, 1936	+1.60	Oct. 15, 1936	+.93
July 23, 1936	+1.20	Nov. 18, 1936	+.57
Aug. 19, 1936	+.70	Dec. 16, 1936	+.61

17L10R1.—Mrs. V. F. Hunnicutt. Stock well, 2 inches in diameter, drilled 75 feet deep. Measuring point, top of ¾-inch plug 0.2 foot above land surface.

Apr. 13, 1936	0.99	Sept. 21, 1936	+1.25
June 10, 1936	+2.04	Oct. 15, 1936	+.93
July 23, 1936	+1.64	Nov. 18, 1936	+1.27
Aug. 19, 1936	+1.40	Dec. 16, 1936	+.75

[2] New measuring point, see description.

TABLE 16.—*Head of water in certain artesian wells and of McIntire Springs, San Luis Valley, Colo.*

Well no.	Location	Estimated altitude of land surface (feet above sea level) [1]	Measured artesian head with reference to the land surface, in feet	Approximate head with reference to sea level
9K6G1	11½ miles south of Saguache.	7,591	54.0	7,645
10J27A1	2 miles north and 4 miles west from Center.	7,672	1.0	7,673
11M4B2	In town of Hooper	7,557	48.0	7,605
12J12P1	4 miles north of Monte Vista.	7,675	0.3	7,675
12K6C1	6 miles north of Monte Vista.	7,666	4.0	7,670
12K14R1	6 miles northeast of Monte Vista.	7,615	15.0	7,630
13Q2N1	12 miles east and 7 miles north from Alamosa.	7,700	14.1+	7,714+
13Q30R1	9 miles northeast of Alamosa.	7,572	12.5+	7,585+
14K25E4	2½ miles northwest of 15L6K1.	7,619	7.5	7,627
14M10A1	"Bucher Well" in Alamosa.	7,530	[2] 62.0	7,592
14S14Q1	In town of Blanca	7,746	6.0	7,752
15L6K1	11 miles southwest of Alamosa.	7,615	22.0	7,637
16L14P1	At schoolhouse in La Jara.	7,601	16.5+	7,617+
16L31A1	4½ miles southwest of La Jara.	7,642	8.0	7,650
16M24L1	3 miles east of Sanford	7,590	5.0	7,595
16N18E1	McIntire Springs	7,520±	0	7,520±
17L23J1	At west edge of Manassa.	7,680	0±	7,680±

[1] Based on topographic map of San Luis Valley, U. S. Geol. Survey Water-Supply Paper 240, pl. 1, 1906.
[2] Reported measurement.

The highest head measured in 1936 was that of a 3-inch well (9K6G1) owned by Victor Crow, about 11½ miles south of Saguache. After being closed in connection with a transmissibility test (table 14) the head in this well built up to 54 feet with reference to the land surface, at which point it was about at equilibrium. The head on well 11M4B2, at Hooper, as measured, was somewhat over 47 feet. The five wells recorded in table 14 are the only ones on which pressure measurements were made over a sufficiently long shut-in period to insure essentially complete equilibrium conditions. Measurements of head were made on a number of other wells, but the readings were generally taken after only short intervals of shut-in, when equilibrium conditions had probably not yet been fully reached.

At La Jara a well (16L14P1) was drilled in September 1936 to be used as a water supply for the Consolidated School there. It was drilled to a depth of 283.5 feet and was cased with 4-inch casing to 200 feet. A. R. Martin, of Sanford, the driller, reported that flows were encountered at practically every 20-foot interval below a depth of 60 feet, with the possible exception of the 220-foot horizon. The well was supplied from flows at approximately the 240, 260, and 280-foot horizons, which increased in strength with depth. Upon completion, the well was allowed to flow without reduction for a period of 8 days, following a practice common among drillers in the valley to give the well an opportunity to clean itself of sand and to create a cavity at the bottom. On October 3, 1936, it had a measured discharge of 125 gallons per minute. The well was shut in at 11:20 a. m., and by 1:22 p. m., the head was 15.95 feet with reference to the top of the casing, or about 16.5 feet with reference to the land surface, which was probably still a little below the head at complete equilibrium.

Well 13Q30R1, on the Stone ranch, about 9 miles northeast of Alamosa, was shut in during a 7-minute interval. The initial measured head was 9.2 feet and the final one 10.5 feet with reference to the top of the casing, or 12.5 feet with reference to the land surface. This well is 3 inches in diameter and had a measured flow of 24 gallons a minute. Well 13Q2N1, owned by C. M. King, 12 miles east and 7 miles north from Alamosa, on land formerly belonging to the Calkins ranch, had a head of 14.1 feet with reference to the land surface after having been shut in for 4 minutes. The well is 2 inches in diameter and had a measured flow of 7 gallons a minute.

The "Bucher" well, 14M10A1, on the east side of the river at Alamosa, taps an aquifer at a depth of approximately 932 feet and is one of the oldest and deepest wells drilled for artesian water in the valley. The owner reported that a gage on the well recently showed a pressure of 27 pounds to the square inch, which would be equal to a water level 62.3 feet above the point of measurement. Siebenthal [58] states that in 1891 Carpenter reported a head of 56 feet. This difference may be due to an increase in pressure, or to differences in the calibration of the gages used.

As a general rule, the head in any locality increases somewhat with the depths of the successive sands. As explained by Siebenthal, this range in head is due in part to interference of a greater number of wells tapping the shallower artesian strata. It is probable, however, that there was an original range in head with depth. Beneath the center of the valley the artesian beds are nearly level, but near the margins they slope upward. Near the outer limits of the basin the confining members of the upper flows feather out and are replaced by sand and gravel. Presumably the confining beds of the lower aquifers extend farther up the slope, and as their intake areas are successively higher, their heads are respectively greater.

The map (pl. 5) shows the area of artesian flow in the San Luis Valley—that is, the area in which the artesian water is under sufficient pressure to rise to the top of the wells and overflow upon the land surface. This area includes the entire interior part of the valley and in some places extends considerably up on the alluvial slopes. In 1936 it covered about 1,430 square miles.

On the east side of the valley the occurrence of five flowing wells in Blanca, drilled after Siebenthal's report was written, has increased the known area of flow. White,[59] in his report on the valley, written in 1916 recognized the possibility of an extension of the area flow to the east, and raised the question as to whether the Blanca area is separated from the main area of artesian flow. Although there is insufficient information to answer this question definitely, the available evidence indicates it to be a separate area of flow, somewhat as shown on the map. It is possible that the artesian aquifers at Blanca are separated from those of the main artesian basin to the west. It is known that two farms on the highway 3 miles northwest of Blanca depend solely upon shallow wells for their domestic supply. There are no artesian wells between Blanca and baldy station, 6 miles west, but west and north of Baldy station there are several nonflowing artesian wells.

[58] Siebenthal, C. E., op. cit., p. 57.

Hydraulic Gradients and Direction of Movement of the Artesian Water

The data on head in table 16 show that the movement of the artesian water is from the sides of the valley toward the interior. Thus the head with reference to sea level is 7,645 feet in well 9K6G1, and 7,605 feet in well 11M4B2, 18½ miles southeast, giving a gradient between these points of 2.1 feet to the mile. The head is 7,673 feet in well 10J27A1 and 7,605 feet in well 11M4B2, 16½ miles east, giving a gradient from west to east of 4.1 feet to the mile. Thus also the difference in head between well 12J12P1 and well 11M4B2 is 70 feet in a distance of 17 miles, or a gradient in a northeast direction of 4.1 feet to the mile. The gradients in any one artesian bed are probably somewhat greater than these figures, as well 11M4B2 is 740 feet deep and those used for comparison are only between 135 and 220 feet deep. It is known that the artesian head in any locality increases with depth. No data were available on measurements of head along the northeast edge of the valley, but it is not unreasonable to assume that the movement of water would be toward the center of the valley. On the east side of the valley, however, two measurements of head indicate the following relationship. Between well 13Q2N1 and well 14M10A1 (the Bucher well at Alamosa), the difference of head is 122 feet in a distance of 14 miles, indicating a gradient toward the center of the valley of 8.7 feet to the mile. Here again the actual gradient is probably somewhat larger, as the Bucher well is among the deepest in the valley and has the highest known head above land surface. The head of well 13Q30R1 is 129 feet lower than that of well 13Q2N1, 5½ miles northeast, indicating a gradient to the southwest of 23.4 feet to the mile. The recorded head of well

[59] White, W. N., The San Luis Valley, Colorado; Irrigation from artesian wells and general irrigation and drainage problems involved in land classification: Manuscript copy in files of Conservation Branch, U. S. Geol. Survey, 1916.

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13Q30R1, located 9 miles northeast of Alamosa, is 7 feet lower than that of well 14M10A1, at Alamosa. This is explainable from three different angles: First, well 13Q30R1 was shut in only 7 minutes when the measurements were made and equilibrium had not been reached by a wide margin; secondly, Alamosa is west of the trough of the valley and the head there is undoubtedly influenced by inflow from the west; and finally, the aquifer supplying well 14M10A1 is over 900 feet below the surface, whereas well 13Q30R1 is a shallow well, probably less than 250 feet deep. Of all the wells measured in the valley, well 14S14Q1, at Blanca, had the highest head with reference to sea level. If there is a connection between the artesian water at Blanca and that in the trough of the valley, the difference in head at Blanca and at Alamosa indicates a hydraulic gradient toward the trough of the valley.

In the portion of the valley lying south of the Rio Grande the movement of water is in general toward the trough of the valley. Between well 14K25E4 and well 14M10A1 there is a difference in head, with reference to sea level, of 35 feet in 11½ miles, or a gradient of 3 feet to the mile in an east direction. Between well 14K25E4 and well 16L14P1, at La Jara, 12 miles southeast, the gradient is about 1 foot to the mile. In the 4-mile stretch between well 16L31A1 and well 16L14P1, at La Jara, there is a difference in head of 33 feet, or a gradient in a northeast direction of 8.2 feet to the mile.

The lowest head with reference to sea level given in the table is that of McIntire Springs (16N18E1), and with the possible exception of Dexter Spring, mentioned by Siebenthal,[40] this is the lowest head of record in the valley. Although Dexter Spring was not identified in 1936, Siebenthal's topographic map indicates that it was lower than McIntire Springs. The movement of water in the southwestern part of the valley is in the direction of the these springs, as is shown by the gradients from two points, one southwest and the other west of the Springs. The difference in head between well 17L23J1, at the west edge of Manassa, and McIntire Springs is 160 feet in a distance of 10 miles, giving an average gradient of 16 feet to the mile. The difference between well 16L14P1, at La Jara, and McIntire Springs is 97 feet in a distance of 8 miles, or an average eastward gradient of 12 feet to the mile. The steepest gradient that was determined was that between well 16M24L1 and McIntire Springs, the difference in head being 75 feet in 1¼ miles, giving a northeast gradient of 30 feet to the mile. Any suggestion that there may be underflow out of the valley passing around the south end of the San Luis Hills is precluded by the differences in heads between the well at Manassa and the well at La Jara, and between these wells and McIntire Springs.

[40] Siebenthal, C. E., op. cit., p. 102.

In the northern half of the valley there is a gentle southward gradient. Thus between well 11M4B2 at Hooper and well 14M10A1 at Alamosa, both of which are deep wells, the difference in head is 13 feet in 19 miles, giving an average gradient of 0.7 foot to the mile. From Alamosa southward to McIntire Springs the gradient increases, the difference in head between well 14M10A1 at Alamosa and McIntire Springs being 70 feet in 13 miles, giving an average southward gradient of 5.4 feet to the mile.

The comparison of the water-surface altitudes of these several representative wells shows rather conclusively that north of the Rio Grande the water moves laterally from the sides of the valley toward the trough. In the trough of the valley the movement of water is southward, following the gentle gradient in that direction. South of the Rio Grande the water moves from the west side of the valley in an eastward direction, the lowest head being in the neighborhood of McIntire Springs.

Fluctuations of Artesian Head

Increase in head produced by irrigation.—Contrary to the usual history of similar artesian basins, the area of artesian flow in the San Luis Valley has increased rather than diminished over a period of development in the last 30 years. The map of the valley (pl. 5) shows the area of flow as delimited by Siebenthal[41] in 1906 and that which was determined by field work in 1936. It shows that in this 30-year period the area of flow has expanded somewhat on the west, south, and east sides of the valley. The increase is quite evident on the gentler alluvial slopes, such as the Rio Grande fan, but not where the slopes are steep.

Along the west side of the Rio Grande alluvial fan the boundary of the area of flow has moved westward, in some places a distance of over a mile. In the vicinity of Manassa, it has moved southward about 2 miles. A well drilled in 1925 at the west edge of Manassa, in the NE¼SE¼ sec. 23, T. 34 N., R. 9 E., lacked only about 10 inches of flowing at the surface. East of the Baca Grant and in the area south of it, a lack of control in the form of nonflowing wells made the interpretation of the limit of flow less accurate than in most other parts of the valley, but according to the best available data the limit of flow conforms nearly to that shown by Siebenthal in 1906. There is little doubt that flowing wells could have been obtained in the vicinity of Blanca in 1906, but Siebenthal's map was compiled before there was any drilling in that area.

To explain this increase in the area of flow it is necessary to consider the history of irrigation development in the valley. Early development occurred in the central part of the valley, north of the Rio Grande,

[41] Siebenthal, C. E., Geology and water resources of the San Luis Valley, Colo.: U. S. Geol. Survey Water-Supply Paper 240, pl. 1, 1906.

in the vicinity of Hooper and Mosca, but as the gravelly land to the west was found to be fertile and suited to cultivation, the development extended westward. On account of a concentration of alkali in the soil, the lands first cultivated were abandoned gradually in favor of the better-drained, gravelly soils on the west side of the valley, both north and south of the Rio Grande. With the development of this area and the consequent increase in surface water diversion, there occurred an increase in artesian-water recharge and consequently an increase in artesian head and an expansion of the area of artesian flow.

Decrease in head produced by mutual interference of artesian wells.—During the course of the artesian-well inventory well owners often reported that the flows of their wells were materially reduced when wells tapping the same flow were drilled in the locality. Probably the chief cause of gradual failure of wells is mutual interference, especially in the larger towns of the valley, where the interference has resulted in drilling to deeper aquifers that are tapped by fewer wells. Even as far back as 1906 the numerous wells in Monte Vista so seriously affected one another that the head had been reduced to about half the original head. Similar overtaxing of the shallower artesian aquifers in Alamosa has resulted in the drilling of a number of wells to aquifers below 800 feet. In 1936 neither the head nor the flow of these deep wells had yet been seriously impaired.

In several places the area of flow did not extend up the slope quite as far in 1936 as was shown by Siebenthal. Probably most of these slight differences are due to lack of control in mapping the limit of flow in 1906, but in at least one locality there has been an actual decrease of the area of flow. Thus two wells on land formerly known as the Calkin's Ranch, in sec. 1, T. 38 N., R. 12 E., and reported by him as flowing wells, were not flowing when seen in 1936, probably because of the interference of wells in the central and western parts of the township. The cessation of the flow of Washington Springs may also be attributed to the drilling of wells.

Seasonal fluctuations.—Near the boundary of the area of flow there is a definite variation in artesian head during the year. Of the wells on the Rio Grande alluvial fan, on which periodic measurements were made (table 15), some are located approximately on the boundary of the area of flow and others outside the area of flow. Those which are located about on the line usually flow during the late spring, summer, and early fall—the period of flow about coinciding with the irrigation season. A common expression in the valley is that the artesian wells "come up with the sub" and "go down with the sub." These seasonal fluctuations are due to the seasonal rise and fall of the water table in the artesian intake belt and probably also in part to the seasonal loading and unloading of the artesian aquifers as the water table above the upper confining bed ri and falls.[42] Figure 55 shows the relation between water levels in four artesian wells and four shallow wells with water-table conditions on the Rio Grande alluvial fan. It shows that the rise and fall of the water levels in the artesian wells occur at about the same time as the rise and fall in the shallow wells. The maximum fluctuation in water level observed during 1936 was 3.07 feet, in well 12J26D1, located south of the Rio Grande near Monte Vista, but in most of the artesian wells on the Rio Grande alluvial fan the fluctuation was about 2 feet. The flowing wells at some distance from the boundary of the area of flow and outside of the irrigation districts appear to have comparatively small seasonal fluctuations in head.

Barometric fluctuations.—The water level in an artesian well generally falls as the atmospheric pressure increases and rises as the atmospheric pressure decreases. The magnitude of this type of fluctuation is dependent upon the amount of variation in atmospheric pressure and upon the degree to which the well acts as a water barometer. The fluctuations of the water level produced by barometric fluctuations and other causes combined are shown in figure 56. A 7-day automatic water-stage recorder was installed on an artesian well, 12K6C1, located about 6 miles north of Monte Vista just inside the area of flow. The well, which was inches in diameter and 150 feet in depth, was adapted above land surface to accommodate the recorder. Hourly barometric readings were obtained from the Alamosa plant of the Public Service Co. of Colorado, 20 miles distant, and after being converted to feet of water, were plotted to the same scale as the hydrograph on the recorder chart. The record for the week of September 8 to 15, 1936, has been reproduced in this figure. In the first 4 days of the week the fluctuations of the water surface in the well were of about the same nature as the fluctuations of the atmospheric pressure at Alamosa. In the latter part of the week the agreement is not quite so close, probably in part because of effects of irrigation and possibly in part because of difference in the barometric pressure at Alamosa and at the well.

Discharge of Artesian Water

Artesian springs.—In the San Luis Valley there are several artesian springs situated near the limit of flow. Washington Springs, near the trough of the valley, are the only known springs that do no occur along the margins of the valley. In all these springs the temperature of the water is comparable to that of the shallow artesian water in the vicinity of the springs.

[42] Meinzer, O. E., Compressibility and elasticity of artesian aquifers: Econ. Geology, vol. 23, pp. 275-276, 1928.

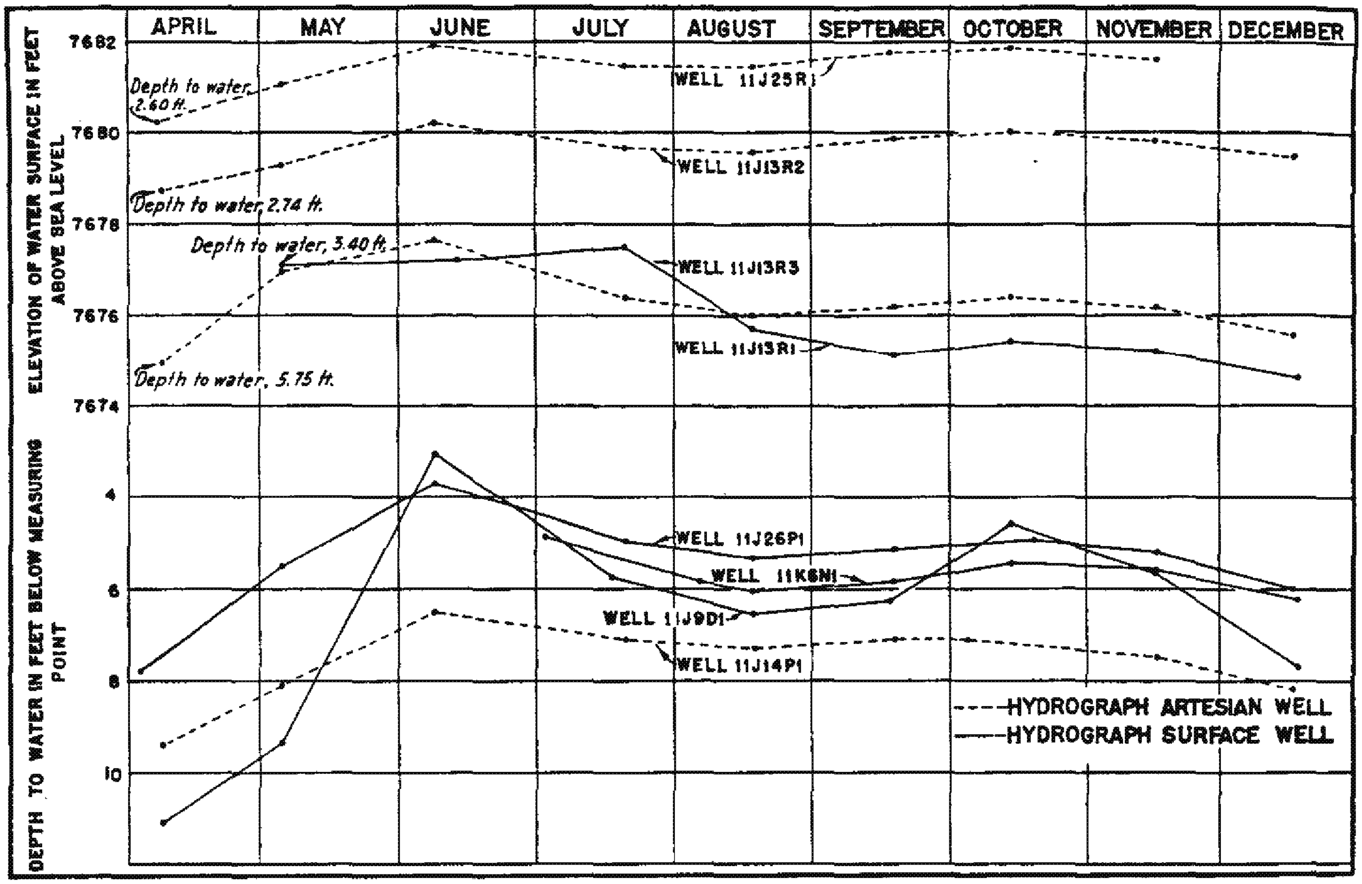

FIGURE 55.—Comparison of hydrographs of four artesian and four surface wells on the Rio Grande alluvial fan during 1936.

Among the large springs in the valley are the McIntire Springs, on the south side of the Conejos River, in the NW¼ sec. 18, T. 35 N., R. 11 E. They rise along the Conejos River at the base of the San Luis Hills at the contact between the Alamosa formation and the volcanics of the San Luis Hills. According to Siebenthal [43] this is probably a fault contact. Confined water moving southeastward in the Alamosa formation comes up along the contact and through the volcanics and escapes at the surface as the McIntire Springs. In addition, there are many small springs along the Conejos River which are probably supplied from water-bearing beds of the Alamosa formation where they abut against the volcanics. In the course of the present investigation the discharge of McIntire Springs was measured four times, using a Price current meter, and was found to be nearly the same each time (see table 17).

Depressions in the margins of the confining beds of the artesian aquifer afford opportunities for the artesian water to spill over the lip of the confining member, forming springs. Springs of this type occur in depressions along the west side of the San Luis Valley. Their discharge may be called artesian reject, as it represents the overflow of the artesian aquifer.

Diamond Springs, which are the largest springs of this type, emerge on low ground south of a meandering distributary from La Jara Creek, in the N½ sec. 31, T. 35 N., R. 9 E. The swampy tract from which the springs emerge covers 160 acres and is characterized by a dense growth of tules, with bodies of water that denote the locations of the different spring openings. The discharge of these springs has increased progressively during the last 30 years, and at the present time it is many times that when first noted. Thirty years ago the spring area had little if any outflow, whereas the average of three measurements in 1936 amounted to about 24.5 second-feet. W. D. Carroll,[44] irrigation division engineer for the State of Colorado, stationed at Alamosa, reported that the flow of these springs was very small 30 years ago, probably not over a quarter of a second-foot, but that the flow began to increase materially about 1916 and has continued to increase since then. Siebenthal[45] makes no mention of these springs in his discussion of springs in the valley. Had they been of consequence at that time he undoubtedly would have reported them, especially in view of the fact that he located an artesian well only a quarter of a mile

[43] Siebenthal, C. E., op. cit., pp. 38, 39.

[44] Personal communication.

[45] Siebenthal C. E., op. cit., pl. 1.

. the spring area. These springs give convincing ..nce in support of the theory that there has been ..sider.. .. increase in recharge of the artesian aquifers on account of the application of surface water for irrigation on the alluvial slopes.

Another group of springs on the west side of the valley, in sec. 12, T. 37 N., R. 7 E., are the source of Spring Creek, a small perennial stream flowing eastward to the valley floor. The measured flow of Spring Creek in November 1936 was 9.74 second-feet. Four other measurements by Dan Jones, deputy State hydrographer, are available, but as they were made in 1928 and 1929 they were not included in the table. They are as follows: April 11, 1928, 14.2 second-feet; January 15, 1929, 12.9 second-feet; March 16, 1929, 13.7 second-feet; and February 18, 1929, 13.2 second-feet. Russell Springs, located on the northwest margin of the valley, in the NE¼ sec. 23, T. 43 N., R. 7 E., are the main source of supply for a series of interconnected lakes known as Russell Lakes, about 2 miles east of the point where the springs emerge. As they are located on the boundary of the area of artesian flow, these springs also represent artesian reject. When measured in November 1936 they were flowing 3.6 second-feet. Both Russell Springs and those which furnish Spring Creek are situated at points along the margin of the valley, topographically lower than the adjacent land ..rface. Unlike Diamond Springs, however, these two ..prings are not the result of irrigation development but have been permanent within the memory of white man.

The results of measurement in 1936 of the discharge of the principal springs in the valley are given in the following table. The total discharge of the artesian springs in 1936 is estimated to average 65 second-feet, or 47,450 acre-feet in the year.

TABLE 17.—*Discharge measurements of artesian springs in the San Luis Valley*

Number	Name	Date of measurement	Discharge (second-feet)	Average discharge (second-feet)
7J23B1	Russell Springs	Nov. 23, 1936	3.60	3.60
14J12N1	Spring Creek	Nov. 27, 1936	9.74	9.74
14N15A1	Washington Springs		(1)	
14N15G1	"Spring Mound" at Washington Springs.		(1)	
16L31F1	Diamond Springs	Apr. 14, 1936	19.29	
		May 6, 1936	27.69	
		June 3, 1936	26.52	24.50
16N18E1	McIntire Springs	Mar. 27, 1936	19.78	
		May 12, 1936	18.44	
		June 3, 1936	18.47	
		July 11, 1936	18.97	18.92
	Estimated discharge of smaller springs.			9.0±
	Total			65.0

[1] Trickle.

Flowing wells.—In order to determine the quantity ..rtesian water discharged annually in the San Luis ..lley an inventory was made of the flowing artesian

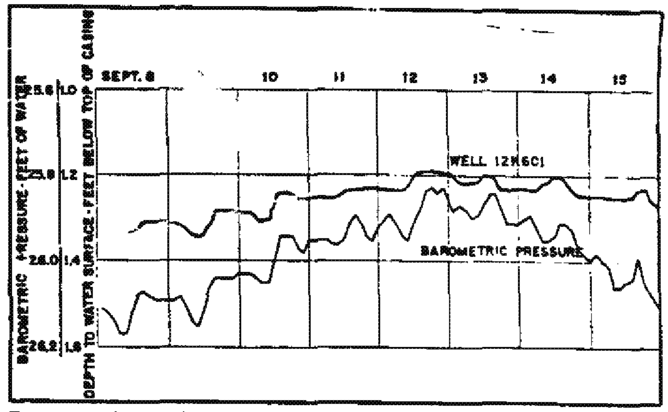

FIGURE 56.—Fluctuations of water level in well 12K6C1, and fluctuations in barometric pressure at Alamosa, September 8-15, 1936.

wells. On account of the lack of time, it was not possible to visit and record every well in the valley. In certain restricted areas the wells in every section were located and measured, but over most of the area, only the wells in the odd-numbered sections were recorded. In connection with the study of water requirements in the Carmel-Bowen area by the Bureau of Agricultural Engineering (see pl. 11), it was necessary to know the total annual discharge of all artesian wells in that area. Accordingly, every well in that area was located and the discharge of each measured. Approximately 32 square miles, lying between the Monte Vista and the Empire canals, were included in this complete inventory, which covered parts of Tps. 36 and 37 N., R. 8 E., and smaller parts of Tps. 36 and 37 N., R. 9 E.

The following townships on the east side of the valley were completely inventoried—that is, every well in each section was located and measured: T. 41 N., R. 11 E.; about 9 sections of T. 41 N., R. 12 E.; T. 40 N., R. 11 E.; T. 40 N., R. 12 E.; T. 39 N., R. 11 E.; T. 39 N., R. 12 E.; T. 38 N., R. 12 E.; and T. 37 N., R. 12 E. Likewise, every section lying within the limit of flow in the Luis Maria Baca Grant No. 4 was covered. In the remainder of the area of flow the wells in only the odd-numbered sections were visited.

Method:—The artesian inventory covered an area of approximately 1,430 square miles, as shown by the area of flow (pl. 5) in which it is estimated there are 6,074 flowing wells. The flow for those wells whose discharge was less than 5 gallons a minute was usually estimated. For those wells whose discharge was greater than 5 gallons a minute, the flow was measured either volumetrically or by use of the "jet" method. In the volumetric measurements a stop-watch was used to obtain the time required to fill a container of known volume. In actual practice, 5- and 15-gallon containers were used, the 5-gallon container for the smaller flows and the 15-gallon container for the larger flows. In using the "jet" method, a measurement was made of the inside diameter of the casing, and the vertical height of the crest of the jet above the top of the casing. The discharge was then computed by using a formula for determining flow from vertical pipes. This formula is written:

$$Q=\frac{10d\sqrt{h^3}}{\sqrt{1+2.525\left(\frac{h}{d}\right)^2}}$$

Where:

Q=discharge in cubic feet per second.

d=diameter of pipe in feet.

h=height of jet in feet.

This formula was checked many times by volumetric measurements and was found to agree rather closely.

In an artesian inventory of this type it is imperative that no wells that serve to form a basis for the estimate of artesian discharge be omitted, and this is especially true where only the wells in each alternate section are inventoried. Thus, in order to obtain an estimate for any given area, such as a township, it is necessary to double the results of the inventory. Any error, due to omission of wells, would, of course, be doubled in the final estimate. In view of this fact, extreme care was taken to visit and measure every well in the odd-numbered sections.

Equally important, was the necessity of qualifying each measurement of flow in terms of the average annual discharge for each well. It is common practice for a large number of the well owners to allow their wells to flow only during the growing season. For the remainder of the year the wells are plugged, allowing only enough water to escape to prevent the wells from freezing during the winter. Therefore, in addition to measuring the discharge of each well, it was necessary to ascertain the proportion of the year that the well was allowed to flow. This period of restricted flow was usually expressed as a percentage of the year, and the average annual discharge of the well was computed accordingly. Most of the wells, however, are allowed to flow unrestricted throughout the year, and hence no corrections were necessary in computing their average annual discharges.

Most of the wells that supply domestic and stock water on the farms and ranches are restricted in flow throughout the year. Many of the domestic wells are reduced and their water is carried through a pipe line into the houses in such a manner that there is a constant flow through the house at all times. Often these domestic wells are opened for full flow during the summer to irrigate small gardens and lawns. For wells of this type, whose flows were governed by usage, the observer, with the aid of the owner, made the closest possible estimate of the average annual discharge.

A special inventory was made of wells in the larges[illegible] towns, namely Alamosa, Center, La Jara, Mon[illegible] Vista, and Sanford, but as there are relatively f[illegible] wells in Moffat, Hooper, and Mosca, these towns were included in the general inventory.

In Alamosa, the estimate of the total number of wells and their average annual discharge was based on all available information that could be obtained from the records of the city clerk, the water commissioner, the public service company, and Ray Wells, who is the resident well driller. It was estimated that there are approximately 250 private wells within the city limits, and that they have an average discharge of 5 gallons a minute. The municipal water plant furnishes water to about 650 services, but the part of Alamosa lying east of the Rio Grande is dependent wholly upon private wells, as it is outside of the city distribution system. A record of the total quantity of artesian water that was pumped by the municipal water plant in 1936 was obtained from the city water commissioner at Alamosa and is shown in the following table:

TABLE 18.—*Artesian water pumped by the city of Alamosa during 1936*

	Gallons
January	6, 840, 900
February	6, 395, 150
March	7, 607, 700
April	10, 455, 250
May	10, 814, 750
June	12, 220, 600
July	12, 813, 850
August	9, 658, 300
September	9, 704, 800
October	3, 593, 150
November	7, 427, 450
December	7, 692, 500

The total number of 720 wells in Monte Vista and 120 in Center was obtained by actual count. After measuring the discharge of several typical wells in each of these towns, an estimate of 3 gallons a minute was made for the average discharge of all wells in Monte Vista and 5 gallons a minute for all wells in Center. In Center, a municipal plant furnishes water to a part of the town. The flow of the single well which furnishes this supply was measured volumetrically. The city of Monte Vista has no municipal water system, and the inhabitants are dependent wholly upon private wells for their water supply. An estimate of 140 wells in La Jara was made after interviewing residents who are familiar with the distribution of the wells in the town. Several typical wells were measured, and an estimate of 5 gallons a minute for all wells was made. On a similar basis the total number of wells in Sanford was estimated at 150, and the average di[illegible] charge was estimated at 3 gallons a minute.

The results of the artesian inventory in the five largest towns are shown in the following table:

TABLE 19.—*Estimated quantity of artesian water used in Alamosa, Center, La Jara, Monte Vista, and Sanford for municipal and domestic supplies during 1936*

Name of town	Estimated number of wells	Estimated annual discharge of private wells (acre-feet)	Quantity furnished by municipal waterworks (acre-feet)	Total (acre-feet)
Alamosa	250	2,016	338	2,354
Center	120	968	49	1,017
La Jara	140	1,130		1,130
Monte Vista	720	3,484		3,484
Sanford	150	725		725
Total	1,380	8,323	387	8,710

Table 20 shows by townships the results of the entire artesian well inventory, including the towns.

The flow of the artesian wells in San Luis Valley ranged from only a trickle to about 350 gallons a minute, with an average flow of about 12 gallons a minute. The average flow of the rural wells—that is, excluding those in the five largest towns—is about 14.5 gallons a minute. Table 21 shows by townships the average open flow of the wells. The wells in the five largest towns—Alamosa, Center, La Jara, Monte Vista, and Sanford—are not included, as these wells are not allowed to flow open, but are reduced and the water used for domestic purposes. This table shows in a general way the magnitude of the yield of the wells in different parts of the valley. On the basis of the average yield per well, it is possible to divide the valley into fairly well defined areas of high and low flow. Three localities in particular have appreciably higher flows than the average, namely, (1) the area southwest of Alamosa, in the vicinity of Henry station and westward to the Fountain neighborhood; (2) the area north of the river, several square miles in extent, the center of which is about 6 miles northeast of Alamosa; and (3) an area including the vicinity of Russell Lakes and extending southward to Veteran School. The last mentioned area is noted for its high artesian head and correspondingly large flows.

Several factors are involved in determining the rate of flow of the different artesian wells in the valley. Listed more or less in the order of their importance, these factors are as follows: (1) The thickness and permeability of the water-bearing beds; (2) the altitude of the land surface at each well; (3) the relation of the well to the intake area; (4) the number and distribution of wells tapping the same aquifer; and (5) the construction and development of the wells.

The strong flows of the wells in the vicinity of Russell Lakes are due in part to the preponderance of gravel in the aquifers of this area, almost to the exclusion of the finer sediments, and in part to the nearness of the intake area on the relatively high Rio Grande alluvial fan. The other two areas of high flow that have been described also have a preponderance of coarse material in the aquifers but do not have such high artesian heads.

Although the interior of the valley lies low it is a region of only moderate to weak flows. The absence of strong flows is due in part to the fact that the water-bearing materials in this region consist chiefly of silt and fine sand and that the clay beds are numerous and reach their maximum thickness, and in part to the remoteness of the region from the intake area.

Summary of artesian discharge.—Prior to the present inventory at least three other estimates had been made of the discharge of the artesian wells in the San Luis Valley. In 1891 Professor Carpenter[46] estimated that there were 2,000 artesian wells in the valley, with an assumed average flow of 25 gallons a minute, and he thus computed the total artesian discharge to be about 110 second-feet, which is equivalent to an annual discharge of about 80,000 acre-feet.

[46] Siebenthal, C. E. Geology and water resources of the San Luis Valley, Colo. U. S. Geol. Survey Water-Supply Paper 240, p. 56, 1910.

TABLE 20.—*Number of artesian wells in the San Luis Valley, Colo., and discharge from them, in acre-feet, during 1936*

	R. 7 E.		R. 8 E.		R. 9 E.		R. 10 E.		R. 11 E.		R. 12 E.		R. 1. W. (Baca Grant)		R. 73 W.		R. 74 W.		R. 75 W.		Total	
	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge	Wells	Discharge
T. 45 N.							20	270													20	270
T. 44 N.			44	1,180	110	4,525	78	2,400	2	15											234	8,120
T. 43 N.	36	2,930	228	16,940	92	1,735	46	455	5	115											407	22,175
T. 1 N.[1]													4	35							4	35
T. 1 S.[1]													5	75							5	75
T. 42 N.	174	4,210	92	5,380	10	80	8	75													284	9,745
T. 41 N.	52	900	276	6,235	54	1,290	60	1,290	8	65	1	10									451	9,790
T. 40 N.	30	30	230	6,635	108	2,375	126	620	35	225	12	60									541	9,995
T. 39 N.	[2] 182	[2] 940	[2] 586	[2] 4,595	82	1,135	92	785	25	150	6	45									973	7,630
T. 38 N.	[2] 102	[2] 620	[2] 432	[2] 5,170	78	755	52	775	106	2,210	90	2,490									860	12,020
T. 37 N.	6	10	165	2,790	212	8,405	421	8,775	166	4,140	47	795									1,022	24,915
T. 36 N.			12	85	216	3,865	142	1,510	39	340											409	5,770
T. 35 N.					370	4,130	368	2,045	28	925											766	7,100
T. 34 N.					52	185	38	905													90	1,090
T. 30 S.																	4	30	4	130	8	160
T. 31 S.															5	55					5	55
Total	582	9,690	2,065	48,980	1,381	28,480	1,451	19,885	414	8,185	156	3,400	9	110	5	55	4	30	4	130	6,074	118,945

[1] Baca Grant.
[2] Segregation of the wells and discharge by townships in Monte Vista is approximate.

TABLE 21.—*Average open flow in gallons a minute of artesian wells in the San Luis Valley, Colo., exclusive of Alamosa, Center, La Jara, Monte Vista, and Sanford*

	R. 7 E.	R. 8 E.	R. 9 E.	R. 10 E.	R. 11 E.	R. 12 E.	R. 1 W. (Baca Grant)	R. 73 W.	R. 74 W.	R. 75 W.
T. 45 N.				4.0						
T. 44 N.		16.6	26.7	19.3	4.0					
T. 43 N.	62.7	53.6	11.8	6.1	14.2					
T. 1 N.							5.8			
T. 1 S.							9.4			
T. 42 N.	16.6	40.8	5.0	5.8						
T. 41 N.	10.7	21.2	15.8	14.3	5.0	7.0				
T. 40 N.	1.7	20.6	14.5	3.2	4.0	3.1				
T. 39 N.	3.9	8.8	8.6	5.2	3.9	4.7				
T. 38 N.	3.5	12.5	6.0	11.3	13.1	17.4				
T. 37 N.	1.0	16.8	46.1	22.9	15.8	11.3				
T. 36 N.		3.2	14.5	9.2	6.3					
T. 35 N.			9.0	3.8	36.8					
T. 34 N.			2.2	14.7						
T. 30 S.								7.0		
T. 31 S.									5.0	20.0

In 1916 White[47] estimated that there were 5,000 artesian wells in the valley, with an average flow of probably not more than 2 or 3 miner's inches (23 to 35 gallons a minute). His estimate of the total potential discharge of all wells, if allowed to flow unrestricted, was 300 second-feet, or about 219,000 acre-feet a year.

In 1919 Debler[48] estimated that there were 5,850 wells in the valley, and on the basis of measurement of 908 wells, he estimated their average flow at 26 gallons a minute. He estimated the potential annual discharge at 245,000 acre-feet, and considering the wells that were closed during a part of the year, he estimated the actual annual discharge at 187,000 acre-feet.

On the basis of the artesian inventory in 1936, it is estimated that there are 6,074 wells in the valley, with an annual discharge of 118,945 acre-feet. If all wells in the valley were allowed to flow unrestricted, their potential annual discharge would be about 142,000 acre-feet. On the basis of the measurements recorded in table 17, the total discharge of the artesian springs in 1936 is estimated at 47,000 acre-feet. Therefore, the total visible discharge from the artesian wells and springs is estimated at about 166,000 acre-feet of which about 27,400 acre-feet occurs in the springs along or near the upper edge of the confining bed, and hence never enters the main part of the aquifer.

General Conclusions

In the present investigation of the artesian basin the main objective was to obtain an estimate of the quantity of water discharged by the artesian wells and springs. As a result most of the time was spend in measuring the discharge of the artesian wells and springs, and very little time was allotted to the study of other phases of the artesian system, such as the extent of the recharge area and the amount of recharge.

The quantity of artesian water moving past the boundary of the area of artesian flow (pl. 5), should be equal to the total discharge from the wells and springs in the area of flow, except that it would be less to the extent that artesian water is taken from storage or more to the extent that this storage is increased or there is discharge by upward percolation through the confining beds or underground leakage from the wells. The distance along the boundary of flow is about 180 miles. As indicated on page 256, the average coefficient of transmissibility to a depth of 160 feet, based on the results of tests of the four wells near the boundary of flow, 9K6G1, 12K14R1, 14K25E4, and 15L6K1, is about 7,000. Deducting the average thickness of the shallow valley fill at the wells, which is about 35 feet, the average depth penetrated by the wells below the top of the first confining bed is about 125 feet. The slope of the piezometric surface, as determined from several pairs of wells close to the boundary of flow, ranges from 4 to 13 feet per mile and averages about 9 feet per mile. Using these figures, the quantity of water moving past the boundary of flow in the 125 feet of beds below the top of the first confining bed was computed to be about 12,800 acre-feet a year. The average thickness of the artesian formation below the top of the first confining bed is not known, but the logs of wells close to the boundary of flow indicate it to be at least 500 feet. Thus, to a depth of 500 feet below the top of the first confining bed, the quantity of water passing the boundary of flow would be about four times as much, or about 50,000 acre-feet a year.

According to these computations less than half the total discharge by artesian wells and springs (excluding Diamond and Russell Springs and similar springs which essentially reject water before it enters the artesian aquifer) can be accounted for by the lateral percolat

[47] White, W. N., The San Luis Valley, Colo.; Irrigation from artesian wells and general irrigation and drainage problems involved in land classification: Manuscript copy in files of Conservation Branch, U. S. Geol. Survey, pp. 12–13, 1916.

[48] Conkling, Harold, and Debler, E. B., Water supply and possible development of irrigation and drainage projects on the Rio Grande River above El Paso, Tex.: Manuscript copy in files of U. S. Bur. Reclamation, Denver, Colo., pp. 16–75, June 18, 1919.

the peripheral intake areas into the area of artesian .. The figures for the average coefficient of transmissibility or for the hydraulic gradient may be too low, or the total thickness of the artesian beds may be greater than was assumed for the computation. It is possible that the transmissibility of the deeper, untested aquifers is greater than that of those which were tested. Further, it is possible that the average slope of the piezometric surface at the boundary is not truly represented by the heads in the wells that could be measured. The gradient between the trough of the valley and the upper limit of artesian flow on the west slope of Mount Blanca, for instance, is much greater than that assumed in the computations.

PART II

SECTION 3.—GROUND WATER IN THE MIDDLE RIO GRAN VALLEY, NEW MEXICO[1]

Method of Investigation

Acknowledgments

The work of installing observation wells in the Middle Rio Grande Valley and reading water levels in them was divided areally into three divisions, which corresponded with the three most important operating divisions of the Middle Rio Grande Conservancy District. B. R. Thompson was in charge of the work in the Albuquerque Division, and aided in overseeing the work in the remainder of the area and in the incidental office work. Nestor Lovato was in charge of the work in the Belen Division, which included nearly half the observation wells installed. W. E. Herkenhoff was in charge of the work in the Socorro division. Robert Colvin joined the force in August, was in charge of most of the leveling done, and bad much of the responsibility for the preparation of the water-table and depth-to-water maps. Marjorie Allen, besides doing the manifold clerical duties of the Albuquerque office, checked a large part of the field notes and otherwise contributed to the engineering phase of the investigation.

Acknowledgment is gratefully made to many organizations who contributed helpfully to the investigation. The surface water division of the United States Geological Survey and the Bureau of Agricultural Engineering both furnished necessary data. The Middle Rio Grande Conservancy District furnished much information, including levels on several lines of wells in the Belen division. Many bench marks placed on observation wells in the Albuquerque Division by the conservancy district in former years, were still intact and were used in this investigation. Many data, collected in connection with the current Texas-New Mexico suit concerning Rio Grande waters, were kindly furnished by Alan Laflin and Raymond Hill. Special acknowledgment is made of the kindness of Dean W. Bloodgood of the Bureau of Agricultural Engineering, and of Fabian Garcia, director of extension work of the Agricultural and Mechanical College, for access to and permission to use the water level data obtained by Mr. Bloodgood in the period 1918–22.

The aeroplane mosaics obtained by the Soil Conservation Service were placed at the disposal of the investigation and photostatic copies furnished to the Ground Water Division. These were the only accurate maps of the area available and without them no accurate survey of water levels could have been made. These maps, however, were not available until late in the investigation.

The Resettlement Administration kindly furnished records of ground-water levels in their observation wells in the Bosque Farms resettlement project, through G. L. Seligmann, project manager.

The Biological Survey, in course of their investigation of the Bosque del Apache grant as a migratory bird refuge, located and ran levels to the observation wells in the grant. They also furnished a topographic map of the area with a contour interval of 1 foot, which assisted greatly in making the map of the area showing the depth to water.

Scope of Investigation

The shortness of the time available for the pre work necessitated that it be of the nature of a su. rather than a thorough investigation. The work involved in covering the entire Middle Valley with observation wells numbering about 900, locating these wells in an unsectionized area for which no accurate detailed maps were available until late in the year, running levels to them, making and recording measurements of water level in them, and cleaning out and deepening them periodically to obtain water samples from them, consumed so much time that little was left for experimental work to clarify important basic problems connected with the source, motion, and disposal of the ground water. The information gathered is to be regarded as base data necessary for a proper ground-water investigation but lacking necessary experimental work to make it complete at present.

The geology and general ground-water conditions of this part of the Rio Grande Valley and tributary area are described concisely by Kirk Bryan in section 1.

Description of Work Done

Area covered.—The Middle Rio Grande Valley extends from White Rock Canyon on the north to San Marcial on the south, a distance of approximately 142 miles. Its average width is about 2 miles. It comprises parts of Sandoval, Bernalillo, Valencia,

[1] By Charles V. Theis, Geological Survey.

Socorro Counties and within its limits are Bernalillo, county seat of Sandoval County; Albuquerque, New Mexico's largest city and the county seat of Bernalillo County; Belen, the county seat of Valencia County; and Socorro, the county seat of Socorro County. Within the valley are the pueblos of the Cochiti, Domingo, San Felipe, Santa Ana, Sandia, and Isleta Indians. The territory covered by the ground-water investigation begins at mile post 877 on the Atchison, Topeka & Santa Fe Railway, about 15 miles south of White Rock Canyon, and extends south to mile post 998, about 7 miles north of San Marcial, thus including the Albuquerque and Belen Valleys and most of the Socorro Valley as defined by Bryan in a preceding section of this report.

Nearly all of this area is in the Middle Rio Grande Conservancy District, which is divided into four operating divisions—Cochiti, extending from the head of the valley to Angostura; Albuquerque, from Angostura to Isleta; Belen, from Isleta to San Acacia; and Socorro, from San Acacia to the north line of the Bosque del Apache Grant. Every effort was made to recover the wells previously located by the Conservancy District in order to have a semicontinuous record of depth to ground water in the valley. Because of difficulties in obtaining permission from the Domingo and San Felipe Indians to do work on their reservations in the Cochiti Division, this area was omitted from the investigation.

Description of wells.—Most of the observation wells are located along highways, roads, trails, and fences that run laterally across the valley, at or near a fence post, tree, telephone pole, or power pole. To facilitate location, a fence post, tree, telephone pole, or power pole near each well was conspicuously painted. Orange paint was used in the Albuquerque and Belen Divisions, white in the Socorro Division.

The field equipment consisted of a 2-inch post-hole auger, with four 42-inch lengths of ½-inch galvanized iron pipe, threaded on both ends, for extensions. With this equipment a depth of 16 feet could be reached. The wells were as a rule cased with 2-inch galvanized downspout. The casing was inserted to a depth of several feet below the ground-water level to insure ample water for measuring at low stages. The lowest 2 feet of the casing was perforated with slots made with a hack saw in order to facilitate the flow of ground water into the well. The depth to the water level ranged from 1 foot to 16.5 feet. Wells 894.4–1E, 3E, 5E, and 6E penetrated to a depth of about 15 feet below the ground-water level. They consist of a sand-point and ½-inch galvanized iron pipe, in 42-inch sections, driven into the ground with a sledge.

The original wells placed by the Conservancy District in the Albuquerque and Socorro Divisions were cased with 2-inch boiler tubing to a depth of generally about 2½ feet. This left the lower portion of the well an open hole which in most wells had caved. Wherever necessary, 2-inch galvanized downspout was substituted for this boiler tubing. None of the wells in the Belen Division had been cased, and all were lost by the time this investigation began.

Measurements of depth to the water level were made monthly in 917 wells in the Middle Rio Grande Valley. The work was usually started on the 8th day of the month, and the wells were read in about the same order each month. The measurements were made from the top of the casing. Field work was started in April, but a complete record is not available for either April or May, because the installation of new wells and the recovery of old wells were not completed. Beginning with September, measurements to the water surface were also made in many drains, canals, and laterals.

System of numbering.—The system of line and well designation used in this investigation is based on two important features of the Rio Grande Valley, namely, the Rio Grande and the Atchison, Topeka & Santa Fe Railway. The lines of wells are given numbers corresponding to the numbers that designate the railway mile posts. If the line or its projection begins at some point between mile posts a decimal is added to the mile-post number. The line numbers increase successively southward. In each line the wells are numbered consecutively to the east and to the west of the Rio Grande.

The Albuquerque Division extends from mile post 877, southward to mile post 915, at the Isleta Pueblo. There are 281 wells in this division of which 167 are reclaimed wells of the Middle Rio Grande Conservancy District. The lines of Conservancy wells on the west side of the Rio Grande extended from mile post 912 north to the town of Atrisco, and were numbered consecutively from 1 to 7 in the system of the Conservancy District. On the east side of the Rio Grande the lines of wells extended northward from mile post 912 to the treating plant of the Atchison, Topeka & Santa Fe Railway and were numbered consecutively from 1 to 8. From Mountain Road, in the city of Albuquerque, which is about the center of the Albuquerque Division, the lines extended northward and were numbered from 1 to 18. The original numbering system was retained in the field.

The Belen Division extends from the Isleta Pueblo southward to the San Acacia diversion dam. There are 461 wells in this division. Very few of the original wells of the Conservancy District were located because none of these wells were cased and all the open holes had caved before this investigation was begun. However, the locations of the present wells correspond approximately to the original locations. The original line numbers as well as the original well numbers were retained in the field. These original line numbers were taken from the station-numbering of the survey lines of the drains.

The Socorro Division extends from the San Acacia diversion dam southward to the town of San Marcial. There are 175 wells in this division.

Method of location on maps.—Most of the wells in the Albuquerque and Belen Divisions were located on aeroplane mosaics furnished by the Soil Conservation Service by means of automobile speedometer and pacing from adjacent features shown on the mosaics. In heavy bosque and cultivated fields where it was impossible to use an automobile, and throughout the Socorro Division the wells were located by a transit stadia surevy. The Atchison, Topeka & Santa Fe Railway was used as a base line.

Notes on level net.—In the Albuquerque Division most of the old Conservancy District benchmarks near wells were found. These consisted either of wooden stakes driven to ground level or no. 60 spikes driven into fence posts, trees, or poles nearby. Most of these altitudes were assumed to be correct, and altitudes on neighboring observation wells at which benchmarks were not found were established by leveling from these points. In general, therefore, the altitudes correspond to the Conservancy District datum. This datum is apparently somewhat at variance with the newer levels established by the United States Coast and Geodetic Survey. Because time was not available for running a complete new system of levels, the old datum was used except for lines 877, 884, 911.8, 908.1, where, in the absence of any altitudes set by the Conservancy District, the Coast and Geodetic Survey datum was used, and line 892.5, where there appeared to be an error of 0.36 foot on the east side of the river and 0.75 foot on the west side, and on line 896.3 where there was an error of from 0.35 to 0.67 foot. From line 877.0 to line 889.6 it appears that the Conservancy datum is from 0.42 to 0.60 foot lower than the Coast and Geodetic Survey datum. From line 890.8 to line 901.5 the Conservancy datum appears to be from 0.10 to 0.23 foot higher than the United States Coast and Geodetic Survey datum. On lines of wells on the west side of the Rio Grande from mile post 902.7 to mile post 912.2 the Conservancy datum appears to be from 0.08 to 0.38 foot below the Coast and Geodetic Survey datum. On the east side of the river from mile post 905.3 to mile post 911.8 the Conservancy datum appears to be from 0.17 to 0.33 foot higher than the Coast and Geodetic Survey datum with the exception of lines 905.3 and 906.1, which are 0.63 and 0.50 foot, respectively, above the United States Coast and Geodetic Survey datum.

In the Belen Division new lines of levels were from benchmarks established by the Conserv District. Altitudes were not obtained on all h... Altitudes on well lines 920.1, 921.1, 921.4, 921.8, 922.9, 923.7, 924.1, 925.3, 928.8, 929.5, 930.3, 931.6, 932.4, 934.2, 936.4, 936.9, 938.6, and 939.6 were established by the Middle Rio Grande Conservancy District in 1936. The remainder were run by the Division of Ground Water of the Geological Survey.

In the Socorro Division all levels were run during the present investigation by the Geological Survey, using benchmarks established by the Conservancy District.

The Water Table

Form and Altitude

Plates 6–9 (map vol.) show the form and altitude of the water table in the irrigated area of the Middle Rio Grande Valley by means of contours at intervals of 1 foot. The control points are the water levels in most of the wells shown and at drains where marked by small arrows. The water levels in the canals are not controlling altitudes, because in general the water table lies considerably below the canals. Seepage from canals, however, raises the water table under them.

The water levels read during October 1936 v used in drawing the contours of the water table . the lines showing the depths to the water table. The shortness of the period of observation makes it inadvisable to use any system of means, as the mean based upon the observations now available would unduly emphasize summer conditions. The indications of the present data are that the water table during the month of October was at approximately its mean position for the year, being somewhat lower than its midsummer position in irrigated areas and somewhat higher than its midsummer position in unirrigated areas, where there was heavy use of water by native vegetation.

The significance of the form of the water table and of its fluctuation is discussed in succeeding parts of this paper.

Depth to Water

Description of maps.—Plates 6–9 (map vol.) show the depth to water during the month of October 1936 in nearly all parts of the Middle Rio Grande Conservancy District. A heavy line represents a depth to water of 8 feet along the outer edge of the valley. In areas outside this line the depth to water is greater than 8 feet. This line generally, but not invariably, follows the bluffs or hill slopes. A similar heavy line sh within the valley in which the depth to water is greater than 8 feet. Such areas are marked 8+. A line of medium weight represents a depth to water of 6 feet. In areas shown between this line and the heavy 8-foot line, the depth to water is between 6 and 8 feet, and the areas are marked 6—8. Light lines mark the 4-, 3-, 2-, 1-, and 0-foot limits. The areas between the 4- and 6-foot lines are marked 4—6. Areas in which the water table is within 4 feet of the surface are cross-ruled and the density of ruling increases with the shallowness of the water table, except that to prevent confusion, areas of surface water are unruled and are designated by the letter S.

The map is based on depths to the water levels in the observation wells in October 1936. Previous determinations of depths to water have been based on mean depths through the year, and it would therefore have been desirable to show mean depths on this map. In the absence of records for a complete year, the data for October were chosen as being probably nearer the annual mean than those of any other month, because in irrigated areas the depth to water is generally less in the summer than in October, whereas in unirrigated areas of natural vegetation it is generally greater. Tables 1 and 2 give the average depth to water and the change in water level from July to October in each subdivision of the valley.

Method of constructing maps.—The ideal method of constructing a map showing depth to water consists in comparing a topographic map of small contour interval with a map of the water table of the same contour interval and referred to the same datum. The construction of a map showing depth to water by this method is a more or less mechanical process of connecting the points of intersection of the two sets of contours. This process reduces the human element to a minimum and insures that topographic irregularities are taken into account.

In the absence of detailed contour maps, the measurements of depth to water may be plotted and the lines showing depth to water may be drawn accordingly. Such a process does not take into account the topographic irregularities between points of observation. If the area is only very gently rolling, as the Rio Grande flood plain, the errors made will presumably balance one another, but local accuracy cannot be attained.

The depth-to-water map of the Bosque del Apache Grant was made by the first method. A topographic map [2] of this area with a 1-foot contour interval was kindly furnished by the United States Biological Survey, and elevations on the observation wells in the grant were determined by the Biological Survey in the course of the mapping. Strict comparability of the topography and the water-table map was therefore assured. The greater amount of detail in this map as compared with the maps of other parts of the valley is at once apparent.

For the remainder of the valley the only topographic maps available were those of the Middle Rio Grande Conservancy District revised from the map prepared by the State engineer of New Mexico in 1918. These maps could not be used for direct comparison with the water-table map. In several places, especially in the Socorro Division, there had been considerable topographic change by floods, principally that of 1929. In the remainder of the area there were so many discrepancies in altitudes as determined in this survey and as shown on the map, that it seemed better to draw the lines showing depth to water directly. In the Middle Rio Grande Conservancy District, therefore, the depths to ground water as determined in the field were plotted on the map. Preliminary lines showing depths to water were drawn on the basis of these data. These lines were then adjusted to conform to relief features shown on the airplane maps of the valley and to the major topographic trends shown on the topographic maps of the Conservancy District.

The resulting map is not accurate in detail. There may be some question as to whether the mapping of depths to water in as much detail as is shown is justified by the data available, either as to depths to water or, more particularly, as to topography. However, the individual errors in mapping should more or less balance each other and the total acreage with specified depths to water in the different localities should be approximately as indicated, and should form a reliable basis for estimating the amount of lowering of the water table effected by the construction of the drains.

Average depths to water and changes in depth since 1927.—Table 1 (p. 274) gives the acreage in each part of the Middle Rio Grande Valley with ground water at different specified depths in October 1936. These acreages were determined by measuring the areas on the depth-to-water map by means of a planimeter. The areas are also expressed in percent of the total area surveyed.

Table 2 (p. 274) gives data on the depth to ground water in the different areas in the Middle Rio Grande Valley at the present time and for the period before drainage was begun. The latter data are taken from the official plan [3] of the Conservancy District and represent average conditions during a full year in 1926

[2] Bosque del Apache migratory waterfowl refuge-proposed, scale 1 inch equals 400 contour interval 1 foot; U. S. Bur. Agr. Eng., 1936.

[3] Burkholder, J. L., Report of the chief engineer, Middle Rio Grande Conservancy District, State of New Mexico, vol. 1, p. 46: 1928?

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and 1927. The data are presented in each case as the fraction of the total area surveyed having ground water over specified depths.

The areas compared are not exactly coextensive because of the indefinite nature of some of them. The areas considered in the present survey are as follows:

1. Algodones-Bernalillo.—Valley land on east side of river bounded on north by first section-line south of south boundary of T. 14 N., on the east by the fourth section line east of east boundary of R. 3 E., on south by first section line north of north boundary of T. 11 N.

2. Coralles.—Valley land on west side of river throughout length of Coralles main canal.

3. Alameda-Albuquerque.—Valley land east of river abutting the Algodones-Bernalillo area and bounded on the south by an arbitrary line 3,000 feet north of north boundary of T. 9 N.

4. Atrisco-Pajarito-Isleta.—Valley land west of river from head of Arenal main canal to an east-west line drawn from west end of Isleta Bridge.

5. Barr.—Valley land east of river abutting the Alameda-Albuquerque area on north; bounded on south by an arbitrary line bearing N. 74° E. from the mouth of the Barr riverside drain.

6. Peralta-Tome.—Valley land east of river from Isleta to bridge over Rio Grande at Belen.

7. Los Lunas-Belen.—Valley land west of river bounded on north by east-west line drawn from west end of Isleta Bridge and on south by south boundary of T. 4 N.

8. San Juan.—Valley land east of river extending from head of San Juan Canal south to La Joya Acequia where it approaches the river in sec. 28, T. 2 N., R. 1 E.

9. San Francisco.—Valley land west of river abutting Los Lunas-Belen area on north, bounded on south by Rio Puerco.

10. San Acacia, Lemitar, Socorro.—Valley land west of river bounded on north by San Acacia acequia, on south by south boundary of the Town of Socorro Grant.

11. San Antonio.—Valley land west of river bounded on north by south line of the Town of Socorro Grant, on sou the north boundary of the Bosque del Apache Grant.

12. Bosque del Apache.—Valley land west of river included in the Bosque del Apache Grant.

The computations of average depth are made in each case by assuming the average depth for each classification to be the intermediate value between the limits for that classification; for instance, the average depth for the area with depth to ground water between 0 and 1 foot is taken as 0.5 foot, and for that between 1 and 2 feet as 1.5 feet. These data are presented graphically in figures 57–60.

The best-drained areas are indicated to be the Peralta-Tome area, the Socorro division, and the Corrales area. The 1926–27 and 1936 percentages for the Bosque del Apache tract are in close agreement. The slight over-all lowering of the water table indicated in this tract is in part due to the slight amount of drainage caused by the extension of the San Antonio riverside drain into the area. This agreement seems to indicate that probably the figures for the other districts are properly comparable.

Fluctuations of the Water Table

Seasonal fluctuations.—The present investigation has not covered enough time to determine the norm seasonal fluctuations of the water table. It has sho as might be expected, that the seasonal fluctuatio in irrigated and unirrigated areas are opposite in trend. The irrigated areas receive water in the growing season in excess of their demand and consequently the water

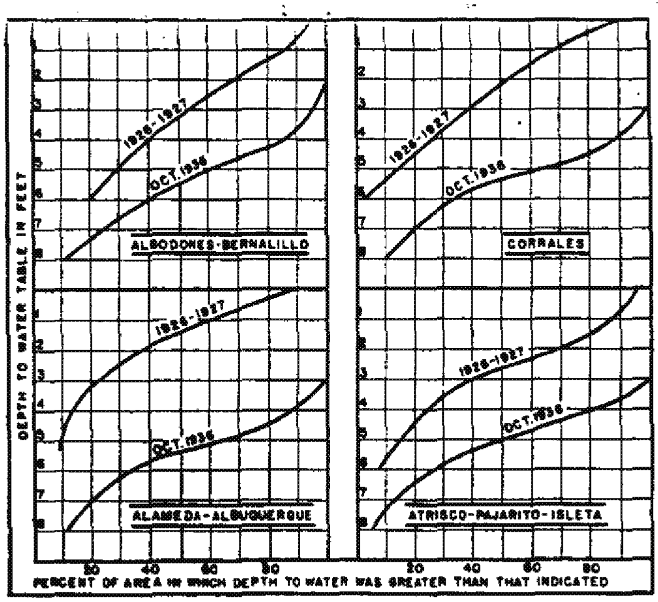

Figure 57.—Depth to water in parts of the Albuquerque Division in 1926-27 and in 1936.

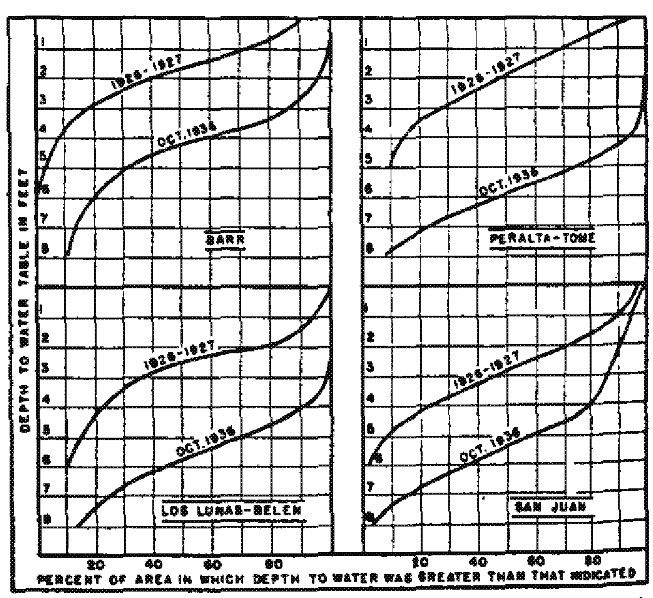

Figure 58.—Depth to water in parts of the Albuquerque and Belen Divisions 1926-27 and in 1936.

ta.le rises in summer. In the unirrigated areas the ·tation draws heavily in summer on the ground . and hence in these areas the water table falls ummer. After the growing season the water table generally falls in the irrigated areas and rises in the unirrigated areas.

These typical changes are shown by the average fluctuations in the several divisions of the valley between July and October 1936, given in table 2, page 274. The Bosque del Apache Grant is unirrigated except by overflow from the Socorro main canal at its north border. Between July and October the water table showed a net average rise of 0.86 foot, and it continued to rise in the ensuing months. There are no areas in which all the land is irrigated and hence the declines of the water table given in table 2, are not entirely representative of the change in irrigated areas. However, the more heavily irrigated areas show the greater decline. The wells on line 900.4, just north of Albuquerque, show the typical fluctuations of the water table in a heavily irrigated area. The water levels in these wells reached maximums in June and July, then fell an average of 1.08 feet by October, and declined 0.64 foot more by January.

Diurnal fluctuations.—Description of areas where diurnal fluctuations were observed.—Studies of the diurnal fluctuations of the water table were made in two ·eas of native vegetation south of Socorro. These udies were made by means of automatic water-stage recorders located on wells 980.4–4W and 993.1–6W. The recorders were furnished for this purpose by the Bureau of Agricultural Engineering.

Well 980.4–4W, which has the longest record, was a dug well with the water table about 4 feet below the land surface. It was located in a grove of small cottonwood trees, with sparse salt grass between the trees, about 1,800 feet west of the Socorro Riverside drain. When the recorder was installed on June 1, 1936, the depth to water was 3.98 feet. The water level in the well sank rather uniformly, except for diurnal fluctuations, until August 3 when it had reached a depth of 5.32 feet. It remained about constant at this level until August 20, when coincident with a rain it rose somewhat. It maintained a depth of more than 5 feet until September 11, when on the occasion of another shower the water table began to rise. On September 27 snow fell in the area. Thereafter the diurnal fluctuations were small and the water table rose steadily but at a constantly diminishing rate to a depth of 2.80 feet on January 1, 1937.

In order to relate the fluctuations observed at the recorder well to fluctuations elsewhere in the immediate neighborhood, and in different types of vegetation, satellite wells were placed in critical localities. Well 980.4–3W was a sandpoint driven about 10 feet below the water table close to the recorder well. Well 980.4–2W was about 525 feet east of the recorder in small cottonwoods. Well 890.4–1W was about 1,100 feet east of the recorder and about 700 feet west of the riverside drain in a grove of large cottonwoods. Well 980.4–5W was 250 feet west of the recorder in sparse salt grass.

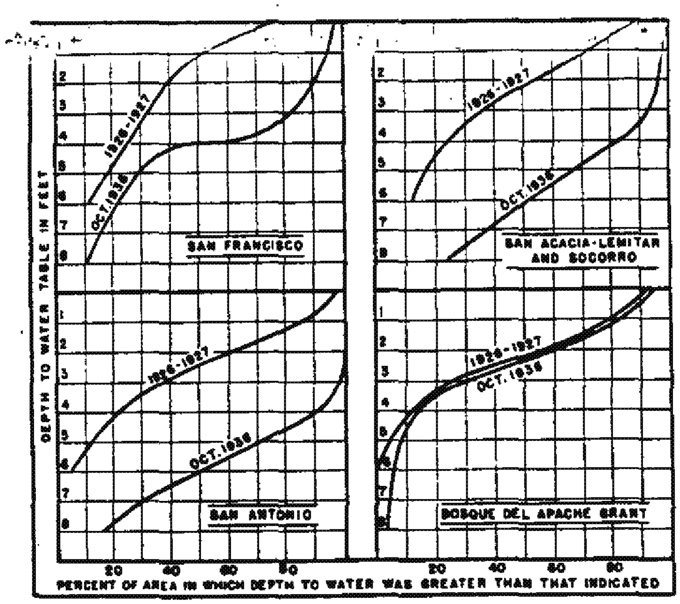

FIGURE 59.—Depth to water in parts of the Belen and Socorro Divisions in 1926-27 and in 1936.

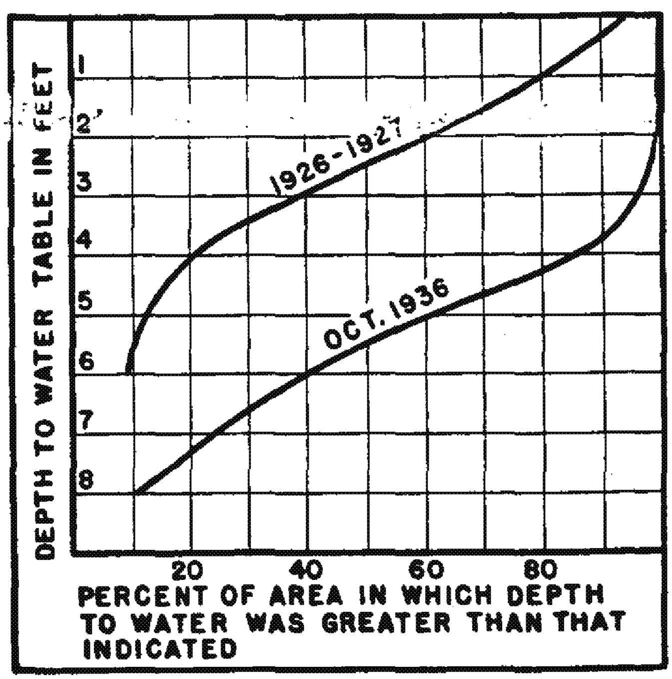

FIGURE 60.—Depth to water in Middle Rio Grande Conservancy District in 1926-27 and in 1936.

TABLE 1.—*Areas in Middle Rio Grande Valley having ground water at given depths in October, 1936*

District	Depth to water, in feet								Total area surveyed	Area not surveyed	To[illegible]ley acreage
	Above surface	0-1 foot	1-2 feet	2-3 feet	3-4 feet	4-6 feet	6-8 feet	Over 8 feet			
Algodones-Bernalillo……acres	0	21.00	12.00	311.00	622.00	3,385.00	1,915.00	777.00	7,043.00	0	7,043.00
percent [1]	0	.29	.17	4.21	8.84	48.16	27.23	11.10	100.00	0	
Corrales……acres	0	0	0	0	352.00	1,722.00	688.00	355.00	3,117.00	631.00	3,748.00
percent [1]	0	0	0	0	11.28	55.24	22.10	11.38	100.00	20.25	
Alameda-Albuquerque……acres	0	0	31.00	597.00	2,072.00	6,535.00	2,901.00	1,853.00	13,989.00	1,468.00	15,457.00
percent [1]	0	0	.22	4.27	14.80	46.70	20.73	13.28	100.00	10.48	
Atrisco, Pajarito, Isleta……acres	0	0	0	11.00	1,832.00	7,025.00	2,850.00	528.00	12,246.00	1,887.00	14,133.00
percent [1]	0	0	0	.10	14.96	57.36	23.27	4.31	100.00	15.41	
Barr……acres	0	13.00	178.00	408.00	1,322.00	1,730.00	402.00	490.00	4,543.00	0	4,543.00
percent [1]	0	.28	3.90	9.00	29.10	38.10	8.85	10.77	100.00	0	
Peralta-Tome……acres	0	0	0	92.00	933.00	9,775.00	7,760.00	1,490.00	20,050.00	0	20,050.00
percent [1]	0	0	0	.46	4.66	48.75	38.70	7.43	100.00	0	
Los Lunas-Belen……acres	0	0	64.00	236.00	1,960.00	11,215.00	7,225.00	3,120.00	23,820.00	674.00	24,494.00
percent [1]	0	0	.27	.99	8.24	47.10	30.30	13.10	100.00	2.82	
San Juan……acres	69.00	363.00	424.00	376.00	583.00	3,815.00	2,645.00	224.00	8,499.00	0	8,499.00
percent [1]	.81	4.27	4.98	4.43	6.86	44.88	31.15	2.62	100.00	0	
San Francisco……acres	154.00	133.00	235.00	408.00	1,843.00	1,437.00	580.00	554.00	5,344.00	0	5,344.00
percent [1]	2.88	2.49	4.40	7.64	34.48	26.87	10.87	10.37	100.00	0	
San Acacia, Lemitar, Socorro……acres	0	182.00	186.00	322.00	1,107.00	3,395.00	2,928.00	2,516.00	10,636.00	0	10,636.00
percent [1]	0	1.71	1.75	3.02	10.40	31.85	27.62	23.65	100.00	0	
San Antonio……acres	0	0	0	91.00	415.00	2,520.00	2,087.00	923.00	6,036.00	0	6,036.00
percent [1]	0	0	0	1.51	6.88	41.75	34.56	15.30	100.00	0	
Bosque del Apache Grant……acres	358.00	614.00	1,772.00	2,040.00	1,476.00	544.00	230.00	208.00	7,442.00	448.00	7,890.00
percent [1]	4.81	10.93	23.80	27.42	19.83	7.32	3.09	2.80	100.00	6.03	
Total for Middle Rio Grande Valley, excluding Bosque del Apache Grant……acres	223.00	712.00	1,130.00	2,852.00	13,041.00	52,554.00	31,981.00	12,830.00	115,323.00	4,660.00	119,983.00
percent [1]	.19	.62	.98	2.46	11.30	45.64	27.69	11.12	100.00	4.04	

[1] The percentage given, including that for unsurveyed area, is the percentage of the surveyed area.

TABLE 2.—*Comparison of depths to ground water in Middle Rio Grande Valley in 1926–27 and in 1936*

		Percentage of area with depth to ground water more than—							Above surface	Unsurveyed area in percent of surveyed	Average depth to water (feet)	Average lowering of water table (feet)	Average change from July to October 1936 (feet)	Total area in each division	
		8 feet	6 feet	4 feet	3 feet	2 feet	1 foot	0 foot						Surveyed (acres)	Unsur-
Algodones-Bernalillo	1926–27	------	20.97	39.71	------	70.21	86.49	95.23	4.77	1.72	3.58	------	------	11,983	197
	1936	11.10	38.33	86.49	95.33	99.54	99.71	100.00	------	0	5.72	2.14	−0.33	7,043	0
Corrales	1926–27	------	2.86	26.69	------	51.71	69.52	91.64	8.36	0	2.48	------	------	3,038	0
	1936	11.38	33.48	88.72	100.00	------	------	------	------	20.25	5.73	3.25	−.30	3,117	631
Alameda-Albuquerque	1926–27	------	8.02	13.18	------	37.19	62.56	88.48	11.52	0	1.99	------	------	14,675	0
	1936	13.28	34.01	80.71	95.51	99.78	100.00	------	------	10.48	5.61	2.62	−.68	13,969	1,468
Atrisco, Pajarito, Isleta	1926–27	------	7.22	24.80	------	72.60	89.25	96.87	3.13	1.17	3.09	------	------	15,823	186
	1936	4.31	[illegible]	[illegible]	99.90	100.00	------	------	------	[illegible]	[illegible]	2.32	−.36	[illegible]	[illegible]
Barr	1926–27	------	[illegible]	[illegible]	------	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	------	------	[illegible]	[illegible]
	1936	10.77	19.62	57.72	86.82	95.82	99.72	100.00	------	0	4.80	2.89	−1.62	4,543	0
Peralta-Tome	1926–27	------	9.33	13.56	------	47.99	69.52	93.24	6.76	0	2.32	------	------	20,541	0
	1936	7.43	46.13	94.88	99.54	100.00	------	------	------	0	5.99	3.67	−.19	20,050	0
Los Lunas-Belen	1926–27	------	10.54	22.39	------	75.39	94.24	99.88	.12	.37	3.23	------	------	25,047	92
	1936	13.10	43.40	90.50	98.74	99.73	100.00	------	------	2.82	5.97	2.74	−.40	23,820	674
San Juan	1926–27	------	1.51	21.69	------	68.22	91.34	96.97	3.03	.39	2.87	------	------	6,198	26
	1936	2.62	33.77	78.65	85.51	89.94	94.92	99.19	.81	0	5.10	2.23	+.05	8,499	0
San Francisco	1926–27	------	11.52	25.65	------	39.26	51.91	75.48	24.52	0	2.12	------	------	4,616	0
	1936	10.37	21.24	48.11	82.59	90.23	94.63	97.12	2.88	0	4.50	2.38	+1.39	5,344	0
San Acacia, Lemitar, Socorro	1926–27	------	12.47	24.36	------	53.55	72.79	88.78	11.22	4.76	2.66	------	------	13,437	640
	1936	23.65	51.27	83.12	93.52	96.54	98.29	100.00	------	0	6.13	3.47	+.22	10,636	0
San Antonio	1926–27	------	4.81	21.63	------	63.31	87.10	97.65	2.35	37.34	2.83	------	------	5,016	2,620
	1936	15.30	49.86	91.61	98.49	100.00	------	------	------	0	6.16	3.33	−.07	6,036	0
Bosque del Apache Grant	1926–27	------	0	11.55	------	60.04	80.12	93.07	6.93	31.55	2.37	------	------	6,290	1,985
	1936	2.80	5.89	13.21	33.04	60.46	84.26	95.19	4.81	6.02	2.60	.23	+.86	7,442	448
Total	1926–27	------	9.54	21.69	------	59.32	79.56	93.85	6.15	4.56	2.75	------	------	124,559	3,761
	1936	11.12	38.81	84.45	95.76	98.21	99.19	99.81	.19	4.04	5.69	2.94	------	115,323	4,660

NOTE.—Bosque del Apache area not included in total. Depths for 1936 are from measurements taken in October; those for the earlier period are averages for 12 consecutive months in 1926 and 1927.

Well 980.4–6W was 1,250 feet west of the recorder in salt grass, and about 800 feet east of the Luis Lopez drain A. Well 980.3–1W was in a willow thicket 600 feet north of the recorder. Well 980.5–1W was in a tornillo thicket 500 feet south of the recorder. The depth to water was about 5 feet in all these wells in midsummer except in 980.4–1W, in which it was about 4 feet. All showed about the same seasonal fluctuation as did the recorder well.

The second recorder was placed over well 993.1–6W, a dug well in a salt-grass meadow about 2 miles north of Elmendorf. The depth to water ranged from 1.8 feet in July to about 0.4 foot when last read in November.

Character of Diurnal Fluctuations.—Figure 61 shows the diurnal fluctuations of the water table in the two wells equipped with recorders for the week of August 17 to 24, 1936. The fluctuations shown are t

...e fluctuations during the growing season. The ...table fluctuated during the course of a day about ... foot at well 980.4–4W, in the cottonwood grove, and slightly over half this amount at well 993.1–6W, in the salt-grass meadow. The recovery of the water table under the cottonwoods generally began several hours after sundown, whereas under the salt grass it began to recover very shortly after sundown. The lag shown by the cottonwoods may be due to different soil conditions, but seems most likely to result from the greater storage of sap in the trees. Presumably a large quantity of water is stored normally in the tree and this furnishes water for transpiration during the early part of the morning. After the tree has ceased transpiring in the evening there is apparently a continued draft on the ground water for some time in order to replenish the sap in the tree.

On August 20, light showers fell at both recorders, amounting to 0.14 inch at Socorro. There was an immediate rise of the water table presumably due to reduction in transpiration by the vegetation and substitution of soil moisture derived from the rainfall for that from capillary rise of ground water. The water table after rising a little for 2 days resumed its downward trend.

Significance of Diurnal Fluctuations.—The typical graph of the daily fluctuation of a shallow water table ... an area overgrown by unirrigated vegetation is a ...ore or less symmetrical curve, falling in the daytime when the vegetation is transpiring water and rising in the night when the vegetation is dormant. The correlation with use by the vegetation is obvious. The vegetation in the daytime uses water in excess of the rate at which it can be delivered to the area by ground-water flow, and consequently the water table lowers; at night the delivery by ground-water flow exceeds the rate of use, and consequently the storage in the area increases and the water table rises. Accompanying the diurnal fluctuations during the growing season there is usually a residual fall of the water table, and there is usually a rise during the nongrowing season. The amount of the residual fall is limited, however, within a narrow range by the root zone of the plants; if the water table should fall below the reach of the roots transpiration would cease and the water table would no longer decline. Thus the amount of daily fluctuation is an index of the use of water by the vegetation.

White [4] has made a quantitative application of this principle to determine the use of water by native vegetation in the Escalante Valley, Utah. At night, when the vegetation is dormant, there is presumably no

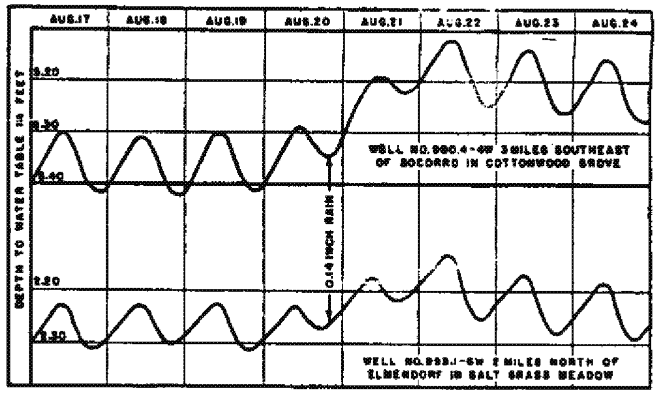

FIGURE 61.—Fluctuations of water table Aug. 17 to 24, 1936, in two wells near Socorro.

loss of water from the area, and the rate of rise of the water table measures the input of ground water into the area. If this rate is projected through the entire 24 hours it represents what would be the rise of the water table if there were no use of water. If this virtual rise of the water table is corrected for the residual rise or fall during the day and multiplied by the factor expressing the quantity of water equivalent to a given change in the water table, which White calls the specific yield, the use of water by the plant for that day will be determined. White [5] expresses the relationship by the formula q equals $y(24r \pm s)$, in which q is the depth of water withdrawn, y is the "specific yield" of the soil in the belt of fluctuation of the water table, r is the hourly rate of rise of the water table during the period of full recovery, generally from midnight to 4 a. m., and s is the net fall or rise of the water table during the 24-hour period. The quantity $(24r \pm s)$ may be called the "virtual fall" of the water table, and represents the theoretical amount the water table would fall, if there were no recharge to the area and the vegetation could nevertheless continue to extract water, the factor y being considered constant. The "virtual fall" of the water table at the two recorder wells is given by months in the following table.

The quantity $(24r \pm s)$, in feet, as determined in two localities of native vegetation, by months:

	Well 980.4–4W (in cottonwood grove)	*Well 993.1–6W (in salt-grass meadow)*
June	9.57	----
July	9.52	6.69
August	9.00	5.44
September	4.57	3.49
October	.76	1.66

The quantities given are of course not the actual water use. They are indexes to the water use, the relationship between the index and the actual use of water being given by the quantity y. The use of water by months

[4] White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil, U. S. Geol. Survey Water-Supply Paper 659, ...-105, 1932.

[5] Idem, p. 61.

is probably in the same ratio as that between the monthly indexes.

Water levels in the satellite wells around well 980.4–4W were read at approximately hourly intervals from 9 a. m. on August 19 to 9 p. m. on August 20, in order to compare diurnal fluctuations in the surrounding territory with that given by the recorder. These records are given graphically in figure 62. All the surrounding wells showed greater fluctuations of water level than the recorder well, excepting wells 980.4–2W and 980.4–3W. The fluctuation in small cottonwoods was about the same as that in the recorder well. In well 980.4–3W, a drive point going about 10 feet below the water table and as close as possible to the recorder well, the water rose and fell about as it did in the recorder well, but it neither rose as high nor fell as low. The ratios of the fall in water level during the day in each of the satellite wells to the fall in the recorder well were as follows: 980.4–3W (drive point near the recorder) 0.7; 980.4–2W (small cottonwoods) 0.8; 980.4–1W (large cottonwoods) 3.8; 980.4–5W (sparse salt grass) 2.3; 980.4–6W (salt grass) 3.0; 980.3–1W (willows) 2.5; and 980.5–1W (tornillo) 3.2. The complete significance of these ~~ratios is in doubt~~. In part, they represent different rates of transpiration and d ent rates of draft on ground water. It is prol significant that the fluctuation in wells 980.4–2W and 980.4–4W, both in groves of small cottonwoods, was about the same, while that in well 980.4–1W, in a grove of large cottonwoods, was much greater. However, because the amount of fluctuation is also dependent on the character of the soil in which the water table fluctuates, it is evident that these ratios are not necessarily the ratios of uses of water by the different types of vegetation.

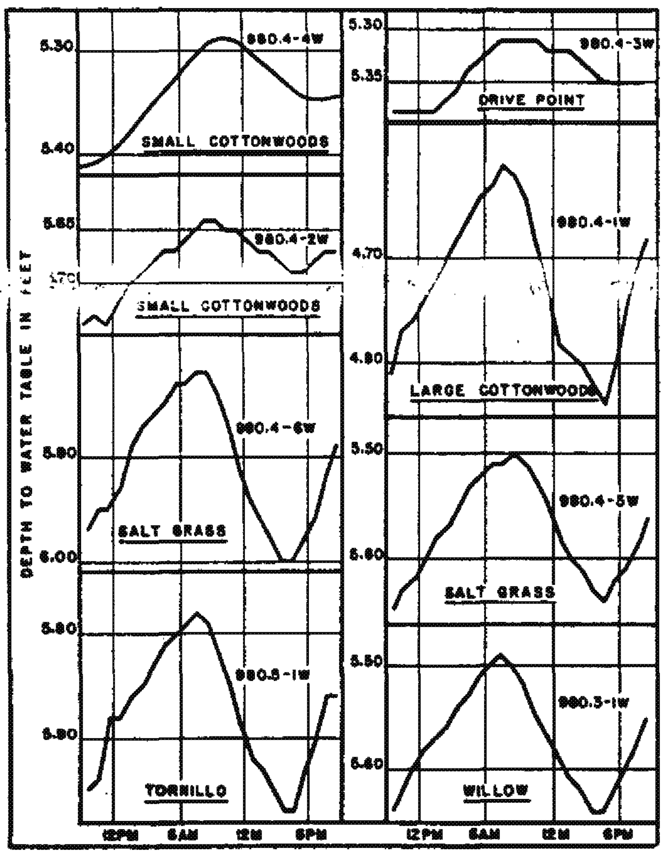

FIGURE 62.—Fluctuations of water table in a group of wells near Socorro Aug. 19 to 20, 1936.

NOTE.—0.14 inch rain fell at 4:40 p. m. Aug. 20, 1936.

Insufficiency of Data for Determining Consumptive Use.—White's study of the relationship between diurnal fluctuations of the water table and use of water by native vegetation in the Escalante Valley was accompanied by intensive study by means of tanks to determine the proper value of "specific yield" to be applied for each soil used. The application of this method of study of consumptive use by natural vegetation produced in his area results closely comparable to results obtained from studies with soil tanks.

The theory appears to be sound but the use of the term "specific yield" is probably unfortunate as implying that the factor y in the formula is the same specific yield factor that is used in other types of investigation. Meinzer [6] has defined specific yield as the ratio of the volume of water which, after being saturated, will yield by gravity, to (2) its own volume. It is implied that the time of draining is unlimited. This is obviously a different amount than would drain in the approximately 12-hour period involved in diurnal fluctuation. A better term would probably be the more general though closely related term "effective porosity", which is defined as the ratio of (1) the volume of water (or other liquid) which after being saturated a soil will yield, under any specified hydraulic conditions, to (2) its own volume.[7] If the factor y is regarded as the effective porosity of the soil, the specific conditions being identical with those involved in the fluctuations in a given locality, the formula appears to be theoretically correct. In order, therefore, to compute by means of water-table fluctuations the use of water by vegetation it is necessary to know the effective porosity specific to the hydrologic condition involved. This factor can probably only be ascertained with exactness by laboratory experiments duplicating the fluctuations in a column of the natural soil. Such methods were used by White in the Escalante Valley. In the present investigation time and personnel were not available for

[6] Meinzer, O. E., Outline of ground-water hydrology; U. S. Geol. Survey Water Supply Paper 494, p. 28; 1923.

[7] Idem.

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similar experiments. It may be of some value, however, to examine certain available data regarding the columns near the recorders.

At the time the hourly readings of water levels in the satellite wells near well 980.4–4W were made, on August 19 and 20, soil samples were taken near both recorders by the Bureau of Agricultural Engineering. Two sets of samples were taken at each recorder, one in the evening of August 19 and the other in the morning of August 20, in the hope that by making soil moisture determinations at high and low stages of the water table, differences in the total soil moisture in the capillary fringe would be noted that could be correlated with the fluctuations of the water table. However, the soil apparently varied so much within the few feet between successive sampling points that no significant differences could be found.

The characteristics of the soil columns near the two recorder wells as determined by the Bureau of Agricultural Engineering are given in tables 3 and 4. The volume weight is the apparent specific gravity of the soil.

It is evident that consumption of water computed from the water-table fluctuations and using the values of pore space minus moisture equivalent by volume as the effective porosity would be exorbitant. Thus the computed values would be about 11 feet at well 980.4–4W for the period June 1 to December 31 and about 3.80 at well 993.1–6W for July 1 to October 31. It is evident that the effective porosity pertaining to these fluctuations is much smaller. In well 993.1–6W the capillary fringe evidently reaches the surface, as the topsoil is quite moist. The pertinent effective porosity must be accordingly reduced. In well 980.4–4W, possible causes for low effective porosity are more difficult to find. It may be that the abrupt change in moisture content at 3 feet noted in both sets of samples, represents a bed of coarser material overlying finer, so that, in this well also, the capillary fringe is definitely broken at this fixed level and is thus prevented from fluctuating with the water table.

Movement of Ground Water

General Principles of Ground-Water Movement

So far as can be learned from experiments approximating the conditions of nature, ground water always moves in conformity with Darcy's law, which states that the rate of flow is equal to a factor expressing the ease of movement through the containing medium multiplied by the pressure gradient under which the water moves. The factor expressing the ease of movement through the containing medium has been evaluated in many ways according to the type of work to which it is desired to apply the factor. That which will be used in this report is the coefficient of permeability defined by Meinzer [8] which expresses this ease of movement as the number of gallons of water at a temperature of 60° F. which will move in 1 day through a cross section of the water-bearing material 1 foot square under a pressure gradient of 1 foot in 1 foot. The ease of movement in an aquifer, as a whole, can under certain conditions be determined

TABLE 3.—*Soil moisture conditions at well 980.4–4W, south of Socorro*

SAMPLES TAKEN 1:50 A. M. AUG. 20, 1936

Depth in feet	Moisture in percent by weight	Pore space, in percent	Volume weight	Moisture equivalent, in percent by weight	Average
0–0.5	14.0	59.6	1.08	18.1	11.6
0.5–1.0	5.5		1.08	5.0	
1.0–1.5	4.3	49.8	1.33	2.2	1.8
1.5–2.0	3.2		1.33	1.4	
2.0–2.5	4.1	37.6	1.66	1.4	1.4
2.5–3.0	5.8		1.66	1.3	
3.0–3.5	18.7	48.1	1.38	2.9	2.4
3.5–4.0	16.1		1.38	1.9	
4.0–4.5	18.9	35.8	1.70	1.8	2.2
4.5–5.0	24.4		1.70	2.5	
5.0–5.5	24.7	41.2	1.57	2.5	2.5
5.5–6.0	26.5		1.57	2.5	
SAMPLES TAKEN AT 10:15 A. M. AUG. 20, 1936					
0–0.5	15.2	47.9	1.39	19.5	11.7
0.5–1.0	6.9		1.38	3.9	
1.0–1.5	3.2	41.6	1.56	2.1	2.0
1.5–2.0	2.5		1.56	1.8	
2.0–2.5	3.3	42.0	1.53	2.0	2.1
2.5–3.0	4.8		1.53	2.2	
3.0–3.5	12.2	23.0	2.04	2.7	2.7
3.5–4.0	16.5		2.04	2.8	
4.0–4.5	20.7	40.9	1.56	3.3	3.5
4.5–5.0	25.8		1.56	3.6	
5.0–5.5	24.6	28.8	1.88	3.2	3.2
5.5–6.0	26.0		1.88	3.1	

TABLE 4.—*Soil moisture conditions at well 993.1–6W, south of Socorro*

SAMPLES TAKEN AT 8:30 P. M., AUG. 19, 1936

Depth in feet	Moisture in percent by weight	Pore space, in percent	Volume weight	Moisture equivalent, in percent by weight	Average
0–0.5	44.7	63.7	1.19	40.8	32.2
0.5–1.0	26.5		1.19	23.5	
1.0–1.5	38.4	61.5	0.98	30.7	37.5
1.5–2.0	51.4		0.98	44.4	
2.0–2.5	42.0	55.5	1.14	37.6	38.7
2.5–3.0	48.3		1.14	39.9	
3.0–3.5	49.4			46.0	
3.5–4.0	65.7			36.3	
SAMPLES TAKEN AT 7:40 A. M., AUG. 20, 1936					
0–0.5	31.0	44.9	1.44	14.0	12.5
0.5–1.0	21.9		1.44	11.0	
1.0–1.5	41.0	57.5	1.07	31.3	34.8
1.5–2.0	48.6		1.07	38.4	
2.0–2.5	47.9	54.0	1.14	35.0	36.7
2.5–3.0	52.2		1.14	37.2	
3.0–3.5	66.9	65.6	0.86	43.5	43.6
3.5–4.0	79.3		0.86	43.7	

[8] Stearns, N. D., Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596, pp. 148, 149; 1927.

by means of pumping tests or otherwise. To express this ease of movement through the entire thickness of the aquifer, the term coefficient of transmissibility will be used and will also be expressed in gallons a day. It equals the average Meinzer coefficient of permeability of the material in the aquifer multiplied by the thickness of the aquifer, in feet.

Darcy's law is in form the same as Ohm's law relating to the flow of electricity, and the same as the law relating to the flow of heat by conduction in solids. For every factor needed to use Darcy's law in the study of ground water, there is an analagous factor in the theories of the conduction of heat and electricity. In general, studies of the movement of ground water are for several reasons more complicated than studies of the movement of heat. Ground water moves through a medium made heterogeneous by geologic processes which were subject to interruption and variation during the period of formation of the medium, whereas problems in conduction of heat and electricity commonly concern more or less homogeneous media fabricated by man. Therefore, although it seems necessary to consider theoretically the movement of water as it would be in a homogeneous medium in order to have a criterion to apply to the observed phenomena, it must be remembered that no theoretical quantitative treatment can exactly express the conditions of movement of ground water in nature. However, the results of such theoretical studies yield criteria in the light of which observed phenomena can be interpreted, in much the same way as the theory of beams yields useful criteria for the construction of wooden structures although it is recognized that wooden members do not conform to the ideal structures of theory and a factor of safety must be applied for safe construction.

Any fluctuation of the water table should be interpreted in the light of changes that have occurred to the east, west, north, and south of it, and vertically below it, and also before it in time. For instance, the water levels observed in shallow observation wells that extend just below the water table generally show the hydrostatic head at the water table with considerable precision, but the head of the water at greater depths in the water-bearing formation may be significantly different, because there is likely to be a vertical pressure gradient even where no artesian structure exists. Again, in nearly all ground-water phenomena there is a lag effect. Many phenomena are not correlated with contemporaneous phenomena elsewhere, but with phenomena of the past. As one instance in point, there must always be a time interval between the rise of the water level in the Rio Grande and the rise of the water level in the riverside drains, and it is therefore probable that the drains generally reach their maximum stages during falling stages of the river.

In homogeneous material the ground water moves in the direction of the slope of the water table. Ho... ...er, by Darcy's law the rate of flow is equal to the ... ...e gradient multiplied by the coefficient of transmis... ...ity and hence in a material that has different transmissibility in different directions, the direction of movement must be deflected from the slope of the water table toward the direction of greater transmissibility.

The medium through which the ground water chiefly moves in the Rio Grande Valley is the alluvium deposited by the river. An aggrading river, such as the Rio Grande, deposits coarse materials under its channel and finer materials on the adjacent flood plain. When the river shifts its course, it scours out some of the flood-plain materials and deposits coarse materials in their place, at the same time depositing finer material over the coarse material in its abandoned channel. Water moves longitudinally through these more or less continuous coarser deposits with comparative ease, but its movement either vertically or transversely to the axis of the valley is retarded by the less permeable flood-plain deposits between the old channelways. The application of this principle to the present study lies chiefly in the interpretation of the maps of the water table, with respect to the direction of the movement of the ground water. In the absence of definite data, it seems to the writer a fair tentative assumption that, in general, the direction of movement is ... haps about half the angle with the river as that water-table gradient as shown by the contours of the water table on the map. If it were possible to construct a water-table map that would be accurate in minute detail, the slope of the water table at any given place, as indicated by the contours, would correspond essentially to the direction of movement of the ground water.

General Character of the Movement

The most obvious characteristic of the ground-water flow indicated by the water-table map and the foregoing discussion is its predominant downstream movement. From the vicinity of Algodones at milepost 880, on the Atchison, Topeka & Santa Fe Ry., where the water table has an altitude of 5,080 feet, to milepost 997, 17 miles south of Socorro, the water table falls 585 feet, or an average of 5 feet to the mile. In places where ground-water recharge occurs, whether from the river, irrigated land, canals, or bordering mesas, the hydrostatic head is built up and consequently there is a tendency for the ground water to move laterally away from these places and also vertically downward. In places where ground water is discharged, whether by vegetation or drains, the head is lowered and consequently there is a tendency for the ground wat... move laterally toward these places and also vert...

…ard. Thus the body of ground water is slowly but …ly moving in a general downstream direction, … new supplies at some places and losing water at …s. Thus the ground water discharged at any place may have had its origin a considerable distance up the valley and may have been brought to the points of discharge through a certain amount of upward as well as lateral movement.

The lateral slopes of the water table, and consequently the lateral movement of the ground water, vary considerably in the different parts of the valley, depending principally on the spacing of the drains. In general, the lateral slope of the water table varies more or less inversely with the width of the valley. The lateral slope is greatest in the Socorro division, where it is as high as 22 feet to the mile, and least in the Belen division. The interior drains in general follow the cienegas, or longitudinal depressions of the flood plain between the borders of the valley and the natural levees of the river. As a consequence, the interior drains are generally incised into land that is lower than the land near the river and in most places lower than the river itself. Hence the water table is here held at its lowest position. Where the valley is narrow, and where the cienega and the drain are consequently close to the river, the gradients from the river to the cienega and from the border of the valley to the cienega are consequently high. The riverside drains are generally on higher land than the interior drains.

Movement Near Riverside Drains

In probably the greater part of the valley the slope of the water table is from the vicinity of the riverside drain toward the interior drain. In the areas where the valley is narrow and the interior drain is only a fraction of a mile from the riverside drain, the slope toward the interior drain is especially great. Many of the canals and laterals closely parallel the riverside drains, and hence wherever there is considerable seepage from the canals or laterals, the ground-water level is held high and causes or accentuates a slope from that vicinity toward the interior drains. In some localities the canal near the riverside drain may be the principal source of the ground water flowing from it in the direction of the interior drain. In some irrigated localities seepage from the water applied to the land may be the principal source but in the Socorro division, where the gradient toward the interior is greatest, there is comparatively little irrigated land near the river. There is also a tendency for water from the river to underpass the drains and to continue percolating to lower hydrostatic levels farther inland.

In connection with the study of the lateral slope of the water table, several observation wells were established in the close vicinity of the Socorro riverside drain opposite milepost 976.5, 1 mile north of Socorro. These wells were placed on a line at right angles to the drain, at intervals of approximately 142, 358, and 554 feet west (inland) from the drain, and 153 and 380 feet east from the drain in the direction of the river, which is about one-fourth mile from the most easterly well. The wells are in a bosque. The line of wells is crossed by the Socorro main canal, and one of the wells (976.5–3W) is very near the canal. There was, however, no irrigation near these wells. Graphical records of the water levels in these wells are given in figure 63.

At the time of the first readings on May 11, 1936, the water levels in wells inland from the drain stood at their highest position during the period of observation, and in the wells between the drain and the river the water levels were nearly but not at their highest position. The water level in the drain stood about 1.1 feet below a line connecting the water levels in the nearest wells on the opposite sides of the drain. Minor fluctuations were recorded during the remainder of May. On June 2, the water level at the well nearest the river had risen about 0.5 foot with respect to its position on May 18. At the same time the water level in the well farthest inland had fallen about 0.4 foot and the relative level of the drain remained the same. The rise of the water in the one well was probably due to flooding by the river and the fall in the other to increased transpiration losses. On June 27 the water level had fallen about 0.2 foot below its initial position in the well near the river and about 0.7 foot on the inland side. The water level in the drain was still about 1.1 feet below the position indicated by the average gradient between the adjacent wells. On July 29 the water near the river was 0.5 foot below its original position and farthest inland it had fallen to its

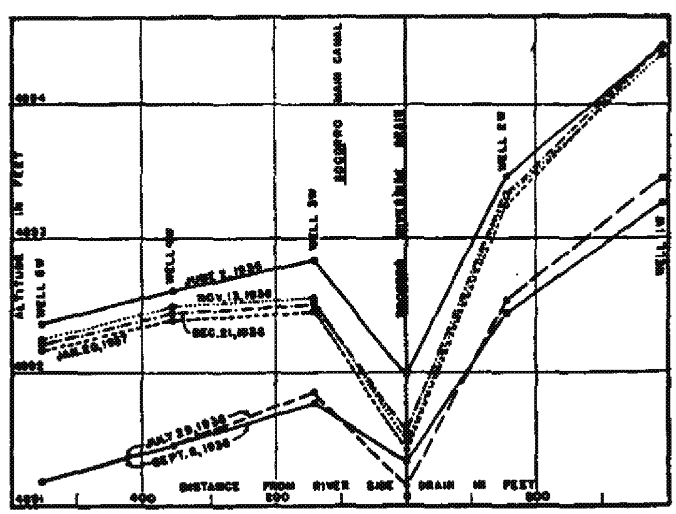

FIGURE 63.—Profiles of water table across Socorro Riverside drain on well line 976.2.

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lowest position during the period of study, about 1.4 feet below its level when first observed. The water level in the drain was slightly over a foot below the position indicated by the average grade between adjacent wells. This approximate position was maintained through August and a part of September. On October 10 the water had risen to a position about intermediate between the extremes shown during the period of reading. The water level in the drain was 1.1 feet below the position indicated by the gradient between adjacent wells. On November 13 the water level had risen almost to its highest position near the river and about 0.4 foot below its highest position at the land end of the line. The water in the drain stood about 1.4 feet below the position indicated by the grade between adjacent wells. On November 16 the canal, which passes between well 3-W and the riverside drain, was closed. There was practically no change in the position of the water table between the previous reading, on November 13, and the next reading, on December 21.

The slope of the water table between well 3-W and the riverside drain indicates that water is moving toward the drain near the water table in this interval. The slope in the opposite direction between wells 3-W and 5-W indicates that water is moving away from the river in that interval. Such a condition w[illegible] be explained by the presence of a source of ground [illegible]er at or near well 3-W, such as seepage from the canal. However, in well 3-W, near the canal, there was [illegible]tively large decline in the water table between [illegible] and September 8, while the canal was continuously filled with water and there was little change in its position between November 13 and January 20, 1937, although the canal did not carry water after November 16. The decline in the wells prior to September 8 was probably due to discharge by the native vegetation, and the subsequent rise was probably due largely to replenishment by ground water from farther up the valley—in part, water from the river that underpasses the drain.

Movement Near Interior Drains

Figure 64 shows the profile of the water table along a north-south line of experimental wells across Armijo drain, on the west side of the river, about 3 miles below Albuquerque. about midway in its course westward to join the Isleta drain. It shows a fairly uniform gradient along most of the profile, except near the drain, where the gradient is greatly increased as the water converges laterally and upward to the drain. This is probably a typical profile of the water table near an interior drain.

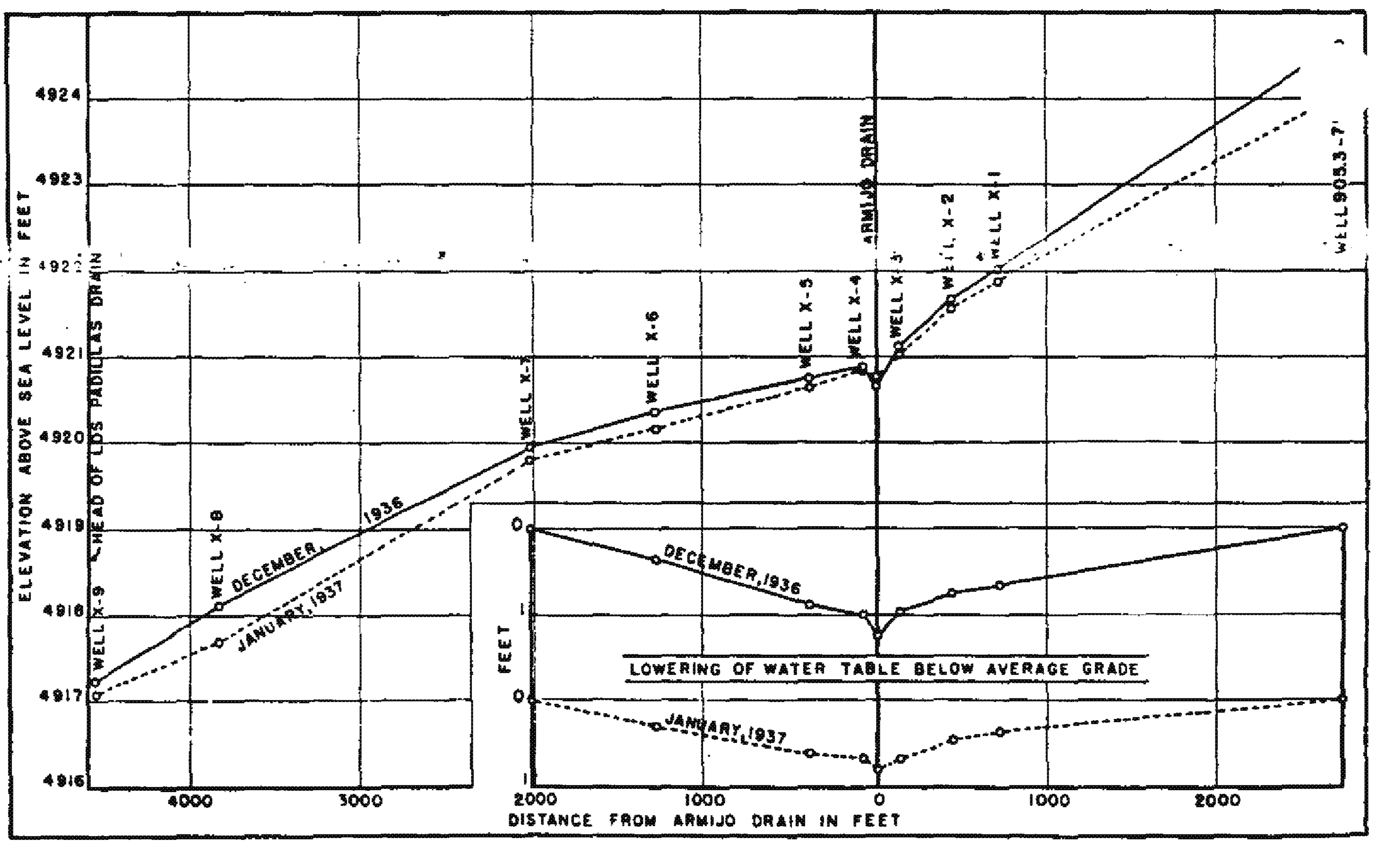

FIGURE 64.—Profile of water table between well 905.3-7W and head of Los Padillas drain.

Coefficients of transmissibility may be computed from the flow in interior drains and the water-table gradients near them. In this case the sum of the gradients on the two sides of the drain toward it are equal to the pick-up of the drain divided by the transmissibility of the aquifer. If the pick-up of the drain is expressed in second-feet per mile and the gradient as a decimal, the coefficient of transmissibility will equal the pick-up divided by the sum of the gradients on the two sides and multiplied by the factor 122.

Some difficulty has been experienced in finding suitable localities in which to make this comparison. Wells used to determine the gradient must be so placed that no interfering source or outlet of ground water occurs between them, and the drains must be capable of being measured with some accuracy. The best locality found was that of the Barr interior drain. Three lines of wells cross this drain, and good records have been obtained on all of them. The data on water-table gradients in this area are given in table 5.

The double average gives the average sum of the gradients on both sides of the drain on the three lines of wells. Gradients toward the drain are considered positive in the tabulation. The double average is plotted on figure 65, together with rates of accretion to the Barr drain taken from exhibit T-33 entered in the present suit between Texas and New Mexico on the adjudication of waters of the Rio Grande. The average monthly values for the two sets of data are given below.

TABLE 5.—*Water-table gradients between certain wells in the Barr district*

Date (1936-37)	Water-table gradient between wells						
	909.0-6E and 909.6-7E	909.6-10E and 909.6 9E	910.2-4E and 910.2-5E	910.2-7E and 910.2-6E	911.2-5E and 911.2-6E	911.2-9E and 911.2-8E	Double average
May 23	0.00235	0.00496	0.00092	0.00327	0.00036	0.00050	0.00412
June 18	.00196	.00343	.00067	.00599	-.00004	.00027	.00410
July 17	.00133	.00491	.00072	.00444	-.00044	.00007	.00368
Aug. 17	.00120	.00422	.00109	.00565	-.00031	.00015	.00400
Sept. 16	.00125	.00439	.00099	.00384	.00044	.00003	.00364
Oct. 20	.00165	.00475	.00244	.00411	-.00004	.00120	.00470
Nov. 17	.00163	.00436	.00186	.00382	.00102	.00027	.00432
Dec. 16	.00157	.00357	-.00015	.00419	.00107	-.00010	.00338
Jan. 26	.00142	.00346	-.00097	.00284	.00111	.00043	.00277
Distance between wells (in feet)	790	740	475	530	225	300	
Distance between nearest well and drain (in feet)	390	180	380	422	450	250	

TABLE 6.—*Average sum of water-table gradients toward Barr drain, average pick-up of the drain, and computed coefficients of transmissibility of the aquifer*

Month (1936-37)	Average sum of water-table gradients	Average accretion to drain (cubic feet per second per mile)	Computed coefficient of transmissibility
June	0.00406	3.07	92,200
July	.00379	2.23	71,700
August	.00391	2.46	76,800
September	.00378	2.22	71,400
October	.00448	1.98	53,800
November	.00431	2.07	58,600
December	.00369	1.57	51,800
January	.00299	1.32	53,800

Beginning with October the computed coefficients of transmissibility are quite accordant. There seems to be little doubt that they are more nearly correct than those computed for June to September, for the summer water levels are influenced by irrigation, which is irregular and furthermore adds water between the wells, whereas the theory assumes that the same amount of water passes the successive wells. Inasmuch as more water is likely to be added to the best drained land, which is land near the drain, the tendency is to make the ratio between the pick-up of the drain and the water-table gradient larger

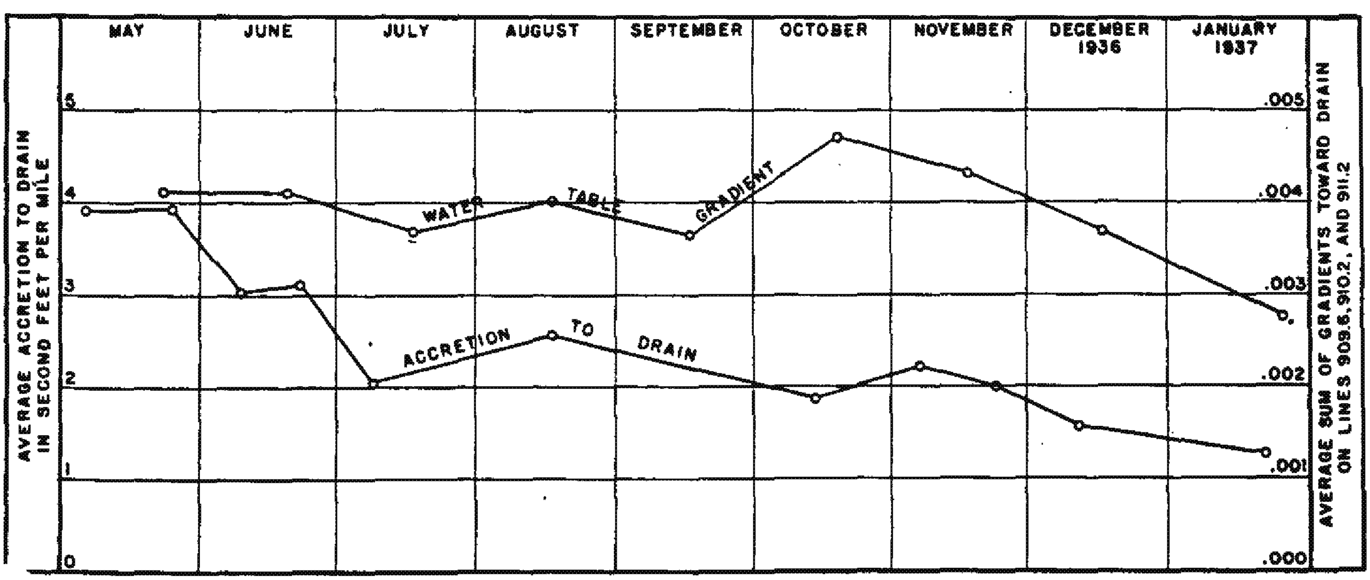

FIGURE 65.—Water-table gradient near Barr interior drain and rate of accretion to drain.

in the irrigated season than at other times. During the nonirrigation season water is taken from storage between the wells chosen to measure the gradient and between the nearest well and the drain. The gradient between the wells therefore corresponds to a smaller quantity of water than enters the drain.

It is therefore believed that the coefficients of transmissibility computed from the data for October to January are more nearly accurate than those computed for June to September, but that even these are somewhat too large. It seems to the writer that a coefficient of 50,000 is likely to represent approximately the average transverse transmissibility of the alluvium of the area and perhaps that of the alluvium in the Middle Rio Grande Valley, but intensive work on this particular problem is needed.

Source of the Ground Water

Ground Water From the Bordering High Lands

The ground water in the Middle Rio Grande Valley has several sources, namely, underflow from the mesas on both sides of the valley, seepage from the river, seepage from the canals, local rainfall, and seepage from irrigated lands.

A considerable amount of ground water in the aggregate must come from the higher lands bordering the valley. A part of the rain that falls on the extensive mesas on both sides of the Rio Grande Valley percolates down to the water table. This is proved by the presence of wells on the mesas with higher water levels than those in the wells in the valley. The only obvious avenue of escape for this water is in the valley. In many places, such as on the east side of the river at Albuquerque, any other disposal is almost certainly prevented by granite masses in the mountains bordering the Rio Grande depression.

Ground water percolates from the bordering highlands into the water-bearing alluvium or fill that underlies the valley and thence comes near the surface and is eventually discharged by the drains or by the vegetation or in other ways. There is doubtless general percolation toward the valley throughout the length of the valley, but the largest contributions come from the vicinities of the arroyos, which intermittently carry large quantities of water. The water-table map shows steep gradients near the debouchures of the large arroyos upon the floodplain, notably below Tijeras Canyon, in the upper part of the Barr district, and near Hell Canyon, above Peralta.

Observation wells were placed in the valley of an arroyo entering the Rio Grance Valley at the north line of the Bosque del Apache Grant and in the valley of the San Antonio Arroyo, above San Antonio. It was hoped that these arroyos would discharge surfac[illegible] during the course of the investigation, and that sig[illegible]cant fluctuations of the water table would be found. However, they did not discharge any water an[illegible] only fluctuations noted were similar to those of parts of the valley.

In many places the water table under the valley near the mesas has a considerable gradient—generally larger than that in the interior of the valley. This indicates considerable ground-water flow, but some part, perhaps a large part, of this is furnished by seepage from high-line canals. It seems impossible to apportion the flow to the two sources with the data at hand, but intensive study in chosen localities of water-table fluctuations when the canals are full and when they are empty might yield results. Studies of the quality of the ground water near the drains might also be indicative of the source, but samples from shallow wells are likely to show only the last increment to ground-water flow; that is, the increment furnished by the canals. Studies of the gradient of the water table under the mesas and of the permeability of the Santa Fe formation underlying them would help answer the question. A study of water-table gradients on both sides of the high-line canals would also be useful, but as the critical canals are on high ground, this would require the use of well-drilling equipment to sink the observation wells.

Some of the water percolating through the perme[illegible] beds of the Santa Fe formation below the m[illegible] doubtless enters the fill below the valley at considera[illegible] depths, eventually rising through the valley fill throughout the width of the valley, and having a part in maintaining the general ground-water level and supplying the drains. As the river flows at a higher level than the ground-water level in the cultivated area and as the flow is from the river toward the land, little if any of the flow from the mesas can escape between the riverside drains. In winter when transpiration and evaporation are very low, most of the water from the mesas is returned to the drains. At this time there is no irrigation but there is perhaps a small amount of recharge from melting snow. There is little water lost by transpiration. Hence the flow of the drains at this time is maintained largely by ground-water flow from the mesas and from the river.

The recharge from the mesas, as well as the specific yield of the valley fill, was computed for the section of the valley between Isleta and Belen by assuming that during this winter period the recharge from precipitation and the discharge by evaporation and transpiration are negligible and that the quantity of water from the river that underpasses the river-side drains approximately compensates for the seepage into these drains from other sources (pp. 285–286). This portion of [illegible]

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[val]ley is the widest part of the middle valley, and, [thr]oughout its length of about 17 miles, irrigated land [a]nd drainage structures are present on both sides of [t]he river. The total flow of the interior drains—the Los Lentes and Los Chaves drains, west of the river, and the Otero, San Fernandez, and Tome east of it—was 50.5 second-feet on December 15, 1936, 37.7 second-feet on January 23, 1937, and 32.8 second-feet on February 25. The average fall of water level in 81 apparently typical wells in this part of the valley was 0.46 foot from December 15 to January 25, and 0.17 foot from January 25 to February 17. The area under consideration contains about 36,000 acres, and therefore approximately 16,600 acre-feet of material was unwatered in the first period, of 41 days, and 6,130 acre-feet in the latter period, of 23 days—equivalent to 405 and 266 acre-feet a day, respectively. The average rate of discharge of the interior drains was 44.1 second-feet in the first period and 35.3 second-feet in the second period. On the foregoing assumptions, the water discharged by these drains must have been derived essentially from ground-water flow from the mesas and removal from storage by lowering of the water table. The rate of flow from the mesas was presumably almost constant. Therefore, the following equations can be written:

$$\text{Mesa increment plus } \frac{405 \text{ times specific yield}}{1.984} \text{ equals } 44.1$$

[a]nd

$$\text{Mesa increment plus } \frac{266 \text{ times specific yield}}{1.984} \text{ equals } 35.3.$$

In these equations 1.984 is the factor for converting from acre-feet a day to second-feet. These two equations can be solved simultaneously to give a mesa increment of 18.3 second-feet, or 1.08 second-feet per mile of valley, and a specific yield of about 12.5 percent.

The movement of ground water in the Rio Grande Valley is complicated because of the number of possible sources and possible outlets, and hence the solution of the pair of simultaneous equations above can be only indicative of the magnitude of the quantities involved. The mesa varies from point to point in its width, intake possibilities and water-carrying capacity and therefore the increment of water from the mesa will vary accordingly. When more data for several stretches of mesa and covering a longer period are available the method used may give good results. There are several possible sources of error. Probably the most important of these is the lack of information as to the amount of ground water from the cultivated area that is tributary to the riverside drains, and, conversely, the amount of water from the river which underpasses the riverside drains. If any recharge occurred in February coincident with the thawing of the ground it decreased the lowering of the water table and as a consequence the computed specific yield is less than the actual and the computed mesa increment larger than the actual.

The data available regarding ground-water conditions before the construction of drains is shown on page 291 to indicate an average mesa increment of from 0.5 to 1 second-foot per mile of valley. Despite the large element of doubt in both methods used to determine the mesa increment the results are comparable. The increase in flow in the Rio Grande canyon between State Line bridge and Embudo indicates a ground water accretion amounting also to about 1 second-foot per mile (p. 224). This argeement helps to corroborate the estimate for mesa seepage in the middle valley, indicating at least that it is of the right order of magnitude. However, direct comparison of ground-water accretions in the two stretches of the river cannot be made because of differences in rainfall and in opportunity for recharge and discharge in the two localities.

A question of probably more direct importance than the actual amount of ground-water contribution from the bordering mesas, is the question as to the increase that may have occurred because of the lowering of the water table by drainage. The lowering of the water table at any point begins a lowering of hydrostatic pressures in all three dimensions that gradually extends farther and farther from the initial point and causes flow from more remote localities. As the water coming into the drained area moves from more and more distant localities, the gradient under which it moves decreases. Hence, with the lowering of the water table in the valley by drainage, the quantity of ground-water inflow from the mesas must have been increased by withdrawal of ground water from storage, and then gradually decreased from the maximum. Eventually, a new equilibrium will be approximately established.

It is obvious that the construction of drains in the Rio Grande Valley has not added new sources of ground water to the bordering highlands. The lowering of the water table in the valley may cause the diversion of some water which formerly percolated underground to some point of discharge other than the Rio Grande. However, in much of the Middle Valley there is no other possible outlet, and when a new equilibrium is established there will be little if any more flow of ground water to the valley than there was under the old regimen.

How will the flow to the valley and hence to the drains vary during the period before equilibrium is attained and water is being withdrawn from storage in the mesas? An approximate answer to this question can be drawn from the mathematics of heat conduction in solids. Darcy's law for ground water is formally the same as that describing the flow of heat in solids. In heat conduction the factors necessary for the quantitative solution of a problem are the temperature gradient, the thermal conductivity of the medium and its specific heat. These are analagous respectively in the theory of ground-water movement to pressure gradient, transmissibility, and specific yield. Hence, the analogs to many problems in ground-water hydrology have already been solved in the theory of heat conduction. One is the problem considered here.

If the water table at the edge of the valley is rapidly lowered by the construction of an interior drain, causing additional flow from the broad mesa bounding the valley, we have the same type of condition as when the temperature of the edge of a broad plate at a previously uniform temperature is suddenly lowered a fixed amount, except for minor differences in transmissibility produced by lowering of the water table. In the type problem it is assumed that the plate is infinite in width, that its initial temperature was θ_0 and that the edge of the plate is brought to a temperature of 0. Under these conditions the rate of flow of heat to the edge is[8]

$$W_0=\frac{K\theta_0}{h\sqrt{\pi t}}$$

in which

W_0=rate of flow of heat to the edge.

K=coefficient of thermal conductivity.

θ_0=initial temperature of plate.

$h=\sqrt{\frac{K}{cp}}$

cp=specific heat per unit volume.

t=time measured from beginning of withdrawal of heat.

This may be integrated to give the amount of heat, M, passing the edge in any interval of time.

$$M=\frac{2K\theta_0}{h\sqrt{\pi}}(\sqrt{t_2}-\sqrt{t_1})$$

in which t_1 and t_2 are the times at the beginning and end of the interval.

This equation can be transposed to the realm of ground-water hydrology by the introduction of dimensional constants, giving

$$Q=0.955\ V_0\sqrt{ST}\,(\sqrt{t_2}-\sqrt{t_1})$$

in which

Q=acre-feet of water contributed per mile.

V_0=amount of lowering of the water table at the drain, in feet.

S=specific yield of material.

T=coefficient of transmissibility.

t_1, t_2=beginning and end of time interval, meas in years, since water table was lowered.

The form of this equation is at present more important than its arithmetical solution, as the sev factors involved are not well enough known to give accurate solution. Time enters as the difference of the square roots of the limits of the interval under consideration. This means that insofar as the conditions of nature approximate the ideal conditions assumed in the mathematical analysis, equal quantities of water were or will be withdrawn from storage under the mesas in the first year after the construction of the drains, in the next three years, in the next 5 years after that, 7 years, 9 years, and so on. In other words the excess rate of inflow from the mesas (over the normal rate) should vary inversely as the square root of the time since the drains were constructed.

If it were assumed that the water table has been lowered 4 feet at the drains near the mesas, that the coefficient of transmissibility of the mesas is the same as that indicated for the part of the valley traversed by the Barr interior drains, that is, 50,000—an assumption that may be quite erroneous—and that the specific yield is 10 percent, then the ground-water flow from the mesas in the sixth year after the construction of the drains would be 58 acre-feet per lineal mile of valley boundary per year greater than before the construction of the drains. The increase of flow of the drains near the hillsides would be somewhat less tha 0.1 second-foot per mile. It is emphasized that t above treatment is a theoretical treatment and th. quantitative statements made in it are not to be considered absolute statements of actual conditions in the valley but are to be used as indications of quantities and behavior to be expected.

Ground Water From Other Sources

In most areas of the middle valley, seepage from irrigated lands is doubtless the main source of supply of ground water. This is indicated by the pronounced drop in ground-water levels in irrigated districts from July, when there was heavy irrigation, to October, when irrigation had decreased although the canals were still operating. This trend is opposite to that occurring in unirrigated areas of natural vegetation. Table 2, page 274, gives the change in average ground-water level between July and October 1936. The Socorro, San Antonio, and Bosque del Apache areas represent areas of little irrigation; the other areas are more or less heavily irrigated.

In the section of this report on the areal description of the recharge, movement, and discharge of the ground water (pp. 286–289), different localities are pointed out where there is evidence of ground water derived from the river. Other localities are discussed where th

[8] Ingersoll, L. R., and Zobel, O. J., Introduction to the mathematical theory of heat conduction, p. 79, Ginn & Co., 1913.

presence of canals bordering the riverside drain makes it doubtful whether the river or the canal is the source of the water which is moving from their vicinity. Generally it may be said that the river is likely to be source of water on the inland side of the riverside drains in areas where interior drains lie within a mile of the riverside drains, and that this condition is most prevalent in the Socorro division.

As mentioned previously, irrigation canals are present in many places close to the riverside drains, and their location here often corresponds with that of a crest in the water table. Water-table divides approximately follow the canals in a number of places in the interior of the valley. In some places this is probably due to more intensive irrigation near the canal, but many of the crests are probably caused by canal seepage.

The Middle Rio Grande Valley has an average annual rainfall of only about 8 inches, which occurs largely in the growing season when there is least opportunity for the rain water to penetrate to the water table. Therefore, it is probable that only a small amount of the ground water has its origin in the local rainfall. Rainfall does, however, have a noticeable effect in reducing ground-water consumption by the vegetation, and this effect is manifested in the rise of the water table during or after relatively light summer rains. Figure 5, giving the fluctuation of the water table near Socorro during the week following August 17, 1936, shows a decided rise of the water table after a rain of only 0.14 inch (at Socorro) on August 20. Similar rise of the water table was observed after each shower during the period of operation of the recorder. It should be noted that these rises are not necessarily due to recharge by the shower; they probably indicate chiefly a diminished draft on the ground-water supply by the vegetation—a substitution of rainfall for ground-water use.

Source of Water in Riverside and Interior Drains

Several lines of evidence show that the main source of water in the riverside drains is the river. The average accretion to the riverside drains is greater than that to the interior drains. The flow of the riverside drains follows the fluctuations in the flow of the river. As the river rises, the ground-water head between the river and the riverside drain is increased, with consequent greater ground-water flow from river to drain and, of probably more importance, the river during its rises also spreads widely over its bed and thus shortens the distance which the water must flow underground between river and drain. The chemical quality of the water in the riverside drains is much nearer to that in the river than it is to that in the interior drains.

The gradients between river and riverside drain are much steeper than those on the inland side of the drain. The gradients from the river to the riverside drains are not shown on the accompanying maps even where there are data, because the contours would be too close to be shown on a map of this scale. In the Albuquerque division, wells were established between the riverside drain and the river wherever feasible. There are no canals near the riverside drains that might furnish seepage to the ground water, on well lines 884.8, 894.4, 905.3 (east of the river), 907.3, 908.1, 911.2 (west of the river), and 911.8. On these lines the average gradient in October between the water levels in the wells nearest the river and in the water levels in the riverside drain was 0.0105, and the average gradient between the water levels in the nearest inland wells and the water levels in the riverside drain was 0.0018. The ratio of the gradient from the river to that from the other side was therefore 5.8. In January 1937, the average gradients from the river and from the inland side were 0.0086 and 0.0018, respectively, and their ratio was 4.8. Canals and other water carriers are present near the riverside drain on well lines 890.8, 892.5, 896.3, 898.5, 909.6, and 911.2 (east of the river), and exert an influence on the water levels inland from the riverside drain. On these lines, the average gradient in October was 0.0111 from the river and only 0.0007 from the inland side, yielding a ratio of 15.9, and in January, when the canals were empty, the average gradient from the river was 0.0122 and that from the other side 0.0011, yielding a ratio of 11.1. If the flow from the two sides of the drain is considered proportional to these gradients, the proportion of the drain flow coming from the river would be for the first set of well lines 85 percent in October and 82 percent in January, and for the second set, 94 percent in October and 92 percent in January. The implication of the data now available is that in the Albuquerque division the preponderant part of the water in the riverside drains comes from the river and that such accretions as come from the inland side may be offset in part at least by losses from the river to the interior drains.

Similar data are not available on ground-water gradients in the Belen and Socorro Divisions. However, the ground-water conditions between the river and the riverside drains in these divisions are not essentially different from those in the Albuquerque Division; there is about the same difference in elevation between the river and the riverside drains, and the intervening distance is on the average about the same as in the Albuquerque Division. Consequently, the rate of movement from the river to the riverside drain is probably about the same. On the whole, the water table in the Belen Division indicates less lateral movement of the ground water either from land to riverside drain or in the reverse direction than is indicated in the Albuquerque Division. Apparently the average accretion to the drain from the inland side is about the same, or perhaps slightly larger. In the Socorro Division there are in most places pronounced gradients from the riverside drains to the interior drains, and in this division, instead of accretions from the inland side to the riverside drains, there are probably losses from the drains to the land.

The ground-water data now available appear to indicate that only a small part of the water in the riverside drains in the middle valley originates inland from the drains. On the other hand, in several localities some river water appears to pass under the riverside drain to be transpired by vegetation or to emerge in the interior drains. These quantities appear to be of the same order of magnitude so that on the whole the discharge of the riverside drains, excluding surface waste into them, may represent approximately the quantity of ground water withdrawn by seepage from the river, while the discharge of the interior drains represents water derived from other sources. This tentative conclusion implied by the ground-water data should be checked against data concerning the chemical quality of the water in river, riverside drains, and interior drains when available.

Areal Description of Recharge, Movement, and Discharge of the Ground Water

Albuquerque Division[a]

The present irrigating system of the Middle Rio Grande Conservancy District follows preexisting ditches in many areas. Some confusion in nomenclature of the various types of ditch results from the retention of the old names. The common Spanish name for a ditch largely regardless of size is acequia. Features still called acequias may take their water from the river, canals, or laterals. In turn, they may feed laterals or other acequias. In the following discussion, when referring to a specific structure the terms are used as used on the accompanying maps of the valley.

From well line 877 to 886.9 the water table slopes from the edge of the mesa to the river and indicates an accretion to the river from the arroyos and mesa slope and to some extent by seepage from the Bernalillo and Algodones acequias. The importance of seepage from the acequias as a source for the ground water is undetermined at present. The acequias are on high ground and the water table is so deep that it was found impossible to determine the gradients of the water table east of the acequias with the equipment at hand. When measurements of water levels during the winter months when the canals are dry are available, it may be possible to estimate the relative importance of the contribution by the acequias. The measurements for December 1936 and January 1937 suggest that the acequias have considerable importance in that the water-table gradients near them, on the whole, decreased somewhat after the acequias were closed.

The Bernalillo (interior) drain begins near well line 886.9. It is a short drain and empties into the Bernalillo riverside drain just below well line 888.5. It apparently intercepts most of the ground-water flow from the east and also receives some accretion from the river. Below the turn of the drain near line 888.5, where it begins its course laterally across the valley, the drain has been usually overfull during the period of readings and has apparently been feeding the ground water in this section. This feature is quite pronounced on plate 1, prepared from October measurements. The causes for this condition appear to be too low a gradient of the drain at this point and the presence of a large bosque area. Transpiration has apparently lowered the ground-water level here considerably below its normal position. The anomaly in elevation between water level in the drain and in the wells to the north became less in months succeeding October. For about 2 miles south of line 888.5 ground water appears to be flowing into the interior of the flood plain from both mesa side and river despite the presence of the Albuquerque main canal near the middle of the area. This appears to be due to the abstraction of ground water near the middle of the valley by the lower part of the Bernalillo drain and by the bosque area to the north.

In the Coralles area, west of the river, extending from well lines 890.8 to 894.4, around which the river makes a loop, the ground water by-passes some of the river water from one end of the loop to the other. Water apparently enters the ground from the river above line 890.8, although seepage from the Coralles main canal must oppose its flow, swings westward to the edge of the valley and returns again to the river in the lower part of the area.

East of the river, in the area between lines 894.4 and 896.3, the Alameda drain picks up a small amount of flow from the areas to the east and to the west. Apparently the major part of the ground water between it and the Albuquerque riverside drain passes into the latter drain. The Los Griegos drain heads just south of line 896.3 about one-fourth of a mile east of the riverside drain. It remains within less than a mile of the river to its junction with the Alameda drain south of line 899.8. Throughout this distance it apparently receives accretions from the river, as the slope of the water table on line 898.5 is from the riverside drain past the acequias. The area between the Alameda and Los Griegos drains is drained in a normal fashion to both sides. Judging by the low lateral gradients there appears to be only a small amount of inflow from the direction of the mesa to the drai

[a] See Pl. 6.

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Fr the junction of Los Griegos with the Alameda o the junction of the Alameda with the riverside outh of line 901.5, the Alameda drain apparently es some increment from the river.

The area in the city of Albuquerque was not surveyed. Because of the many artificial conditions in the city, including paving over a large area, sewers, pumping plants, and irrigation of lawns, the water table is abnormally distorted and is not typical of the area in general. The water table in most places in the city is deep and the expense of maintaining a system of deeper wells was not considered warranted.

The Barr district is a narrow strip of valley bottom on the east side of the river extending from Albuquerque to Isleta. Considerable water moves into this area from the direction of the mesa. This water is discharged into the riverside drain in portions of the area where there are no interior drains but is intercepted by the interior drains where present. As the Barr Canal lies to the east of the observation wells, it as well as ground water from the mesa may be the source of this water. Apparently it is the source of some of the water, for on well lines 909.6 and 910.2 the water table in the wells nearest the canal fell more than in neighboring wells in the period from November 1936 to January 1937, in the later part of which period the canals were dry. On the other hand, the reverse tendency was shown on line 906.1, where the water levels in the near the Barr Canal and the San Jose lateral fell than in neighboring wells. A decision as to the main source of the water must be deferred until a systematic study of the fluctuations in water level near the mesas and high canals between irrigation and nonirrigation seasons can be made, and until seepage losses in the canals are determined. The Barr riverside drain is apparently effective in draining the land throughout its length and there appears to be no accretion from the river to the cultivated area.

The area between Albuquerque and Isleta on the west side of the river is called the Isleta-Atrisco district. The Isleta interior drain includes a short section of riverside drain at its head opposite Albuquerque. There appears to be some movement from the river above line 902.7, but inasmuch as the area is heavily irrigated, seepage water from irrigation may be the source of most of the water moving into the upper end of the interior drain. The Armijo drain heads south of line 903.2 and swings directly west to empty into the Isleta drain south of line 905.3. The distance between these two drains increases southward. As a result much of the water normally flowing south is diverted to the drains near the head of the Armijo and as a consequence less water continues south and the slope of the water table decreases. North of the westward flowing portion of the the slope of the water table increases and south of it the slope decreases as a consequence of the action of the drain. The Los Padillas drain heads near line 907.3 and runs south to join the Isleta drain between lines 911.2 and 912.5. Because of its nearness to the river, the water table gradually swings toward it and away from the river. In this area some water apparently moves from the riverside drain to the Los Padillas drain, the amount increasing toward the mouth of the Atrisco riverside drain just south of line 912.5.

Belen Division [10]

The Belen division includes the widest part of the Middle Rio Grande Valley and in many places it includes land on both sides of the river. In general, the water table lies at somewhat less slope and is less distorted from a general southerly slope than in the other divisions, and there is less slope from the riverside drains to the interior drains.

The Peralta-Tome area lies on the east side of the river and extends from Isleta to a point opposite Belen, a distance of about 17 miles. The valley expands rapidly just below Isleta. The water table shows that the river is feeding the ground water for a distance of about 2 miles, probably as a result of the deficiency of the normal ground-water flow from the north where it is cut off by the hills at Isleta.

The Otero drain heads at the southern boundary of the Isleta Pueblo Grant, near well line 917.8. The crest of the water table roughly follows the Otero lateral, and this canal probably is the source of much of the water moving to the drain. The Otero drain and the Tome drain diverge southward between lines 917.8 and 920.5, and apparently as a consequence the gradient of the water table and the velocity of the ground water decrease. There is inflow of water from the east throughout this distance, either ground-water seepage from the mesa or seepage from the Chical lateral on the hillside. Hell Canyon opens on to the flood plain of the river at Chical and considerable ground water is probably coming from this arroyo.

South of line 925.4, Tome Butte juts out into the flood plain of the river and decreases the width of the valley east of the river to about one-half of that above. Between line 920.5 and this locality the ground water apparently receives accretions from the river which are small compared with accretions from irrigation and canal seepage. As the ground water approaches Tome Butte in its general movement down the valley, much of it percolates into the Tome drain, which here swings westward around the butte. The crest of the water table from line 925.4 to line 930.2 follows canals and laterals and apparently shows seepage from them. From this point to the southern end of the area the ground water has a component of flow toward the river

[10] See pl. 7.

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in part caused by seepage from the canal on the hillside and in part by the constriction of the valley in the downstream direction.

On the west side of the river, the area from Isleta to Belen is interlaced with canals. Seepage from one or another of the canals could cause any of the effects observed in the irregularities in the water table. In general in this area the ground water flows toward the river where there are no intermediate interior drains and away from it where there are. Apparently the water table is held high by seepage from the Belen high line canal as the valley begins to widen below well line 919.1, and by seepage from the Huning lateral above Los Lunas. Motion is toward the riverside drain between Los Lunas and the head of the Los Chaves drain. South of this point to well line 925.3 the ground water in general moves toward the interior drain, apparently little influenced by intervening canals. Farther south, to the mouth of the drain near Belen, the crest of the water table follows canal lines, and the ground water moves from the land to the riverside drain as well as to the interior drains, indicating loss of water from the canals and irrigated land to the drains. There is apparently considerable movement from the edge of the valley into the drains. The presence of the Belen high line canal on the edge of the mesa makes it probable that much of this water is derived by seepage from it. From Belen south to the lower end of the Sabinal riverside drain, near Sabinal, canal seepage and irrigation water furnish ground water that percolates both to the riverside and interior drains.

A narrow strip of land on the west side of the river between Sabinal and Abeytas is undrained. The scanty control for water-table elevations indicate that there is little lateral slope of the water table in the area, a condition which apparently existed in most of the middle Rio Grande Valley before drainage (see p. 289, and fig. 66).

The area between Abeytas and the Rio Puerco is poorly drained. Bernardo Lake is maintained at a high level and distorts the water table in its vicinity. There is practically no gradient of the water table from United States Highway 60 south to the Rio Puerco.

The San Juan-Las Nutrias area lies east of the river, about opposite the Abeytas-Puerco area on the west. At the upper end of this area the ground water is draining west to the river, probably because of seepage from the San Juan arroyo. Throughout most of the remainder of the area ground water moves from the river into the interior drain. On lines 944.6 and 945.3 the ground-water level near the riverside drain is higher than in the interior area despite the presence of canals and wasteways in the interior.

Socorro Division [11]

The Socorro division of the Middle Rio Gra... Conservancy District comprises a narrow strip ... on the west side of the river between the constric... the valley at San Acacia and the north line of the Bosque del Apache grant, where drainage structures end except for a prolongation of the San Antonio riverside drain downstream in order to obtain sufficient fall.

Because of the narrowness of the valley area in this division, the ground water moves from both sides to the interior drains under considerable gradient. Throughout the area canals and laterals border the riverside drains so that it is impossible to tell in most places whether the source of the water is seepage from the river or from these canals. In addition certain anomalous ground-water conditions exist due to disturbances in the drain flow.

In the upper part of the division in the area drained by the San Acacia drain, the water-table gradients are much flatter than ordinarily found in this division, presumably because of the interception of ground water coming from the north by the westward-flowing upper portion of this drain. Below the mouth of this drain the southerly gradient of the water table increases. The upper portion of the Polvadera drain causes a pronounced diversion of water from the direction of the river to it. The lower portion of the drain, south of about line 969.1, was ineffective as a drain at the time of observation, and the water level in the ... stood higher than the adjacent water table, ...sumably as a result of clogging of the drain at a culvert at the bend of the drain. From this point to the constriction of the valley at the Pueblitos crossing, flow from the direction of the river toward the mesa is indicated, with canal seepage or irrigation near the canals causing crests in the water table.

The Luis Lopez drain C begins just below the Pueblitos constriction within several hundred feet of the river. Relatively rapid flow of ground water into the drain from both sides is indicated by the steep slope of the water table. A portion of this water is probably derived from the river. The lower portion of this drain is also ineffective and was feeding the ground water at the time of observation.

Between the mouth of the Luis Lopez drain A and the head of the short Luis Lopez drain B, the ground water tends to resume its general southerly course. The water is deflected toward drain B throughout its course and the movement toward drain B is strengthened by the checking of the Socorro riverside drain at its mouth to feed the Socorro main canal.

The Luis Lopez drain C which begins just south of well line 982, deflects the ground water to it in its

[11] See pl. 8.

upper course but in its lower course, near line 986.2, ...ently, like most of the other interior drains of ...sion, is overfull and has little effect as a drain.

...om the mouth of the Luis Lopez drain C to the ...d of the Socorro Division, at line 990.3, the ground water moves in general down the valley and has little transverse movement.

Bosque del Apache Grant [11]

The Bosque del Apache Grant is not in the Middle Rio Grande Conservancy District. It is undrained and practically unirrigated. It therefore furnishes types of ground-water phenomena which were presumably more or less characteristic of the whole valley before drainage.

The difference between the character of the water table, and hence the ground-water flow, in this area and in the developed area of the conservancy district is significant. The water table slopes rather uniformly southward and shows comparatively few irregularities, indicating that lateral flow of the ground water is small. The ground-water contours approach the river nearly at right angles, except near the mouth of the San Antonio riverside drain, where they are deflected by the adjustment of the water table between the grade of the drain above and that of the river below.

Considering the size of the area in which transpiration takes place, greater lateral gradients might be expected even in October when the readings represented ... the map were made. Moreover, the lateral gra...its on lines 994.1 and 995.1 on the last of June were not much greater than they were in October. This condition is probably due to the overflow of surface water. The Socorro main canal and the San Antonio riverside drain both contribute water to this area. The water runs southward and spreads out in ponds. This surface water no doubt furnishes much of the water used by the vegetation and keeps the water table built up in the center of the tract.

Ground-Water Conditions Before Construction of Drains

Previous Ground-Water Investigations

It was hoped at the beginning of this investigation that a detailed comparison could be made of ground-water conditions before and after the drainage developments were made in the Middle Rio Grande Valley. This hope has not been realized, but certain comparisons and contrasts can be made. Two comprehensive ground-water investigations had been made in the Middle Valley prior to the present one. In the period from 1918 to 1922, about 1,100 observation wells were installed by the State engineer of New Mexico, the New Mexico College of Agriculture, the United States Bureau of Agricultural Engineering, and several of the drainage districts. Water-level measurements in over 900 of these wells were made monthly or oftener. A bulletin based on these studies was later published by Bloodgood.[12a] The base data gathered during this investigation were never published but were kindly made available for the present study by Mr. Bloodgood, and by Prof. Fabian Garcia, director of the New Mexico Agricultural Experiment Station. The second investigation of ground-water levels was made in connection with the study preliminary to the installation of the Middle Rio Grande Conservancy District project. The results of this investigation were published by Donnell.[12b] The base data of this investigation were not available for the present investigation.

Direct comparison of the data from the Bloodgood investigation with those of the present investigation was in general impossible because of uncertainty as to the locations of the old wells, as there were no accurate maps of the valley prior to 1935 and most of the wells could not be located in the field because the old casings and markings had disappeared. As the water table sloped approximately 5 feet to the mile down the valley, a north or south displacement of the wells on the map to the extent of 1,000 feet from their true position in the field could cause an error in the indicated position of the water table of about 1 foot. Such an error would significantly affect the indicated lateral slope of the water table.

In a few areas enough of the old wells were found to give key localities for locating the remainder. One of the areas which was best covered with wells in the 1918–22 investigation was that between Albuquerque and Alameda. Figure 66 shows a map of the water table in this area based on the unpublished data of Bloodgood. The mean altitude of the water table through the period of record was used in making this map.

Seepage From the River Previous to Drainage

Figure 66 shows that previous to the installation of the drainage system, the ground-water contours in the area between Albuquerque and Alameda were nearly at right angles to the river, which indicates that in this area there was very little movement of ground water either into or out of the river during the period 1918–22. If this condition is typical of the valley it indicates that the amount of ground-water seepage from the river was small. Rough contour maps of the Belen and Albuquerque divisions for months showing high and low ground-water stages in the period 1918–22, plotted according to locations on the old maps, indicate flat lateral gradients. The undrained Bosque

[11] pl. 9.

[12a] Bloodgood, D. W., The ground water of Middle Rio Grande Valley and its relation to drainage; Agr. Exper. Sta., New Mexico Coll. Agriculture, Bull. 184, 1930.

[12b] Donnell, P. S., Report on ground-water determination: Middle Rio Grande Conservancy District Official Plan, Exhibit R-3, 1928.

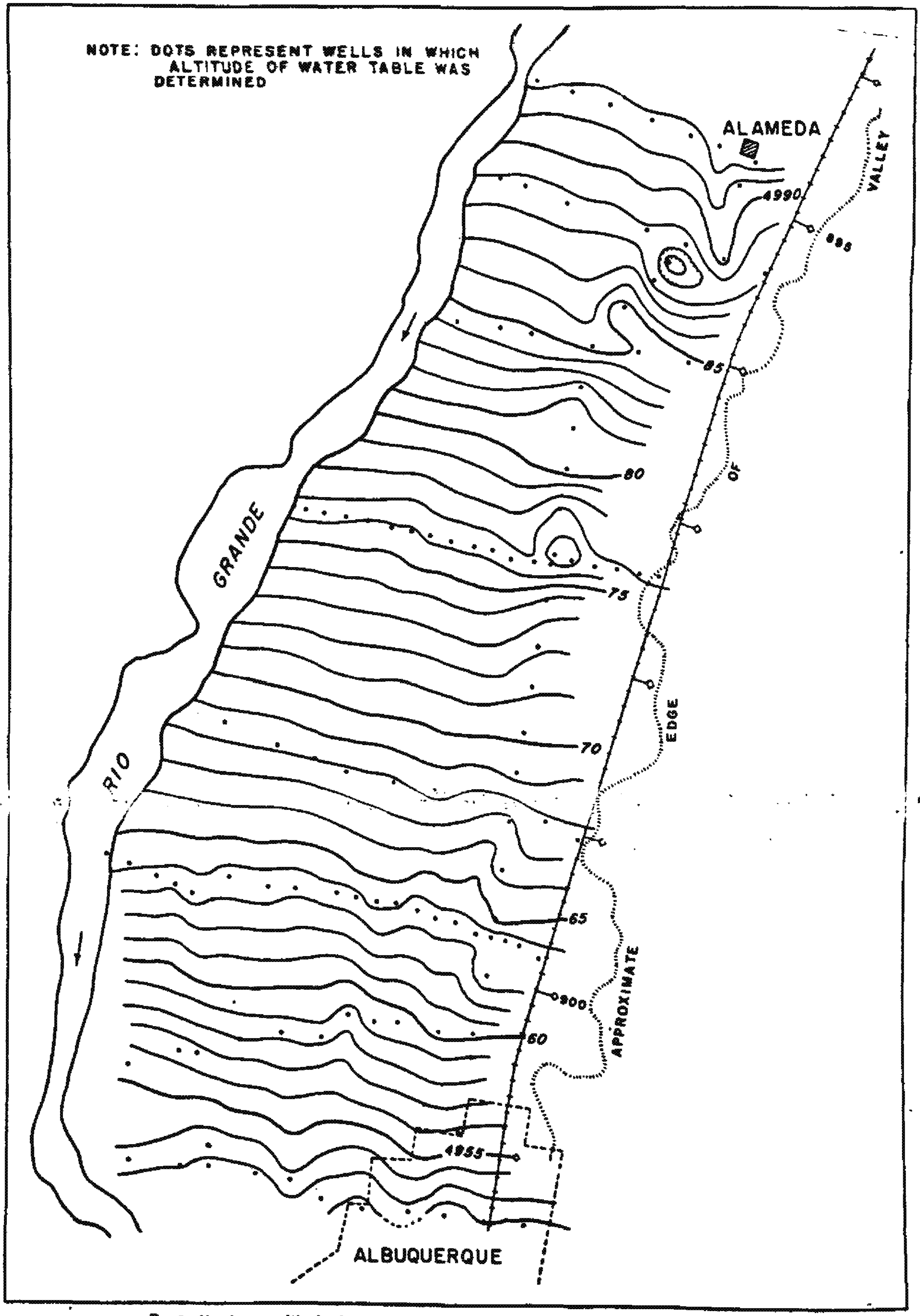

FIGURE 66.—Average altitude of water table in the area between Albuquerque and Alameda, 1918-22.

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del Apache Grant shows the same low lateral gradients ... Bloodgood[13] gives typical ground-water pro- across the valley. The average gradient near the ...er as scaled from these diagrams is about 0.0006 in ...ernalillo County, based on nine profiles; about the same in Valencia County, based on eight profiles; and about the same in Socorro County, based on the two profiles within the area covered by the present investigation. Some of the gradients represented in these profiles are known to be too because large wells near the river are north of the others used in constructing the profiles, but such errors are probably balanced by the displacement southward of wells near the riveron other lines.

If the coefficient of transmissibility were 50,000, as was tentatively estimated for the Barr district (p. 281), and if 0.0006 were assumed as the average gradient of the water table near the river before drainage was begun, a seepage loss from the river of about one-fourth second-foot per mile would be indicated. If the length of the valley between Pena Blanca and San Marcial is taken as 150 miles, the total seepage from the river on both sides before drainage was begun would have been 50,000 acre-feet a year.

Seepage from the Mesas Previous to Drainage

Although a final opinion should await additional data, a tentative opinion as to the amount of ground-water flow from the borders of the valley previous to drain- e can also be formed. Figure 66 indicates that in parts of this area where relatively good data are available, the ground-water contours approach the mesas only slightly deflected from perpendicularity, and such deflection as there is indicates in some places movement toward the mesas. There is therefore little evidence of movement from the mesas to the flood plain in this area. The contours in the Bosque del Apache area also approach the mesas near to perpendicularity, and little flow is indicated in this area where control is good. Averages of the water-table gradients from the mesa to the flood plain as shown on the profiles drawn by Bloodgood[14] are 0.0008 in Bernalillo County on the basis of eight profiles, 0.0003 in Valencia County, on the basis of seven profiles; and 0.0014 in Socorro County on the basis of two profiles. The general average is 0.00065. This general average gradient indicated is about the same as that from the river. Therefore, if the same transmissibility were assumed, the contribution of ground water from the mesas would have been about 50,000 acre-feet a year in the 150 miles between Pena Blanca and San Marcial. This figure might be increased somewhat to take into consideration concentrated flow near the debouchures of arroyos, on which data are scarce, and other unknown factors but it does not seem that on the above assumptions the inflow could have much exceeded 100,000 acre-feet a year. This last figure represents a contribution of about 0.5 second-foot per mile of valley border or about 1 second-foot per lineal mile of valley.

On pages 282–284, it is shown that the data now available on drain flows during winter periods suggest also that the ground-water flow from the mesas may be about 1 second-foot per lineal mile of valley. However, both sets of figures are subject to considerable revision as more data become available.

Seepage From Irrigation and Floods

If the foregoing estimates of river and mesa seepage are approximately correct, the much larger apparent loss of water from the river in this section must have been due largely to other causes, and there must have been other and more important sources of water to support the transpiration of the native vegetation. Losses from the river other than by seepage were by diversion for irrigation, spreading of the water and consequent infiltration during floods, and evaporation from the river channel, which was probably greater than now because of the present lowering of the water table between the levees. The first two of these processes made contributions to the ground-water supply in the valley and the spreading of flood water also furnished soil moisture that fed the native vegetation without reaching the water table. Diversion for irrigation was probably by far most important. There is apparently no good way of determining what former diversions were, but if the estimates here arrived at for ground-water flow are of correct general magnitude, the use of water on the land under cultivation was presumably large. The irrigators were doubtless constrained to irrigate when there was sufficient water in the river, and it would seem that they probably used quantities larger than necessary at such times in the hope of tiding over water shortages to come. This is somewhat the same principle as is used today in the "subbing" in the San Luis Valley. The water supporting the transpiration of native vegetation was probably derived largely from excess of water used for irrigation.

It was shown in the report by Bloodgood[15] that in the period covered by his investigation there was a direct relationship between variations in river surface levels and the fluctuation of the ground-water table. Prior to the construction of the El Vado Dam and permanent diversion structures in the valley, irrigation was largely dependent upon the stage of the river. Hence, the correlation noted was at least partly due to the agency of irrigation.

[13] Bloodgood, D. W., op. cit., pp. 21, 24, 29, 31, 38, 40, 42, 44, 49, and 51.
[14] Idem.

[15] Op. cit., pp. 58–60.

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PART III

WATER UTILIZATION

Report of the United States Bureau of Agricultural Engineering [1]

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[1] By Harry F. Blaney, irrigation engineer; Paul A. Ewing, irrigation economist; O. W. Israelsen, irrigation engineer; Carl Rohwer, irrigation engineer; Fred C. Scobey, principal irrigation engineer. A contribution from U. S. Department of Agriculture, Henry A. Wallace, Secretary; Bureau of Agricultural Engineering, S. H. McCrory, chief; Division rigation, W. W. McLaughlin, chief.

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PART III

SECTION 1.—INTRODUCTION

This is a report by the Bureau of Agricultural Engineering, made in compliance with the terms of its memorandum of agreement with the National Resources Committee, approved February 28, 1936. Therein the Bureau was charged with the principal duties of ascertaining the consumptive use of water in the major divisions of Rio Grande Basin above Fort Quitman, Tex., mapping the areas, and tabulating statistics of the lands in agricultural crops and water-consuming native vegetation and other areas using water in appreciable quantities. The report deals with these matters in two principal chapters which are preceded by such other discussions as are necessary to make it cover all the subjects specified in the agreement and provide a setting against which the two essential discussions will stand out clearly.

Synopsis

By the terms of an agreement with the National Resources Committee, approved February 28, 1936, the Bureau of Agricultural Engineering was charged with the two principal duties (among several, all of which are described in detail in this report) of ascertaining the consumptive use of water in the major divisions of Rio Grande Basin above Fort Quitman, Tex., and mapping and tabulating the areas in agricultural crops and water-consuming native vegetation. This report relates the results of the bureau's undertakings in discharge of these obligations.

Involved in the studies was a portion of Rio Grande's length totaling some 700 miles. A difference in altitudes of nearly 6,000 feet was also involved. So long a stretch and so wide a difference in elevations were marked by many variations of climate and soils and by wide differences and shifts in acreages and kinds of crops.

The waters of Rio Grande above Fort Quitman are largely consumed by native vegetation and irrigated crops in Colorado, New Mexico, Texas, and Mexico. In the usual year only a small portion of the total water production of the Rio Grande Basin above Fort Quitman escapes from it unconsumed, and that small part consists mostly of unusable return flow and flood-peak flows originating below Elephant Butte Reservoir.

There is considerable variability in the estimates made previously by engineers and others for unit values of consumptive use in the three major valleys of the basin. This variability is not extraordinary. It is difficult to make precise estimates because there are so many factors influencing the consumptive use. However, some variability in estimates is attributable to lack of specific definitions.

Most estimates for San Luis Valley are in reality estimates of stream-flow depletion rather than of consumptive use as defined by the Bureau of Agricultural Engineering to include annual precipitation and draft on ground-water supplies.

Not all the estimates by engineers, of use of water in Mesilla Valley are strictly comparable with each other. Some include the entire Rio Grande project, while others are concerned specifically and alone with the Mesilla Valley portion of the project. Experiments on the use of water on crops in Mesilla Valley have also been conducted by the New Mexico Agricu[illegible] Experiment Station and the Bureau of Agric[illegible] Engineering for many years, and the results of these experiments likewise differ between themselves and with estimates of other investigators.

As defined by the Bureau of Agricultural Engineering, in a basic sense consumptive use is "the sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time."

As applied to the Upper Rio Grande Basin problem, valley consumptive use is considered equal to the amount of water that flows into a valley (or tract) during a 12-month year plus the yearly precipitation on the valley floor (or tract) plus the water in ground storage at the beginning of the year minus the amount of water in ground storage at the end of the year minus the yearly outflow; all amounts measured in acre-feet. The unit consumptive use of water per acre of irrigated land is equal to the consumptive use in acre-feet divided by irrigated area; and the unit consumptive use per acre of entire valley (or tract) is equal to the consumptive use in acre-feet divided by entire valley (or tract) area. The unit use is expressed in acre-feet per acre or depth in feet.

The Bureau does not have available sufficient experimental data relative to rates of evaporation from soils following rains in the Upper Rio Grande Basin to constitute a basis for estimating the effectiveness of the rainfall. Therefore all the annual precipitation has been designated as a part of the consumptive use, it being recognized, however, that knowledge of the amount of stream-flow depletion (heretofore designated consumptive use by some writers) is of vital practical importance in the solution of Rio Grande water-use problems.

The amount of water which annually flows into a valley, or onto a particular land area, minus the amount which flows out of the valley or off the particular land area, is designated stream-flow depletion, and in a developed area is usually less than the consumptive use.

The consumptive use of water studies conducted by the Bureau of Agricultural Engineering in San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley in 1936 may be considered as having two parts: First, analysis of available hydrologic data as a basis of determining consumptive use of water on large representative tracts or areas, these including past records and the results of field work during 1936; and, second, evapo-transpiration and evaporation measurements by means of tanks, and soil moisture studies, involving both native vegetation and irrigated crops.

Unfortunately funds to start the 1936 investigation were not available until April, and many of the field studies could not be gotten fully under way until the latter part of May. Thus in addition to being of limited significance because of representing only a single year, the 1936 results, especially those obtained from the tank and soil moisture studies, are properly subject to criticism because they are not completely representative even to that extent. Though their present applicability is thus restricted, they are here recorded to permit comparison and use with such other similar data as are now available or may later be accumulated. Further field studies throughout the basin, but especially in the Middle Valley, and extending over a much longer period, are needed.

The inflow-outflow method and the integration method were found to be the most satisfactory for estimating consumptive use of water for large areas.

The inflow-outflow method is probably the most reliable method to apply in San Luis Valley and Mesilla Valley. Conditions are less favorable for its use in the Middle Rio Grande Valley. However, the integration method will produce satisfactory results, if based upon careful estimates of unit consumptive use by the principal agricultural crops and native vegetation, and upon an accurate land classification.

Reliable data for determining use of water by the inflow-outflow method for a period of years were available only in part of San Luis Valley and in Mesilla Valley. The annual consumptive use determined by this method in the southwest area in San Luis Valley for the period 1925 to 1936 inclusive averaged 1.66 acre-feet per acre for the entire tract of 400,000 acres. In the Mesilla Valley it averaged 2.73 acre-feet per acre for the 18-year period 1919 to 1936. In the Isleta-Belen area, Middle Rio Grande Valley, less dependable data indicated a consumptive use of 2.7 acre-feet per acre for 1936.

Since data for determining consumptive use by the inflow-outflow method are obtainable only in certain areas of the Upper Rio Grande Basin, it is believed that with the data available, the integration method offers the best (or most feasible) means of estimating the present consumptive use requirements for the major subdivisions of the basin. However, the estimates presented in this report must be regarded as qualified by the following considerations: (*1*) Maps showing the vegetative cover and groundwater contours were not available when the estimates were made, nor were complete stream-flow analyses at hand; (*2*) final consideration had not then been given the results of the salinity studies by the Bureau of Plant Industry, which had as one important purpose the determination of the effects of saline water on irrigation requirements, and the extent to which it will be necessary, in some areas, to apply more irrigation water than is usually needed to meet the normal consumptive-use requirements, thus increasing the opportunity for evapo-transpiration losses; (*3*) the history of agriculture has been marked by so many drastic shifts as to suggest the possibility of future changes which will substantially alter the water requirements of the basin's major divisions. For instance, such alterations might conceivably follow extensive additional storage in Colorado; or economic or other events not now foreseen or predicted might bring about crop substitutions in Mesilla Valley as important as the relatively recent introduction of cotton.

Estimates of average annual unit consumptive use requirements (including precipitation) along the main stem of the Rio Grande, representing the present judg-

Location	Average consumptive use, in acre-feet per acre, for—			
	Irrigated lands	Native vegetation	Miscellaneous areas	Total area mapped
San Luis Valley, Colo.	1.7	1.4	1.2	1.5
Colorado-New Mexico, State line to San Marcial, N. Mex.	2.6	3.6	3.2	3.2
San Marcial, N. Mex., to Fort Quitman, Tex.	2.8	4.0	3.7	3.2

ment of the Bureau of Agricultural Engineering, are as above (see tables 124 to 129, inclusive, for details).

The original plan for mapping the vegetative cover was much simpler than the plan finally followed. Essentially, however, the initial purpose of ascertaining the areas of irrigated land and other land "using appreciable quantities of water" was retained, and on the map which has been prepared the entire area between the lower fringes of the hills and bluffs along the main stem of Rio Grande through New Mexico and Texas was accounted for. Such limits were set for the work in Colorado as would keep the map from including areas which could not meet the stipulation of "using appreciable quantities of water."

Resulting from the vegetative cover survey were the following area totals, as of 1936. These results are in substantial accord with results of other surveys, especially in San Luis, Mesilla, and El Paso Valleys:

Location	Mapped areas (in acres)			
	Irrigated lands	Native vegetation	Miscellaneous areas	Total area mapped
San Luis Valley, Colo.	600, 243	737, 199	109, 210	1, 446, 652
Colorado-New Mexico State line to San Marcial, N. Mex.	152, 782	140, 910	73, 217	366, 909
San Marcial, N. Mex., to Fort Quitman, Tex.	170, 569	70, 062	38, 625	279, 256
Total	923, 594	948, 171	221, 052	2, 092, 817

Geographical Description

Rio Grande, rising in the San Juan Range, drains the mountain area east and south of the Continental Divide, in the south central part of Colorado. Its total drainage area in that State is 7,870 square miles. For some 80 miles its course is easterly as a mountain stream, until it enters San Luis Valley, a fertile, extensive, flat area lying between ranges of the Rocky Mountains. (Pl. 10.) This valley has a general elevation of 7,500 feet; the mountains surrounding it rise several thousand feet higher. Rio Grande cuts through it diagonally from northwest to southeast, and receives from the adjacent mountains the waters of nearly thirty streams, most important of which are Conejos River and Alamosa, La Jara, Costilla, Culebra, and Trinchera Creeks. A short distance north of the New Mexico line the river enters the long Rio Grande Canyon, through which it continues into that State. (Pl. 11.)

The drainage of the mountains bordering the northern part of the San Luis Valley is received by several streams, notably San Luis, La Garita, Carnero, and Saguache Creeks, which terminate in the north-central portion of the valley in a number of lakes having no visible outlets. This large area is accordingly referred to locally and by many writers as the "dead", "sump", or "closed" area, and in later sections of this report will be described by the last-mentioned term. The portion strictly tributary to Rio Grande is correspondingly known as the "live" area. (Pl. 11.) The greater part of this live area is in the southwester portion of the valley, and frequent references will be made to it by that general expression. Similarly, the portion east of the river and south of the closed area will be referred to as the southeast area.

Many enterprises, large and small, divert water from the streams in the basin, for the irrigation of lands in all its portions. Notable in this connection is the fact that most of the irrigated farms in the closed area are served by canals diverting from Rio Grande. Some storage has been created on various streams; other storage possibilities are still under consideration.

San Luis Valley extends a short distance into New Mexico, and several of the smaller tributaries entering the river in Colorado rise south of the interstate line. Its most important tributaries in New Mexico are the Red (or Colorado), Hondo, Taos, Penasco, Embudo, Pojoaque, Santa Fe, Santa Cruz, Chama, Jemez, Puerco, and Salado rivers or creeks. (Pl. 1.) The narrow canyon through which the river flows in entering the State is succeeded by others, so that the first extensive agricultural area does not appear until it enters Espanola Valley, which centers in the town of that name. After again constricting its channel below Espanola Valley (pl. 12), the river emerges from White Rock Canyon at Cochiti.

There begins the Middle Rio Grande Conservancy District, the modern successor of a multitude of small irrigation systems which, for many decades preceding its creation, served valley lands extending some 150 miles nearly to San Marcial. (Plates 13–16, incl.) Important in the operation of the district's system is its storage at El Vado reservoir on the upper reaches of Rio Chama. (Pl. 1.) The headquarters of the district is Albuquerque, altitude of which is about 5,000 feet.

San Marcial, marking the lower terminus of the Middle Rio Grande Valley, is also the approximate upper limit of the lake created by Elephant Butte Dam. below which extend the several areas comprising Lower Rio Grande Valley. The Elephant Butte storage serves the lands in New Mexico and Texas making up the Rio Grande project of the United States Bureau of Reclamation. (Plates 18–21, incl.) Most important of these natural units are Mesilla Valley, which comprises the larger portion of the New Mexico half of the project, and El Paso Valley, which likewise includes the greater part of the project's area in Texas. (Pl. 20.) The two valleys are separated from each other by the narrow constriction just above El Paso, so that a part of Mesilla Valley is in Texas; and the pass is utilized as the site of a dam by which a portion of the river's flow is diverted to Mexico. From El Paso to its mouth the river constitutes the international boundary. The altitude of El Paso is about 3,700 feet.

The New Mexico portion of the Rio Grande project is organized as Elephant Butte Irrigation District. The Texas portion is similarly organized as El Paso County Water Improvement District No. 1. The project's lower boundary is just above the El Paso-Hudspeth County line, and at this place the project delivers waste and drainage water to the canals of the Hudspeth County Conservation and Reclamation District No. 1, which serves most of the irrigated areas in Hudspeth County above Fort Quitman. (Pl. 22.) Some agricultural areas not under its canals are irrigated by individually owned farm systems. The entire valley area under present consideration includes none of the lands in Mexico, and none in the United States below the river gaging station at Fort Quitman, Tex. No considerable tributaries enter Rio Grande between El Paso and Fort Quitman in the United States. The altitude of Fort Quitman station is about 3,450 feet.

Involved in the studies here reported there was accordingly a portion of the Rio Grande's length totaling some 700 miles. A difference in altitudes of nearly 6,000 feet was likewise involved. So long a stretch and so wide a difference in elevations were marked by many variations of climate and soils and by characteristic diversifications in the agriculture which is the principal consumer of the river's water. Descriptions of some of these conditions appear in later sections of this report, notably those which affect the use of water.

HISTORY OF IRRIGATION DEVELOPMENT

Irrigation in the Rio Grande Basin above Fort Quitman had its beginnings many decades ago. In some localities it was practiced long before the coming of the white men. Not only are the remains of extensive irrigation works of unquestioned antiquity in evidence, but the early Spanish explorers found the Indians near Socorro and elsewhere in the Middle Valley, diverting and using water for the irrigation of their crops.

The Spanish settlers brought with them a considerable knowledge and experience in irrigation institutions and practice, which they proceeded to adapt to the conditions they found in the Southwest. The result was that the Spanish and Indian methods were blended, and out of this amalgamation arose irrigation practices and forms of organization which, in New Mexico, continued with little change until the existing systems were supplanted by the modern works of the Bureau of Reclamation and the Middle Rio Grande Conservancy District. Indeed, above the latter, long-standing agricultural practices have persisted to this day, and many of the older works are still in service.

In Texas and Colorado, the Spaniards were likewise active in extending their colonization and irrigation activities, but the total number of acequias and the area irrigated were relatively small. Some irrigation works in Texas were built in connection with mission settlements, but irrigation of Spanish origin in these two States is of small proportions in their present irrigation development.

San Luis Valley

The latter statement is especially true as regards San Luis Valley. (Pl. 11.) While irrigation had its beginnings there before the stimulation provided by the arrival of settlers from the Eastern and Southern States, the rise of the Valley to a position of agricultural importance took place abruptly during the last two decades of the nineteenth century. While properly subject, on the score of close accuracy, to the examination given it in later paragraphs, table 1 provides a statistical history of irrigation development in the Valley sufficiently illustrative for the present purpose.

Water Commissioner's Statistics

Table 1 presents not only the yearly totals of irrigated acreage in San Luis Valley from 1880 to 1936, but also the totals for each of the water commissioners' districts comprising irrigation division no. 3, the boundaries of which are those of that major portion of the Valley which is in Colorado.

Footnote 1 of table 1 shows the source of the statistics for the period 1880 to 1896 to be a report by W. W. Follett (20),[1] an engineer employed in 1896 by the United States Government to make a survey of the irrigation development of that entire stretch of the Rio Grande Basin in Colorado, New Mexico, and Texas with which the present report is concerned.

Several other statistical data which relate the progress of irrigation development in San Luis Valley are assembled in later tabulations, but these, with reference to each other and to table 1, betray a disconcerting lack of harmony. Mr. Follett discussed candidly the difficulties he encountered in assembling the figures for 1880–96, and in the portion of his report headed Résumé of Colorado Statistics (p. 72) expressed the following conclusions regarding them:

> It is likely that the total acreage given in these tables is within 10 percent of the amount cultivated during 1895 and 1896. * * * Prior to 1895, however, the statements of the acreage may not be nearer than 15 percent. * * * I think that these percentages of error in the totals are maxima, as a large error

[1] Figures in parentheses refer to the listings in the Bibliography of this report.

TABLE 1.—*Area irrigated in San Luis Valley, Colo.*[1]

[In acres]

Year	District 20	District 21	District 22	District 24	District 25	District 26	District 27	District 35	Total all districts
1880	26,205	15,100	24,100	8,650	34,100	16,680	4,000	2,640	131,475
1881	29,670	17,800	31,200	8,700	35,340	17,270	4,000	2,640	146,620
1882	44,115	18,300	33,700	8,700	35,950	17,600	4,000	2,640	165,085
1883	56,315	19,900	44,400	8,800	36,810	18,725	4,000	2,640	191,590
1884	58,785	22,000	45,400	8,800	39,120	20,380	4,000	2,670	201,155
1885	61,935	24,000	51,700	8,800	39,450	20,655	4,000	2,670	213,210
1886	66,045	29,300	56,400	8,800	39,930	21,230	4,000	2,890	228,595
1887	72,675	38,200	57,400	8,800	40,950	22,210	4,000	2,890	247,125
1888	88,630	42,000	59,400	8,800	43,600	22,505	4,000	4,040	272,975
1889	97,535	42,000	60,000	8,800	45,950	22,505	4,000	4,520	285,310
1890	112,485	44,000	60,000	10,000	45,950	22,505	4,000	4,780	303,715
1891	166,480	46,000	55,000	10,000	46,750	21,430	4,000	4,780	354,440
1892	216,685	45,000	80,000	10,000	47,550	20,290	4,000	4,780	398,305
1893	179,785	44,000	45,000	10,000	46,200	19,160	4,000	4,780	352,925
1894	166,085	42,000	50,000	10,000	44,750	18,020	4,000	4,780	339,635
1895	164,795	41,550	55,000	9,500	42,940	16,850	4,040	4,430	339,105
1896	139,795	37,940	60,625	7,050	46,295	20,205	2,670	4,180	318,760
1897	162,229	39,929	[2]60,000	6,199	45,408	12,360	4,586	[2]4,500	335,211
1898	134,277	28,604	[2]45,000	10,537	23,941	19,857	[2]3,000	[2]4,000	269,216
1899	200,544	[2]45,000	[2]50,000	10,637	44,591	3,755	1,569	[2]5,000	361,096
1900	209,650	58,934	[2]55,000	10,541	46,098	23,606	[2]3,000	[2]6,000	412,829
1901	258,000	17,600	[2]60,000	10,528	44,686	23,658	2,000	10,000	426,472
1902	96,920	22,342	[2]30,000	11,067	14,519	5,155	1,303	6,245	187,551
1903	[3]175,000	30,121	43,920	11,045	43,075	11,275	3,230	[2]6,000	323,666
1904	126,234	14,412	[2]35,000	6,739	16,141	5,479	3,531	[2]4,000	211,536
1905	232,246	28,456	[2]70,000	8,407	[2]16,000	16,143	2,585	[2]5,000	377,837
1906	249,931	31,000	73,004	16,655	16,180	20,116	1,555	[2]5,000	413,441
1907	267,057	30,675	74,798	17,068	26,797	24,273	1,801	11,900	454,369
1908	276,099	38,485	66,730	16,800	25,338	14,175	1,532	[2]5,000	444,259
1909	208,302	21,942	104,748	20,412	[4]22,744	25,021	4,282	[2]4,000	421,451
1910	248,097	34,146	93,442	35,910	20,281	24,709	5,397	3,478	465,460
1911	247,077	61,732	87,524	18,292	19,738	25,694	4,241	4,700	468,998
1912	271,656	59,794	117,081	13,846	17,604	29,396	6,250	4,162	519,789
1913	251,752	61,009	97,951	15,226	18,936	28,499	5,452	[2]10,000	488,825
1914	300,287	51,444	85,730	15,294	19,600	31,636	6,025	16,928	526,944
1915	280,280	50,842	88,365	12,627	26,011	30,932	4,244	20,060	513,361
1616	304,271	56,140	98,760	12,945	21,218	27,920	4,132	12,535	536,921
1917	316,875	44,212	97,555	29,908	15,991	37,765	4,208	14,820	561,334
1918	225,446	40,140	97,040	10,516	22,151	26,575	2,146	11,776	435,790
1919	310,259	38,669	101,457	25,928	23,511	37,527	4,766	16,058	558,175
1920	329,561	41,387	99,760	13,799	21,810	37,222	7,604	16,401	567,544
1921	325,249	30,858	89,420	22,347	40,609	53,057	5,100	40,802	616,442
1922	342,148	42,196	99,270	17,904	21,035	35,127	6,740	24,349	588,769
1923	379,349	41,821	135,365	16,794	9,650	45,583	5,229	8,943	642,734
1924	337,767	40,806	136,840	31,987	22,278	19,766	8,195	17,539	615,178
1925	334,581	44,537	128,180	31,536	17,776	46,763	6,827	11,640	621,836
1926	356,904	47,003	117,038	32,423	[4]32,267	50,320	5,902	11,707	653,564
1927	452,568	55,984	106,863	33,203	62,216	47,802	5,485	15,550	779,671
1928	370,098	61,146	103,390	33,811	63,866	49,067	7,546	14,211	703,137
1929	403,772	53,859	104,368	34,645	49,418	58,067	7,158	25,190	736,47[illegible]
1930	426,340	43,920	102,050	35,589	34,245	44,682	6,696	28,871	722,393
1931	380,096	44,381	90,585	33,423	33,954	22,265	8,285	39,830	652,809
1932	412,984	57,297	87,104	30,886	47,116	30,918	5,752	33,730	705,787
1933	409,313	44,647	86,831	32,400	26,573	25,376	6,074	29,720	660,934
1934	378,494	38,737	92,477	30,686	26,946	44,944	6,241	20,241	638,766
1935	389,709	102,510	107,833	30,614	27,372	66,960	8,403	22,323	755,724
1936	390,127	46,256	113,510	33,139	26,540	25,477	5,330	22,435	663,014

[1] As shown to and including 1930 by Debler (17). Data for 1880–96 from report by W. W. Follett (20); figures largely supplied by water commissioners in San Luis Valley. Other unmarked quantities from biennial reports of State engineers of Colorado or from annual reports by division engineer for division 3 on file at Denver, Colo.

[2] Estimated, in order to complete total for division.

[3] Available records at State office show approximately 37,000 acres for district 20 in this year but are believed incomplete. The figure shown is an estimate based on general conditions applying in this year.

[4] Published figures are higher by 60,000 acres in 1909 and 30,000 acres in 1926 on account of inclusion of pasture land on Baca grant. For other years since 1903 at least, such pasture lands are not included.

one way on one ditch or in one district may be balanced by an error the other way in another district.[3]

Owing to the method adopted by stopping acreage when a decree stops * * * the acreage is sure to be large enough each year prior to about 1889, as a ditch very seldom waters its full amount of land the first year of its construction, while the supposition on which the acreage was handled does do this.

At an earlier place in his report (p. 57) Follett remarked as follows regarding the figures referred to in the foregoing quotation:

The State legislature of 1889 passed a bill, which became a law, instructing the State engineer to gather each year and embody in his biennial report statistics as to the amount of water used and land irrigated by each ditch in the State. It became the duty of the water commissioners to collect this information under instructions from the State engineer and superintendents of the several divisions. The work had to be paid for, however, by the counties, and prior to 1896 the county commissioners in several counties have refused to allow the bills of the water commissioners for this work. This has resulted in either no statistics being gathered in those counties, or in what were obtained being collected in a perfunctory way from the returns made by the owners or managers of the different ditches, without any attempt at eliminating errors and obtaining accurate results. This has been especially true in the third division, no agricultural returns whatever having been made from there until 1895, when partial reports were returned from districts 20, 21, 24, 25, 26, and 27. This year Mr. Anderson, the superintendent, made an heroic attempt to obtain accurate returns. He has succeeded fairly well, although there are still many apparent discrepancies in them.

My report on the use of water in Colorado is based on the returns for 1895 and 1896, supplemented by quite a voluminous correspondence, both by mail and wire, with Mr. Anderson and

[3] Boundaries of water districts in irrigation division no. 3, the San Luis Valley, are shown on plate 1, as nearly as may be.

other parties, and some information I collected in Denver, ...mosa, and Antonito. As before stated, it is to be regretted ...ore time was not spent in the valley in the personal gather... data, as a few days of such work would have added very ...ially to the accuracy and consequent value of the report.

While most writers concerned with the history of the agricultural development of San Luis Valley have quoted Follett's irrigated acreage statistics for the years 1880 to 1896, it has by no means been the universal custom to quote his opinion of their reliability. This is not to say, however, that the accuracy of the commissioners' statistics for San Luis Valley, for the whole range of years since 1880, has been free from examination. For example, Tipton's analysis of various statistics (66), quoting Howard D. Sullivan, then (1924) deputy commissioner and statistician of the Colorado State Board of Immigration, says bluntly that "the water commissioners' figures are invariably much too high." The conclusion reached by Tipton was that "the final result (of the analysis) shows an approximate irrigated acreage in San Luis Valley of from 375,000 to 425,000 acres", for the 5-year period 1919 to 1923, although the commissioners' figures for that period ranged from 558,175 acres to 642,734 acres. An actual field survey of irrigated areas in the valley, made by Tipton in 1925–26 in an attempt to resolve definitely the doubts which occasioned his 1924 analysis, produced a total of 494,200 acres, or 80 percent of the ...936 reported by the water commissioners for 1925. ... p. 329). Osgood's survey (table 27) showed 507,471 acres irrigated in 1927, while the commissioners' reports for that year showed 779,671 acres. The Bliss survey as of 1932 (table 27) showed 534,806 acres as compared with the commissioners' total of 705.787, while the Dallas survey as of 1934 (table 27) showed 428,737 acres as compared with 638,766 acres reported by the commissioners.

The lack of harmony between the commissioners' figures and those mentioned above, as well as others to be discussed in later paragraphs led the Bureau of Agricultural Engineering to write State Engineer Hinderlider, toward the close of the survey here reported, requesting him to describe the method by which the commissioners' figures were obtained and the way the work of canvassing has been paid for, together with such comment as he might care to make regarding the validity and reliability of the figures. Mr. Hinderlider's response was as follows:

> Replying to your letter * * *, desiring to be advised of the method pursued in past years in collecting official data on irrigated and irrigable areas in the San Luis Valley, and the quantity of water diverted, will say that an act of the legislature in 1903 provides that the water commissioner shall keep reports which shall contain a statement of the actual carrying ...city and the amount of water actually carried by each ... or canal in his district for each and every day when water ...ing carried, the total number of acres lying under each ditch or canal, and the number of acres actually irrigated therefrom; also a statement of the kind of crop and the acreage under each decreed ditch or canal, the amount of water stored in each reservoir, the amount used therefrom, with the dates of such storage and use; and such reports shall be on blanks, or in books prepared for that purpose and furnished by the State engineer. The law requires that such reports shall be subscribed and sworn to by the water commissioner, and filed in the office of the irrigation division engineer. It is customary also to file copy of such reports in the office of the State engineer.
>
> Presumably, the reports of the water commissioners in the San Luis Valley, Colo., are compiled in conformity with the provisions of law. We all appreciate the fact, however, that, due to human frailties, and the fact that water commissioners in question are paid by the boards of county commissioners on a per diem basis, the time is limited in which to prepare such reports. Generally speaking, the amount irrigated in any one year under each ditch is obtained from the superintendent or secretary of the ditch company, or the individual water users under the smaller ditches. It is not customary for the water commissioner to make personal investigation to determine such acreages.
>
> The results of a careful cruise of practically all of the irrigated lands in the Arkansas and South Platte River basins in this State a few years ago by this office disclosed that the amount of irrigated land, as shown by the water commissioners' reports, was somewhat high, and that the reports of the United States Bureau of the Census were somewhat low. It must be obvious why this would be true.
>
> In the reports of the commissioner of water district no. 20 in the San Luis Valley, a considerable acreage is included as pasture land where water is intermittently applied as the same may be available in the river, for the protection of blue-stem pastures.
>
> As you doubtless are aware, practically all of the larger irrigation canals in district 20, which is by far the largest district in the valley, have been equipped with automatic registers, and the amount of water diverted has been quite accurately determined.
>
> Cruises of lands under the large Rio Grande canal, and the Empire canal, both diverting water from the Rio Grande River, were made by Mr. Tipton in 1931 and 1932. It is my understanding that you have copies of that report, which could be compared with records of the water commissioners, of lands irrigated under the same canals for the same year, from which it could be ascertained what variance, if any, exists between the commissioner's report and the cruise made by Mr. Tipton.

Acreage Statistics Compared

Also involved in the 1924 analysis by Tipton were the statistics assembled by the United States Bureau of Agricultural Economics in cooperation with the Division of Agricultural Statistics (then a part of the Colorado State Board of Immigration, but now in the Colorado State Planning Commission). The pertinent figures are those of cropped and irrigated acreage reported, by counties, by the county assessors. A discrepancy is involved in comparing these (and Federal farm census) figures with those representing the Colorado portion of San Luis Valley as a unit for the reason that parts of Hinsdale, Mineral, and Saguache Counties are outside the San Luis Basin; but as these outside parts are of relatively small agricultural importance, such a comparison is not vitally affected by them.

Ignoring this difference in boundaries, therefore, table 2 shows for 1924, 1929, and 1934, the irrigated acreages in San Luis Valley as reported by the water commissioners, the Colorado Cooperative Crop Reporting Service, and the Federal census.

Aside from illustrating the wide discrepancies between the data from the three sources, table 2 appears to be in line with the conclusion stated in Mr. Hinderlider's letter above quoted with reference to the Arkansas and South Platte Basins, that "the amount of irrigated land, as shown by the water commissioners' reports, was somewhat high, and that the report of the United States Bureau of the Census was somewhat low." However, it is not obvious why this must be true.

TABLE 2.—*Area irrigated, San Luis Valley, Colo., by specified years*

[In acres]

Source of data	1924	1929	1934
Colorado Water Commissioners' reports	[1] 615,178	[2] 582,497	[3] 488,334
Colorado Division of Agricultural Statistics, for Colorado Cooperative Crop Reporting Service	[4] 349,843	[5] 341,856	[6] 315,650
United States Irrigation Census		[7] 627,391	
United States Farm Census	[8] 306,348	[9] 288,758	[10] 285,650

[1] Including 275,868 acres of "native grasses" and an unspecified acreage of pasture.
[2] Not including 153,980 acres pasture.
[3] Not including 150,432 acres pasture.
[4] Not including irrigated pasture, nor 302 acres of unirrigated crops harvested.
[5] 20 acres additional not irrigated.
[6] Not including pasture.
[7] "Rio Grande and tributaries" plus "independent streams." All land reported as receiving water.
[8] All harvested crops, not including pasture, but including 195,648 acres of "hay crops."
[9] Irrigated crops harvested, not including irrigated pasture nor areas of crop failure and idle or fallow land.
[10] "Irrigated land from which crops were harvested"; hence does not include irrigated pasture nor areas of crop failure and idle or fallow land.

The agreement between the figures compiled by the Colorado Cooperative Crop Reporting Service and those resulting from the Federal farm censuses is much closer than that between the commissioners' totals and either of the other two compilations; but the lack of harmony between the 1929 Federal irrigation census figure and the 1929 farm census total needs explanation. It is perhaps sufficient to say (after noting that the discrepancy is somewhat mitigated by the inclusion in the irrigation census figure of a large but unspecified acreage of pasture, etc.) that the Federal irrigation census obtains its San Luis Valley acreage data from essentially the same sources as those which contribute to the commissioners' compilations, while the Federal farm census is conducted independently of the other canvass as far as large enterprises are concerned, being, in fact, a farm-to-farm rather than an enterprise-to-enterprise enumeration.

The 1924 analysis by Tipton (66) went into a comparison similar to that now attempted. A portion of the summary by Mr. Sullivan, there reproduced, is pertinent here, and is quoted below:

1. The United States census report of "cropped acreage" is fairly accurate, except that it is consistently low. This is due to some farms having been missed by the census taker. This is easily accounted for, as the census taker gets 33 cents per schedule, and in a sparsely settled country, as the Valley, some isolated farms would naturally be overlooked. A questionnaire was sent by the Board of Immigration to 1,500 farmers distributed over the State. One question that was asked was whether or not the farmer had been visited by the United States census taker. The result showed that from 5 to 8 percent had not been visited.

2. The water commissioners' figures are invariably much too high.

3. The county assessors' reports are considered fairly accurate for all crops except native hay and alfalfa. For these two crops the figures are very low. This is due to two causes. First, at the time the assessor makes his canvass in the spring, the farmer does not know how many acres of hay he is going to cut, as this depends on the water supply for that year. Second, at the time the State board of immigration began its investigations, the farmer was asked how many acres of each crop he intended to plant that particular year. As alfalfa and native hay are perennial crops, in some cases they may not have been reported and a false return acquired in this way. This query has been changed and now the farmer is asked how many acres of each crop he intends to harvest.

In general, the reports from the county assessors are improving all the time, but the error in the report on forage for the 5-year period being investigated is fairly consistent.

4. In both the census report and the county assessor's report on "cropped acreage", there is no allowance made for the item of "irrigated pasture." An arbitrary figure of 50,000 acres for the Valley for this item is conservative.

The foregoing perhaps needs no comment except as regards the matter of completeness in the Federal farm census. In brief, the fact that a farm operator is not interviewed by a census taker is no proof that the census does not include his farm. In cases where the farm operators cannot be found, the best reports available from other sources are obtained. The following quotation from the Instructions to Enumerators issued by the Bureau of the Census to the enumerators employed in the 1930 census is illustrative of the long-standing practice:

Obtain information with regard to a farm from the farm operator in every case where this is possible. If it is necessary to accept the statements of a member of his family, or of some other person, be sure that this person is able to give you reliable information.

When you find a farm whose operator lives outside your district, or who with his family is outside the district at the time of enumeration, so that it is not possible for you to see him or his family personally, secure the information for this farm as best you may from a neighbor or from any other reliable source that may be available, and note at the top of the schedule that it was so obtained. It is essential that you turn in a completed schedule for *every farm in your district.*

In addressing the Denver office of the Bureau of Agricultural Economics to obtain copies of the publications from which the statistics in the second line of table 2 were abstracted, the Bureau of Agricultural Engineering wrote that Federal census reports were not involved in the request, as they were already available. In reply,

F. K. Reed, agricultural statistician, wrote in part as follows:

> ... noted that you want this information for a selected group ... counties in what we call the San Luis Valley located in south ... central Colorado. Also, that you mention having access to tabulations of the Federal Bureau of the Census for the 3 census years. I might point out that I view these data as carried in the publications enclosed as being less reliable than those given in the Federal census publications. This is particularly true for the San Luis Valley counties where it has always been very difficult to get satisfactory enumerations through our assessors. Hence, if you plan to use the information given in the enclosed bulletins to get some measure of true agricultural production in those counties for the years in question or a measure of the amount of land available for potential agricultural production, I might suggest that the data mentioned above be given due consideration.

Mr. Reed's favorable implication regarding the Federal farm census figures, taken with Mr. Hinderlider's comments relative to the commissioners' data, appears in a detailing of the Valley's agricultural history to justify some further attention to the census statistics by themselves as well as in comparison with the figures obtained by the other agencies, although the farm censuses were taken only at decennial periods until 1925, and only at 5-year intervals since then.

In such an examination, some results of which appear in table 2, the discrepancies in total acreage figures are fully as disconcertingly matched by wide differences in the figures reported elsewhere for specified crops. The important potato crop provides a good example. The ...perative Crop Reporting Service reported 33,410 ...es in potatoes in 1929, the Federal census reported 37,243 acres, and the water commissioners reported 40,027. In 1934 the differences were wider, the corresponding figures being 30,760 acres, 43,078 acres, and 53,483 acres. In the case of the large acreage in hay crops (including legumes "saved for hay") the 1934 figures were, respectively, 227,620 acres, 168,990 acres, and 310,493 acres.

No figures on irrigated pasture appear in the reports of the Cooperative Crop Reporting Service. The census has reported a variety of figures on pasture since 1924 (plowable pasture, woodland pasture, and other pasture), of which those descriptive of "plowable pasture" might appear to have significance as applying to San Luis Valley (50,499 acres in 1924, 72,555 acres in 1929, 30,842 acres in 1934) if the definition permitted.[3] The water commissioners reported 153,980 acres of irrigated pasture in 1929 and 150,000 acres in 1934. There is, in fact, basis for much confusion over this item, as was discovered in the vegetative-cover mapping which formed an essential portion of the investigation here reported. Regarding both hay land and pasture land, even more pointedly than in the case of land raising the other crops, the question of sufficiency of the practiced irrigation may serve to raise puzzling doubts as to just what "irrigation" shall be understood to mean. For example, Mr. Hinderlider noted (page 301) with specific reference to water district no. 20, that a "considerable acreage is included as pasture land, where water is intermittently applied as the same may be available in the river." How this matter was handled in the 1936 mapping is discussed in the chapter headed "Vegetative cover survey."

No statistics pertinent to San Luis Valley appear in the reports of the 1850 and 1860 Federal censuses. The 1870 census showed for the (then) counties of Conejos, Costilla, and Saguache a total area of "improved land" in farms of only 12,797 acres, with no segregation into crop acreages but with production figures indicative of small crops of grain, alfalfa, and potatoes. Ten years later (1880 census) the following totals were reported for the (then) counties of Conejos, Costilla, Rio Grande, and Saguache:

	Acres
Total improved	67, 125
Tilled, including fallow and grass in rotation, whether pasture or meadow	39, 933
Permanent meadows, permanent pastures, orchards, and vineyards	27, 192

Follett's San Luis Valley figure for 1880 was 131,475 acres irrigated. (See table 1.)

The Bureau of the Census conducted its first irrigation canvass in 1890. For the crop year then reported (1889), 1,037 irrigated farms (number of irrigators) were enumerated. The total acreage of the irrigated farms was shown as 413,726 acres, of which 147,830 acres was irrigated. This irrigated acreage was accounted for only to the following extent: Cereals, 27,456 acres; alfalfa, 1,089 acres. (Follett's 1889 figure for San Luis Valley was 285,310 acres. See table 1.)

The 1890 census reported 168,000 acres as "improved" in the counties then including San Luis Valley.

The 1889 census total for the irrigated area in the San Luis Valley counties was somewhat lower than the total shown in the Report on Irrigation by the Office of Irrigation Inquiry, United States Department of Agriculture, published in 1893 as Senate Executive Document No. 41, Fifty-second Congress, first session. As of (apparently) 1891, 275,760 acres was reported as "cultivated" by the four major ditch companies then operating and by "small farmers" (p. 154); but in the same document (p. 156) R. C. Nisbet, of Pueblo County, estimated the "area under cultivation" in Conejos, Costilla, Rio Grande, and Saguache Counties as only 100,000 acres, although he also estimated that 2,000,000 acres was under ditch. The Report of the Special Committee of the United States Senate on the Irrigation and Reclamation of Arid Lands (75) had shown the following figures representing the Rio Grande drainage area

[3] ...d used only for pasture or grazing in 1934 which could be plowed and used for ... without clearing, draining or irrigating.

TABLE 3.—*Areas of specified crops grown in San Luis Valley, Colo., 1902–35 (except 1903, 1904, and 1919), as reported by water district commissioners*

[In acres]

Year	Alfalfa	Natural grasses	Cereals	Pasture	Market garden peas	Potatoes	Sugar beets	Lettuce	Field peas	Beans	Cauliflower	Cabbage or chards, carrots	Sweet-clover	Other crops	Summer fallow	Total irrigated
1935	66,960	226,931	957,81	162,184	8,873	48,792	2,174	1,508	80,876	2,595		897	2,066	56,150		755,724
1934	64,025	178,187	77,272	160,432	9,747	53,463	1,510	2,032	48,607	1,613		532	18,061	33,270		638,761
1933	54,246	119,980	59,938	67,061	7,179	25,339		327	27,514	2,229			9,183	18,967		391,963
1932	80,830	192,999	97,832	155,506	13,448	67,515	679	2,280	52,961	2,150	1,863	313	16,773	21,218		706,367
1931	97,822	224,828	73,582		8,902	57,556	1,581	1,581	60,717	1,555	155	147	22,775	7,897		652,809
1930	83,199	337,846	113,502		5,827	45,665	396	3,664	68,376	1,283	851	87	28,810	30,802		722,393
1929	83,261	233,627	84,107	144,899	9,320	40,027		4,031	67,997	892	1,250	306		45,136	9,081	736,477
1928	86,331	155,719	89,613		3,877	39,328	862	3,294	80,694			57		163,360		703,135
1927	96,275	225,017	92,323		3,319	44,558		4,837	82,695	1,534		79	26,005	202,729		779,671
1926	91,091	341,398	90,022		4,617	28,487	2,409	4,226	73,278	1,782			27,922	11,009	8,921	683,564
1925	85,547	290,358	92,539		2,411	23,353	1,471	4,032	78,377	2,325	118	134		41,171		621,830
1924	81,233	275,868	87,390		755	26,964	123	860	86,058	1,998		59	3,134	50,792		615,178
1923	79,201	322,789	91,611		905	35,668		636	85,375	2,991		63	2,905	20,122		642,734
1922	69,373	234,261	84,252		913	46,448			76,811			77		76,633		586,768
1921	72,629	182,270	128,900		701	35,636			75,089			63		121,155		616,442
1920	60,718	167,535	97,010		649	28,023			68,115	1,295		112		34,849		458,306
1918	47,227	166,126	81,572		1,117	24,276			90,796			108		24,567		435,789
1917	55,498	207,393	114,484		1,386	17,773			104,834			73		60,113		561,334
1916	54,564	222,558	118,136		474	12,086			88,515			84		40,504		536,921
1915	41,976	235,584	112,003		487	9,702	37		58,304			202		55,066		513,361
1914	34,160	229,227	162,627	36,062	381	9,802	15		37,789			19				510,016
1913	29,122	227,321	130,099		392	11,806	3,069		78,145			39				378,825
1912	31,227	224,740	186,243		492	13,875	7,307		49,160			40		6,600		519,789
1911	2,521	198,935	151,325		236	16,355	5,449		74,128			51				468,998
1910	18,189	185,446	209,736		400	14,625	393		36,633			40				465,462
1909	16,909	246,004	177,956		142	11,251	4		25,136			49				477,451
1908	13,661	190,298	142,394		275	7,534	10		85,024			43				439,239
1907	10,854	212,215	100,110		827	5,105			125,061			197				454,369
1906	10,594	134,885	118,968		189	7,440			147,013			64				420,341
1905	8,000	100,000							40,000			100		170,000		318,100
1902	9,939	91,623	39,135			3,408	795					110		12,537		157,547

in Colorado, apparently for 1889: under ditch, 596,097 acres; actually irrigated, 250,263 acres.

The 1900 Federal irrigation census reported as the "acreage irrigated from streams" in 1899, for the third water division, 295,988 acres. For the entire State of Colorado, 7,058 acres was reported as irrigated from flowing wells, almost all of which was undoubtedly in San Luis Valley. (Water commissioners' total, 361,097 acres. See table 1.) The Census total for "improved" land in all farms was 381,062 acres.

A special census of irrigation taken by the Bureau of the Census in 1902, enumerated as irrigated from Rio Grande and tributaries, 1,319 farms and 303,985 acres. (Water commissioners' total was 187,551 acres. Commissioners' totals for 1900 and 1901 were 412,829 and 426,472. Severe drought was cited as the reason for the decline in 1902. See table 1.)

The 1910 irrigation census (for 1909) reported as irrigated in the Rio Grande drainage basin 460,781 acres. The 1920 irrigation census (for 1919) reported the total as 608,924 acres—both higher figures than the commissioners reported. The census total for improved land in all farms in 1910 was 588,905 acres. The corresponding 1920 total was 499,668 acres.

Whatever the uncertainties created by such comparisons as those set out in the preceding paragraphs, they should be resolved so far as the present situation is concerned by the tabulations resulting from the 1936 vegetative cover mapping (table A).[4]

The general crop history of San Luis Valley may be traced clearly enough for the present merely informative purpose, from table 3. (Discrepancies in the totals shown in tables 1 and 3 are not considered serious enough, in this comparison, to require explanation or adjustment.)

Drainage, Storage, and Allied Problems

San Luis Valley's rapid agricultural development in the 1880's and 1890's, influenced by a lack of sufficient storage, the widespread practice of "subirrigation" (see p. 317), and the uncontrolled flow of many artesian wells, early combined to bring about a serious condition calling for extensive drainage. The following paragraphs[5] concisely describe this condition (with particular reference to the closed area) and further explain some of the circumstances producing it:

On casual inspection, the entire valley seems to slope very gently and drain into the Rio Grande, which enters the basin almost due west of Alamosa and turns south at the city toward the New Mexico line. However, as a matter of fact, an imperceptible low divide in the valley floor parallels the north side of the Rio Grande, at a distance of 2 to 5 miles, from the point where it enters the basin near the town of Monte Vista southeastward to a point below Alamosa. This divide converts the northern part of the valley into a basin that is "closed" so far as natural drainage is concerned.

Within this closed area such of the waters of the local streams and of the diversions from the Rio Grande as are not consumed in irrigation and by natural growth or by evaporation, finally find their way into a low trough parallel to the foot of the eastern range. There, in seasons of abundant run-off, the waste waters collect in numerous small lakes, swamps, and low waterlogged areas. In seasons of moderate run-off the areas of free-water surface and swamp are greatly diminished. After a series of dry years, San Luis and Head Lakes constitute the only free-

[4] For comparison with analyses of Middle Valley statistics on page 308, see especially 1936 San Luis Valley figures on "areas formerly irrigated" (158,694 acres), and discussion of the mapping of these areas on page 406.

[5] From 1935 report by Stout, Fowler, and Debler (59).

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water surfaces. The water table throughout the trough is ordinarily relatively high.

* * * *

The history of the development is interesting. The first area irrigated was along the Alamosa-Salida railroad line, in the lower part of the trough immediately west of and parallel to the natural seeped area. In this section of the basin a broad belt of land was rapidly brought under irrigation. Drainage difficulties soon developed that led to progressive abandonment of lands along the eastern border of this irrigated zone and to its progressive extension westward. As years went by, this progressive shifting of the irrigated zone westward continued until its western margin had reached the extreme west side of the valley and the broad stretch of once-occupied lands to the eastward was left to revert to its original state, badly damaged, however, by alkali.

Drainage of the western area then became necessary, and the waters developed thereby aided in a progressive reoccupation of a part of the neighboring lands to the eastward that were once occupied and then abandoned on account of becoming waterlogged and affected by alkali.

* * * The growing demand for water has led to the re-use of the drainage return from the higher areas to the westward, unless limited in some way. As matters now stand, drain waters are reapplied with no return therefrom during the irrigation season. In ordinary years, waters are so used only in the period from April to October, but in years of subnormal rainfall and run-off, such irrigation is extended throughout the winter. Little water has issued from any of the drains into the sump area in the past 6 or 7 years.

It appears certain that this re-use of drainage water will be extended and continued, and additional lands brought back into use east of present occupied territory until the area consumes practically all the natural and return supply.

Throughout its modern history the Valley has been notable for its great number of artesian wells. The 1936 investigation by the Geological Survey disclosed that the number of these wells, including pumped and flowing, urban and rural, was 6,074. The total estimated annual discharge was 118,945 acre-feet. There were also a large number of artesian springs of estimated annual discharge totalling 47,450 acre-feet.

As of January 1, 1930, the Federal irrigation census reported that 614 of the flowing wells were used for irrigation, the remainder being domestic and stock-watering wells. In general, the irrigation wells are the larger, the average capacity of those enumerated in 1930 being 62½ gallons per minute.

Since all but seven of the flowing wells reported for Colorado were in San Luis Valley, practically all (say 3,600 acres, or about 6 acres per well) of the total acreage (3,786 acres) was Valley land. Most of the irrigation wells—542 of the 1930 total—are in the "live" area of the Valley, the remaining 72 being in the portion tributary to Saguache and San Luis Creeks (Pl. 11.)

The 1930 census reported only one pumped well used for irrigation, but there are now many more, the growth of this phase of irrigation supply having been one of the most notable developments of the last few years. It is still continuing, the section around Center having experienced a marked activity in the establishment of new pumping plants during the past year. According to the United States Geological Survey, there are now 160 pumped irrigation wells in the area east of the Rio Grande canal and north of the river. Forty-six of these wells were installed in 1936.

Practically no control of the discharge of many of the flowing wells (domestic and stock as well as irrigation) has been exercised. Notwithstanding the small acreage (mostly farm gardens and pastures) which is watered from this source, this lack of curb has contributed to the raising of the water table in some portions of the Valley, so having been a factor in creating the need for drainage.

Conkling describes 1919 conditions as affected by the water table in the following (selected) paragraphs (12):

The geological formation is such that an artesian basin exists under the valley floor * * *. This basin is fed by creeks and rivers flowing across the outwash as they leave the mountains and possibly by percolation in the mountains themselves, although it seems improbable that any large contribution occurs from this source. The calculated head of the flowing wells defines the altitude of the impermeable stratum which forms the top of the aquifers and as some of the larger canals divert above this altitude and above the point in the stream where measurements have shown seepage losses to occur, it is probable that the loss from canals is contributing to some extent to the basin, and in succeeding calculations some estimates are made of this quantity.

* * * Siebenthal gives the number of artesian wells as 3,234 with an average discharge of 40 gallons per minute.

* * * The wells are, in general cased to the first clay bed which appears to be the upper confining layer of the artesian basin; hence capping successfully conserves the water for use elsewhere and shuts off the contribution to ground-water.

* * * It was * * * found that the artesian basin had extended westward in the neighborhood of Center since Siebenthal's time. (Pl. 5.) The maximum extension is about 2 miles and gradually diminishes from this distance to nothing near Saguache and Monte Vista. The only way of accounting for this is contribution to the basin which did not exist before irrigation began. If this is correct, when the basin finally reaches a state of equilibrium, there may be more outflow from the valley than is hereinafter estimated.

There are said to be 850,000 acres of seeped land in the valley. This is hardly true. There are 850,000 acres * * * under which the water table lies 8 feet or less of the surface. With the coarse subsoils of part of the valley, this water table hardly affects the surface on a part of the valley and it can be successfully farmed. The area east of the north and south line 3 miles west of Mosca is in mind. At Mosca the water table is about 4 or 5 feet below the surface and about 6 miles east of Alamosa about 8 feet. It can be said with truth that there are 850,000 acres which should be seeped if more of the land were irrigated.

* * * there are areas unaffected by ground-water on the outwash slopes of the Conejos, Alamosa, Rio Grande, and Saguache Rivers totaling 200,000 acres, giving a total, in addition to the small areas along the Sangre de Cristo Range, of 1,050,000 which are near the larger streams, are largely under ditches diverting from them or will have ground-water very close to the surface with the best possible system of drainage.

* * * It is evident that much more land can be irrigated than at present. Such extension depends largely on ability to control the discharge by reservoirs.

For the entire Valley the 1930 census reported 25 reservoirs used for irrigation storage, with total capacity of 281,994 acre-feet (of which less than one-third was on Rio Grande, Conejos, and Alamosa Rivers). These figures are not in agreement with statistics obtained by the Bureau of Agricultural Engineering in 1936, when 15 reservoirs alone were represented as having total capacity of 312,625 acre-feet. In addition to the 15 mentioned, each of which had a capacity of more than 1,000 acre-feet, a number of small storages were listed. Some of these were not irrigation reservoirs; however, the discrepancy in acre-foot totals is explainable by the excessive capacity of some of the reservoirs relative to the amounts of water retained in any but exceptional years.

Notable is the fact that, with one exception, all the major storages were created since 1900—that is, after drainage needs had already become serious; but as illustrated by Tipton (69) in table 4 (for the lands between Alamosa and Del Norte), the spring flow is still utilized to an extent considerably in excess of the ideal demand.

TABLE 4.—*Assumed ideal irrigation demand (600,000 acre-feet) on Rio Grande between Alamosa and Del Norte, Colo. (after Tipton)*

Month	Assumed demand acre-feet	Percent total seasonal	Actual diversion percent total seasonal
April	30,000	5	6
May	102,000	17	29
June	162,000	27	31
July	156,000	26	16
August	108,000	18	12
September	30,000	5	5
October	12,000	2	[1] 1
Total	600,000	100	100

[1] Shown as 7 percent in report from which table was copied. Correction made arbitrarily by Bureau of Agricultural Engineering to produce total of 100.

The existing storage is locally asserted to have been effective in improving irrigation use,[5] but as is the case elsewhere in Upper Rio Grande Basin as well as in many other irrigated valleys of the West, the need for extensive drainage persists, although it is obvious from table 5 that the existing drains have been effective in protecting a large area which without them would now be partly, if not wholly unproductive.

TABLE 5.—*Land in drainage enterprises, its condition and use, San Luis Valley, Colo., 1930*

[Assembled from the more elaborate tabulations for Alamosa, Conejos, Rio Grande and Saguache counties in the reports of the Federal drainage census of 1930]

[In acres]

Land in organized drainage enterprises	168,946
Land in occupied farms	118,133
Improved land	117,553
Land in planted crops	107,543
Land idle	55,053
Land unfit to raise any crop	2,428
Land unfit to raise any crop prior to drainage	90,342
Land fit to raise crops (partial and normal)	166,518
Land fit to raise crops prior to drainage	78,604

Middle Valley

The several available sources of statistical information relative to the irrigation development of the main and tributary valley areas between the Colorado State line and San Marcial are the Follett report of 1896, Federal census compilations, and certain surveys made by the State of New Mexico.

As in the case of his San Luis Valley tabulations, Follett's figures (20) were accompanied by certain reservations.[7] In the New Mexico investigation, he did not have a basis for estimates equivalent to the more or less unsatisfactory water commissioner records he found in Colorado. Accordingly, the figures he finally reported were largely the product of a canvass he conducted personally.[8]

Follett's tabulations covered the years 1880 to 1896, and were made according to "water districts" of his own creation. The boundaries of these districts were such as to permit combinations of figures applicable to the

[5] In a personal communication to Mr. Stafford, Mr. Tipton writes that "on the Rio Grande proper there is only about 80,000 acre-feet of effective storage and * * * this storage is used to the limit in an attempt to reduce the distorted method of using water between Del Norte and Alamosa. 50,000 acre-feet of the effective storage is owned by the San Luis Valley Irrigation District, commonly known as the Farmers' Union. * * * the use of water by this system is almost identical with the assumed ideal (shown in table 4) * * * While the Farmers' Union system has sufficient direct flow decrees to permit large spring diversions, yet such diversions are not made. Before the construction of the Farmers' Union reservoir the diversions by the Farmers' Union canal were distorted in the same manner as the majority of the diversions along the stream between Del Norte and Alamosa.

"There is no question but what if substantial storage were provided on the stream the high spring diversions would be reduced and the late summer diversions would be increased by the release of the reservoir water * * *" (See also p. 329).

Also with reference to the effect of present storage, Mr. Hinderlider in a letter to Mr. McLaughlin writes that "for the 22-year period, 1915–36, the amount of water used from reservoirs by canals diverting in district 20 averaged 49,100 acre-feet per year and 34,000 acre-feet of this amount was used by one system—the Farmers' Union. The total acreage irrigated in district 20 is about 280,000 acres of which amount the Farmers' Union irrigates about 46,000 acres. Therefore, an average of 34,000 acre-feet of the stored water was used on an acreage representing about 16.5 percent of the total acreage irrigated in district 20.

"An analysis of the use of the water by the Farmers' Union indicates that the seasonal distribution for the diversions by the Farmers' Union approaches the seasonal ideal distribution (as set up in table 4, above).

"For the period 1926–35 the mean annual diversion by canals in district 20 was 538,300 acre-feet. 53,400 acre-feet of this quantity was diverted by the Farmers' Union canal, leaving 484,900 acre-feet as the aggregate diversions of the remaining canals in district 20. About 30,000 acre-feet of the 53,400 acre-feet diverted by Farmers' Union diversions, was reservoir water; and about 17,100 acre-feet of the balance of 484,900 acre-feet diversions, was reservoir water. In other words, an average of 56 percent of the total diversion by the Farmers' Union was stored water, while the stored water diverted by the other canals was only about 3.5 percent of the total diversion. * * *

"Available reservoir water has resulted in a material change in the seasonal distribution of the diversions of the Farmers' Union canal. For the years 1925 to 1928 inclusive (for which period the data has been determined) the Farmers' Union in the month of May diverted on an average only 60 percent of the water available to it under its decrees, the maximum for any May being 80 percent and the minimum being 46 percent. During the months of June for the above period an average of only 89 percent of the water available to it under its decrees was diverted by the Farmers' Union. The reservoir water available to the other systems on the river being only about 3.5 percent of the total diversion by those systems, is too small to change materially the distorted seasonal use."

[7] In considering the information relating to New Mexico the method of obtaining it must be borne in mind and due allowance made for its probable error. I believe that the total area of irrigated land given for each district is within 15 percent, and possibly within 10 percent, of the area actually watered an average year. (P. 74.)

[8] A part of the commissioners along the Rio Grande ditches were able to give me statements of acreage which were pretty close, but where there were no commissioners it was difficult to learn the areas watered. Whatever land I saw I estimated as well as possible, and obtained from the inhabitants their estimates also as a check on mine. (P. 74.)

investigation here reported. Such a segregation appears in table 6.

TABLE 6.—*Areas irrigated in Rio Grande drainage basin of New Mexico from Colorado State line to San Marcial, as reported by Follett (20)*

[In acres]

Year	State line to White Rock Canyon	White Rock Canyon to San Marcial	State line to San Marcial
Prior to 1880	111,410	34,370	145,780
1880	113,360	32,470	145,830
1881	113,360	31,700	145,060
1882	113,460	31,700	145,160
1883	113,450	31,700	145,150
1884	113,850	31,700	145,550
1885	113,650	31,700	145,350
1886	114,670	31,700	146,370
1887	114,970	31,700	146,670
1888	115,050	31,700	146,750
1889	115,130	31,700	146,830
1890	116,380	31,700	148,080
1891	117,080	31,700	148,780
1892	117,680	31,700	149,380
1893	118,400	31,700	150,100
1894	118,440	31,700	150,140
1895	119,980	31,700	151,680
1896	118,330	31,700	150,030

Table 7 is a compilation by Hedke (27), assertedly based on the Follett surveys, a survey made by H. W. Yeo in 1910, and a drainage investigation conducted by the State of New Mexico in 1918. The discrepancy between the 1896 figure (31,700 acres) shown in table 6 and the figure for "acres under development" (50,000) appearing in table 7, both attributed to Follett, Hedke explains as follows: "Follett says, 'Their (the figures') probable error ranges from 10 to 20 percent for the areas watered', etc. Since the above figure of 31,700 acres, for the area watered in the Middle Rio Grande Valley was based on estimates and testimony obtained from those who could only use an estimate of the total areas under the ditches or previously irrigated as the basis for comparison, the error of 10 to 20 percent on the net area could easily involve the further error of 10 to 20 percent on the gross area, which together would readily extend his figure to 50,000 acres, and such is assumed . . ."

A fault in this reasoning appears to lie in the evident assumption that Follett's admitted possible error lay entirely and consistently in the direction of deficiency. Hedke's previous comment that "the data (Follett's) were secured from interviews and only purports to give the area farmed for that year, 1896, and in no way covers previously irrigated areas nor the areas under the ditch developments" is likewise not clearly supported by the descriptions of his "districts" recited by Follett.[9]

TABLE 7.—*Progress of irrigation development in the Middle Rio Grande Valley, based by Hedke (27) on the reports of W. W. Follett, engineer for International Boundary Commission (20), H. W. Yeo, engineer, United States Bureau of Reclamation, and 1918 drainage survey by State of New Mexico*

Time, up to—	Number of ditches	Second-feet capacity	Acres under development	Acres failed	Remarks
1600	22	537	25,565	....	Indian development.
1700	61	1,445	72,580	....	Indian with Spanish.
1800	70	1,806	100,380	....	Above with Spanish grants.
1850	80	2,099	123,315	....	Natural increase.
1880	82	2,145	124,800	....	Transcontinental traffic and Civil War demand completed developments.
1896 [1]	71	1,779	50,000	74,800	Due to short water supply, rising water table, railroad supply competition and railroad labor demand.
1910	79	2,121	45,220	79,580	Further shortage and further rising water table.
1918	55	1,957	47,000	77,800	War period.
1925	60	1,850	40,000	84,800	Estimated present condition.

[1] Deduced from W. W. Follett's report (see table 6).

Hedke ends his analysis of the early figures in table 7 with the remark that "the size and capacity of the ditches, even as existing in 1910, confirm the conclusion that the entire area was in cultivation at one time, and not so far distant, as the ditches had not deteriorated to the requirements of the then cultivated areas." Yeo appears to have had a similar opinion, yet such a conclusion was not reached by Follett, notwithstanding his observation of areas previously irrigated and the excessive capacities of ditches. Indeed, modern practice in most irrigated sections, including Rio Grande Valley, scarcely justifies the broad assumption that areas have been watered in the past to the full extent of the carrying capacities of their canals. Follett's notes regarding the more or less migratory nature of the agriculture along the river, as forced by the deterioration of the land, seem to provide the more likely explanation of the evidences of prior extensive cultivation, although he himself was outspoken in commenting on the effects upon lower irrigators of the rapid developments in San Luis Valley.

While the early farm statistics of the United States census were obtained under much difficulty, they are of interest in the present discussion. No irrigation statistics were collected until 1890; but the 1850 census enumerated only 166,201 acres of "improved" land in the entire territory, distributed among the then counties as follows: Bernalillo, 13,436; Rio Arriba, 30,417; Santa Ana, 3,197; Santa Fe, 19,081; San Miguel, 42,880; Taos, 10,469; Valencia, 46,721.

[9] District no. 13, upper Albuquerque. The Mexicans, or Spaniards, settled on the vacant land in this district from 100 to 300 years ago. While the arable land probably amounts to over 40,000 acres, only about 8,000 is under cultivation. Much of the balance has been tilled at some time in the past; but as the land lies nearly level, and so has little natural drainage, as mentioned above, the lavish use of water has filled it with alkali and much of it has been abandoned, the owners simply moving back onto a little higher ground. I could see nothing, however, to lead me to the belief that the total acreage had raised materially in the past 15 years.

District no. 14, lower Albuquerque. While there is fully 75,000 acres of arable land in the district, less than one-fourth of this amount is cultivated. Much formerly watered has been abandoned and is now marsh land, white with alkali. In this district and in district no. 15 evidence exists of there having been more land under cultivation at one time than is now tilled. I am satisfied that the shrinkage in these two districts is fully 10 percent, the larger proportion of it being in district no. 15. I was told that this contraction of area occurred about 1880, * * * I have therefore added to district 14 about 1,500 acres prior to 1880 and about 500 acres for 1880.

District no. 15, Socorro. There is probably not more than 20,000 acres of arable land in the whole distance of 80 miles from the mouth of the Puerco to San Marcial, and of this less than 6,000 acres is tilled. The evidence of the shrinkage in the area cultivated was here plain, and I therefore added to the 1894 acreage 1,200 prior to 1880, and enough to make a total of 6,000 acres in 1880.

In 1860 a lower total, 149,274 (improved) acres, was reported, distributed by counties as follows: Arizona, 12,216; Bernalillo, 12,189; Dona Ana, 14,490; Mora, 3,243; Rio Arriba, 28,077; Santa Ana, 4,947; Santa Fe, 13,266; San Miguel, 21,550; Socorro, 7,175; Taos, 9,777; Valencia, 22,344. (Pl. 1)

The corresponding county distribution for 1870 was as follows, the total being 143,007 (improved) acres: Bernalillo, 4,966; Colfax, 2,817; Dona Ana, 17,184; Lincoln, 9,887; Mora, 20,503; Rio Arriba, 6,721; San Miguel, 20,541; Santa Ana, 1,534; Santa Fe, 10,925; Socorro, 4,655; Taos, 33,686; Valencia, 9,588.

The 1880 census figures were slightly more detailed than those just quoted, as shown in table 8.

TABLE 8.—*Statistics of agriculture for New Mexico, as reported by the 1880 Federal census*

[In acres]

County	Improved land	Tilled, including fallow and grass in rotation whether pasture or meadow	Permanent meadows, permanent pastures, orchards and vineyards
Bernalillo	3,821	3,642	179
Colfax	51,606	37,568	14,038
Dona Ana	25,786	24,246	1,540
Grant	5,267	4,575	692
Lincoln	4,821	4,662	159
Mora	18,848	14,700	4,148
Rio Arriba	18,762	17,097	1,665
San Miguel	27,861	20,051	7,810
Santa Fe	8,619	3,800	4,819
Socorro	26,013	17,802	8,211
Taos	33,740	32,901	839
Valencia	12,248	9,722	2,526
Total	237,392	190,766	46,626

Thus, assuming that the then counties of Bernalillo, Socorro, and Valencia included the lands in the middle portion of the Rio Grande Valley now under consideration, but remembering that they also included other farmed areas, the 42,082 acres of improved land shown for them in table 8 is not inharmonious with the 34,370 acres of irrigated land in the Valley between White Rock Canyon and San Marcial reported by Follett (see table 6), but falls far short of the 124,800 acres "under development" shown in Hedke's tabulation (table 7).

The Federal irrigation census of 1890 reported, for 1889, only 15,554 acres of irrigated land in the counties of Bernalillo, Socorro, and Valencia. The total farm area in the three counties was 173,465 acres, of which approximately 37,600 acres was "improved." In 1899 the same counties reported 28,511 acres irrigated and 48,438 acres improved. The corresponding census figures for 1909 (including Sandoval County) were 105,943 acres improved, 77,682 acres irrigated. The 1919 figures were 114,990 acres improved and 68,101 acres irrigated.

For the counties above what is now Sandoval (that is, Rio Arriba, Santa Fe, and Taos) the "improved" and "irrigated" acreage figures reported by the cens.. were respectively as follows: (The "irrigated" figures are for the preceding crop years.) 1890, improve.. (approximately), 30,353 acres and irrigated, 14,' acres; 1900, improved, 45,601 acres and irrigat.. 35,914 acres; 1910, improved, 79,329 acres and irrigated, 103,339 acres; 1920, improved, 114,561 acres and irrigated, 116,225 acres. (Pl. 1.)

Census figures from the 1925 and later canvasses, for both the counties involving the area discussed in preceding paragraphs and the counties involving the Valley lands between White Rock Canyon and the Colorado State line are shown in table 9.

TABLE 9.—*Selected statistics of agriculture in Rio Grande Valley, N. Mex., from reports of the United States Census*

[In acres]

Area	Census of— 1925	1930	1935
State line to White Rock Canyon: [1]			
Irrigated	(2)	101,489	[3] 39,021
Crop land harvested	64,166	64,310	54,067
Crop failure	26,474	5,176	43,632
Crop land idle or fallow	33,258	16,039	12,987
Plowable pasture	137,974	74,459	63,021
White Rock Canyon to San Marcial: [4]			
Irrigated	(2)	69,955	[3] 34,303
Crop land harvested	65,486	57,576	43,295
Crop failure	14,396	7,100	57,486
Crop land idle or fallow	11,584	14,527	14,402
Plowable pasture	87,390	68,919	91,496

[1] Rio Arriba, Santa Fe, and Taos Counties.
[2] Not reported.
[3] "Irrigated land from which crops were harvested" (in 1934). Hence does include irrigated pastures, irrigated crop failure and irrigated fallow lands.
[4] Bernalillo, Sandoval, Socorro, and Valencia Counties.

While it is possible to make almost any showing desired from the statistics in the preceding paragraphs and tables, they disclose an approximate agreement on a total area which presumably would be agriculturally productive under favorable conditions of water supply and drainage. Although the census figures fairly well support Follett's acreage estimates for 1880 and prior years, and do not justify the 1850 and 1880 estimates shown in table 7, they nevertheless are not absolutely inharmonious with those shown for 1896 and the later years. Thus if, in the 1925 summations, the crop land harvested, crop-failure land, and idle or fallow land are taken to represent the then crop areas, the total (91,500 acres) does not have to be increased unreasonably from the "plowable" pasture to come to an approximation with Hedke's combined acreage of 124,800 acres in "acres under development" and "acres failed", and the latest figures provided by the census (1934) would likewise indicate a total developed area (115,000 acres) approaching the Hedke figure.

In brief, these comparisons, including Follett's descriptions, while not proving beyond question that anything like as much as 124,800 acres was ever irrigated in a single year in the area between White Rock Canyon and San Marcial, do appear to support the supposition that lands making up such a total have used water productively from time to time in periods recent enough for present consideration.

A similar somewhat loose conclusion may be drawn from comparing the 1934 census total of harvested, failed, and fallow acreages in the Valley section above White Rock Canyon (110,686 acres) with Follett's 1896 total of 118,330 acres. Apparently the two Valley areas are of about equal weight as far as extent of agricultural development and possibilities are concerned.

In all the compilations, whatever the other indications, the handicap of short water supply stands out sharply. This, therefore, is no new circumstance, but the census figures for the 1934 crop year emphasize it strongly, since the areas of crop failure reported in both sections of the Valley were substantially larger than acreages of "irrigated land from which crops were harvested." Neither census nor other statistics are available to disclose how the crops above Cochiti fared in 1935, but the Middle Rio Grande Conservancy District made its first complete crop census in 1936, results of which were handed the Bureau of Agricultural Engineering in advance of the completion of the Bureau's 1936 tabulations of the vegetative cover. The latter showed 59,159 acres irrigated. (See table 123 and supplementary table B.) The acreages reported by the district are listed below:

	Acres
Alfalfa	17, 125
Small grains	16, 477
Corn	13, 596
Orchards and vineyards	1, 564
Gardens	3. 990
Vega meadow land	3, 500
Miscellaneous	5, 042
Total	61, 294

Pertinent crop statistics from the three most recent Federal census reports are shown in table 10. The 1929 figures represent irrigated crops; the others, all crops.

TABLE 10.—*Selected crop statistics for counties in Rio Grande Valley between Colorado State line and San Marcial, from reports of the United States Census*

[In acres]

Crop	State line to White Rock Canyon[1]			White Rock Canyon to San Marcial[2]		
	1921	1929	1934	1924	1929	1934
Hay crops	27, 339	20, 433	21, 404	25, 213	12, 657	17, 511
Legumes (principally beans)	11, 070	4, 309	3, 902	11, 563	837	2, 695
Cereals, including corn	20, 957	13, 424	23, 309	25, 016	17, 489	17, 845
Vegetables, including potatoes	484	1, 684	2, 251	693	1, 521	2, 251
Orchard fruits, nuts, and vineyards	1, 569	1, 542	1, 357	1, 897	1, 437	1, 875
Other crops	19	63	508	44	47	831

[1] Rio Arriba, Santa Fe, and Taos Counties.
[2] Bernalillo, Sandoval, Socorro, and Valencia Counties.

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Middle Rio Grande Conservancy District is closely coextensive with the entire Valley area between White Rock Canyon and San Marcial, its upper terminus being Cochiti and its lower terminus about 3 miles below San Antonio. (Plates 13–16, incl.)

C. H. Howell, former chief engineer of the district, in an article published by the University of New Mexico (83) in 1935 says that the organization and construction of the district were attributable to conditions existing in the Middle Valley prior to 1930, when construction of the system was started, as follows:

1. A water-logged or seeped condition of about 85,000 acres of lands which were formerly cultivated.
2. The dangers of flood damage from the Rio Grande and its tributaries.
2. An obsolete and inefficient irrigation system.

The following paragraphs represent a condensation and rearrangement (by the Bureau of Agricultural Engineering) of Mr. Howell's description of these conditions and the means adopted for their correction:

For the portion of the river below Corrales the river bed is in most cases only a few feet lower than lands on either side. In the Socorro Division it is actually higher than the farm lands west of it. In times of high water the tendency is for the flood waters to seek out the low places and form entirely new channels through the farm lands and villages. All Albuquerque, not on the mesa, is built in the flood water channel of the Rio Grande.

To remedy this condition a system of intercepting drains was laid out near and parallel to the river channel. These drains are some 10 feet deep at their upper ends and are built on a grade flatter than that of the river itself. They end in practically no cut and the water surface in the drain meets the low-water surface elevation of the river.

These riverside drains overlap; above the lower end of one drain another is started, so as to drain the area which would not be affected by the first drain because that drain is there no lower than the river. To drain the interior low-lying areas, interior drains were dug. These are located, in general, through the lowest lands and discharge into the riverside drains.

The material excavated from the riverside drains was used to form levees. Thus one handling of the material produced both a levee and a drain. The levees are from 8 to 10 feet high, so spaced as to pass 40,000 second-feet of water at the upper end of the district and 50,000 at the lower end. Those immediately adjacent to Albuquerque have been raised and are designed to handle about 75,000 second-feet. Considerable straightening of the river by cut-offs has also been done. Levees built total 181 miles, and about 40 miles of pile and wire protection have been installed.

At the beginning of the investigation of this project the land was served by 60 irrigation ditches, all primitive, generally small, and without permanent diversion dams or adequate headworks. Their structures were inadequate for economical distribution and use of water. However, before the Rio Grande became in reality an exaggerated arroyo, the old primitive ditches were made to serve. As the river channel filled, the difficulties of operating the ditches increased rapidly. For instance, in many cases, it was necessary each year to construct long diversion dams of sand, to corral the low flows which formerly had come directly into the heading but then wandered through the sands of the river bed. After each little flash flood these sand dams had to be replaced.

Because different communities could not agree among themselves, numerous canals ran parallel to each other for miles. Each mile required its separate maintenance and cleaning. The owners of each ditch sought to get all the water in time of shortage and keep others from getting theirs.

A new irrigation system has been built, but the old system has not been entirely abandoned. For convenience, the district has been divided into four construction and operating divisions: Cochiti, Albuquerque, Belen, and Socorro. Each has its own diversion dam, main canal or canals, new lateral system, and old ditches, which have been revamped.

El Vado dam and reservoir is considered a fifth division. The dam is built across Chama River in Rio Arriba County, about 17 miles west of Tierra Amarilla. It is a gravel embankment, 1,300 feet long and 180 feet high, with upstream slope of 1½ to 1 protected by a ¼-inch steel plate. This face plate connects with vertical concrete cut-off wall, which is carried down to solid rock. The downstream slope is 2 to 1 and is formed of boulders and loose rock. The spillway is an open steel-lined chute, placed in a shale and sandstone cut which is 80 feet deep. The spillway is controlled by an automatic radial gate 23½ feet high and 36 feet wide. The outlet works consist of a 78-inch steel penstock placed in the 12-foot diameter diversion tunnel, and controlled at its upper end by a butterfly valve and at its lower end by two 48-inch balanced valves.

The spillway has a discharge capacity of 20,000 second-feet before the dam is overtopped. The outlet works have a maximum capacity of 1,500 second-feet. An auxiliary spillway or blow-off plug is formed by means of a low dyke which closes a saddle in the right rim of the reservoir. The top of this dyke is 1.5 feet below the top of the dam, so that before the dam can be overtopped, 1.5 feet of water will pour over the dyke and wash it out. It is estimated that when this spillway blows, 50,000 second-feet will be discharged. The storage capacity of the reservoir is 200,000 acre-feet. (Pl. 1.)

No such elaborate corrective construction has been undertaken in the Valley sections above Cochiti. There the 1930 irrigation census listed 11 irrigation storage reservoirs with a total capacity of approximately 40,000 acre-feet (not including the El Vado storage, of course). No irrigation wells, either flowing or pumped, were reported. The 1930 drainage census reported no organized drainage enterprise in the three upper counties.

Pueblo Irrigation

Not to be overlooked in any presentation of the past and present status of irrigation in Rio Grande Valley is the story of the Indian pueblos. Such a description was contributed by Gen. H. F. Robinson, then supervising engineer of the United States Indian Service, to Hosea's 1928 report (32), and quoted by various other writers. It is again reproduced in the following paragraphs and table 11, being considered generally pertinent to the present circumstances notwithstanding various developments (such as the creation of Middle Rio Grande Conservancy District) since its preparation:

The water rights for the Pueblo Indians of New Mexico the oldest on the Rio Grande and its tributaries, and the Unite States claims *priorities* for such rights over any other cl whatsoever.

When the Spanish Conquistadores first arrived in this cou they found the Pueblo Indians diverting water from the streams and cultivating the irrigated lands. Today the Indians are doing this, very much as their forefathers did it, using the same general methods, diverting the water in the same ditches and irrigating the same lands as in 1540. The Government, through the Indian Service, has assisted the Indian in improving his ditches and providing structures for the diversion and control of the water.

From time to time, beginning almost as soon as the crown of Spain gave specific grants to the various Indian communities in the year 1692, non-Indians have gained a foothold on the grants and have acquired certain rights of occupancy and possession both of land and of water with which to irrigate the lands. * * *

Inasmuch as until the title to the lands and water are extinguished as to the Indians, they may still be considered as Indian, and a statement as to the area of land occupied by the non-Indians have been included herewith.

There is presented in tabular form a list of all of the pueblos showing (a) the source of water, (b) the number and (c) the length of their canals and (d) and (e) the acres of land under canal on these grants for which water is claimed. The list does not include figures for the non-Indian lands on the Santa Clara Grant.

TABLE 11.—*Irrigable areas under canals of Indian pueblos in Rio Grande Valley, N. Mex. (after Robinson)*

[In acres]

Pueblo	Source of water	Canals		Irrigabl under	
		Number	Total length	Indians	Indians
Acoma	Rio San Jose	5	17	900	None
Cochiti	Rio Grande	2	10	1,506	693
Isleta	do	4	26	6,352	179
Jemez	Rio Jemez	5	13.5	1,600	311
Laguna	Rio San Jose	11	33	3,220	None
Nambe	Rio Nambe	3	[illegible]	1,490	[illegible]
Picuris	Rio Pueblo	3	2.7	155	2,930
Sandia	Rio Grande	1	8	3,145	1,132
San Felipe	do	2	18	4,116	17
San Ildefonso	Rio Pojoaque	3	4	326	1,118
San Juan	Rio Grande	3	12.1	887	690
	Rio Chama	2		150	500
Santa Clara	Rio Grande	1	9.5	650	(1)
	Santa Clara Creek	1	2		(1)
Santo Domingo	Rio Grande	2	17	4,545	364
Santa Ana	do	1	5	1,226	170
Taos	Rio Lucero and Rio Pueblo	20	26.6	5,400	2,956
Tesuque	Rio Tesuque	4	5.3	811	93
Zia	Rio Jemez	1	6.5	1,229	None
Total				[2] 37,808	12,246
Total from Rio Grande only.				22,727	3,245

[1] Unknown. All the irrigable land on the east of the river, the area around Guachupangue (from Santa Clara Creek) and Espanola and north has been lost to the Indians.

[2] Shown by Robinson as 27,810.

The agricultural use of these pueblo lands is illustrated by tables 12 and 13, which comprise data supplied by the Bureau of Indian Affairs. Table 12 represents the year 1930 and five pueblos only, these being the only data along the lines shown which are available for the group. Table 13 is more comprehensive in providing a record of cropped acreages over a l- period for all but one of the 18 pueblos listed.

TABLE 12.—*Areas supplied with water from Rio Grande and tributaries by Pueblo Indians in Middle Rio Grande conservancy district, 1930* [1]

[In acres]

Pueblo	Irrigable area						Unirrigable area		
	Irrigated from surface and subsurface sources			Using subsurface water only					
	Cropped	Fallow	Total	Grasslands [2]	Bosque	Swamp and lake [2]	Riverside lands	River bed	Total area
Cochiti	449	373	822	226	394	0	332	690	2,464
Santo Domingo	940	757	1,697	401	1,124	151	205	980	4,558
San Felipe	1,168	338	1,506	349	543	26	225	1,180	3,829
Santa Ana	614	0	614	192	278	23	275	460	1,842
Sandia	698	42	740	1,107	1,425	104	171	350	3,897
Isleta	2,642	825	3,467	1,397	828	41	305	1,410	7,448

[1] District rights-of-way are not included.
[2] Used little water after 1930 because the land was drained.

A reasonable representation of the agriculture practiced is provided by the 1936 records of Taos, Acoma, Cochiti, Laguna, and Picuris pueblos. These, consolidated, show a total cropped area of 4,290 acres, distributed as follows: Alfalfa, 1,007 acres; beans, 39 acres; chili, 7 acres; corn, 1,977 acres; other cereals, 1,017 acres; native grasses, 13 acres; orchards and vineyards, 97 acres; gardens, 133 acres. Thus corn and other ›eals constituted 70 percent of the cropped area, and lfa 23 percent of the remainder.

Lower Valley

Although without as long an agricultural history, the valley areas below San Marcial have had farming characteristics similar to those of the Middle Valley. The modernization process now going on between Cochiti and San Marcial at the hands of the Middle Rio Grande Conservency District is not unlike that undertaken only 20 years ago in Mesilla and El Paso valleys through the medium of the United States Bureau of Reclamation.

Follett's investigation preceded the creation of the Bureau's Rio Grande project by a considerable period but paved the way for it in ways the recital of which is not essential to this discussion. His acreage tabulation continued below San Marcial and ended at the pass above El Paso, so including the area now submerged by the storage behind the Elephant Butte Dam, the two small valleys (Palomas and Rincon) between that structure and Selden Canyon, and Mesilla Valley complete. He discussed the agriculture of El Paso Valley but presented no statistical history of it. At the time of his survey, what is now Hudspeth County was a part of El Paso County. The present Hudspeth Conservation and Reclamation District of course did not then exist, its creation (1924) postdating that of Rio Grande project by several years.

Follett's descriptions of the areas between San Marcial and El Paso were as follows:

District No. 16, Rincon.—District No. 16 extends from San Marcial to old Fort Selden, at the upper end of the Mesilla Valley, and I have named it the Rincon district. Just below San Marcial the river swings to the westward, running around Fra Cristobal and Caballo Mountains, which form the western battlements of the Jornado del Muerto. The bluffs are near together and leave between them only small valleys until the river turns eastward again around the Caballos, toward Rincon. There the valley widens and four-fifths of the tillage in the district is found in an almost solid body, which is watered by two large ditches, the Colorado and Loma Padre.

This country was overrun by the Apaches until about 1860, and no settlements were made until 1862 or 1863. Then part of the small upper valleys were occupied, and a few years later the lower and larger valleys was settled and the Colorado ditch built. About 1884 some people took up the remaining small valleys. In 1892 a large number of families who had become disheartened by the continued failures of crops in the El Paso and the lower end of the Mesilla valleys left that country and, moving into the bosque above Rincon, took out the Loma Padre ditch, irrigating their first crop in 1893. The colony is now

TABLE 13.—*Cropped areas in Indian pueblos along Rio Grande and tributaries, New Mexico, by years, 1917 to 1936 (except 1919, 1920, and 1935)*

[In acres]

Year	Taos	Acoma	Cochiti	Isleta	Jemez	Laguna	Nambe	Picuris	Pojoaque [1]
1917	2,470	674	312	3,600	2,090	(1)	300	(1)	....
1918	2,263	(1)	402	2,099	2,080	(1)	(1)	(1)	....
1921	1,888	(1)	329	(1)	1,446	(1)	232	124	....
1922	(1)	697	341	(1)	1,473	1,897	224	124	....
1923	1,522	413	287	1,750	1,500	882	117	120	....
1924	(1)	551	293	2,500	1,528	901	239	(1)	....
1925	1,248	393	334	2,525	1,559	898	247	90	....
1926	1,173	863	329	2,400	1,405	(1)	81	105	....
1927	1,586	502	(1)	2,400	1,407	1,448	116	105	....
1928	1,623	485	360	2,400	1,407	1,385	115	106	....
1929	1,208	(1)	455	1,880	1,435	(1)	140	75	....
1930	1,211	582	449	2,642	1,439	1,855	117	82	....
1931	1,394	679	679	2,705	1,043	1,522	74	78	....
1932	1,959	749	584	3,040	1,134	1,650	270	112	....
1933	2,308	968	629	2,946	1,131	1,687	253	174	....
	1,505	950	468	2,435	1,001	1,503	191	134	....
	1,269	868	628	(1)	(1)	1,336	(1)	188	....

Year	Sandia	San Felipe	San Ildefonso	San Juan	Santa Ana	Santa Clara	Santo Domingo	Tesuque	Zia
1917	(1)	(1)	175	486	(1)	412	900	320	232
1918	208	(1)	(1)	412	95	505	860	(1)	246
1921	(1)	809	242	596	(1)	347	(1)	282	445
1922	862	819	173	462	600	301	730	262	343
1923	927	836	214	723	653	392	857	142	392
1924	927	915	238	847	377	472	463	308	389
1925	498	815	217	687	812	469	649	308	389
1926	763	1,168	81	500	1,003	215	755	61	286
1927	763	1,169	100	418	1,010	148	(1)	101	292
1928	713	1,168	100	473	674	232	1,411	98	292
1929	763	1,168	160	653	1,003	357	1,050	118	315
1930	763	1,168	162	586	1,003	336	940	131	350
1931	611	1,118	148	578	406	222	1,506	164	190
1932	671	1,012	222	703	587	267	1,397	197	164
1933	672	1,078	203	671	608	343	1,366	227	353
	622	1,030	131	628	582	212	1,179	217	230
	(1)	(1)	(1)	(1)	(1)	(1)	(1)	190	(1)

[1] No record available.

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flourishing, having raised a good crop in 1896 from an area of about 3,600 acres, all of which has been reclaimed from the bosque in the last 4 years.

The water supply of district No. 16 is rather precarious, but the irrigators are skillful and crops are raised with a small amount of water.

District No. 17, Mesilla Valley.—The Mesilla Valley extends from old Fort Selden to the pass, some 5 miles above El Paso. Together with the El Paso Valley below the pass, it forms the most fertile area along the whole river. The altitude of the Mesilla Valley is a little under 4,000 feet. The climate is warm, and fruit of remarkably fine flavor is raised in abundance.

I could not learn, however, that the valley was settled at an early day. Dona Ana was in existence in 1846, but was then new. It is probable that the Apaches prevented earlier Spanish or Mexican occupation.

The valley filled up rapidly after 1846. In 1865 some 35,000 acres were in cultivation. In that year the river made a change of channel, breaking up the ditches, and the acreage decreased somewhat. The year of 1879 was one of poor water supply. As a result of this, the Picacho ditch, watering some 2,500 acres west of the river, about opposite to Las Cruces, was abandoned. A considerable area under the Dona Ana ditch was also soon after abandoned, the land watered by it decreasing from 7,000 acres in 1882 to 4,600 acres in 1888. All of this 2,400 acres still remains idle except some 800 acres, which a man named Schiller has colonized and is irrigating with water pumped from wells. This area is not included in my estimate of acreage.

In 1884 a severe flood started another change of channel near the lower end of the valley, and the high waters of 1885 and 1886 completed the work. This change of channel cut into several pieces La Union ditch, previously watering some 4,000 acres, and caused the temporary abandonment of nearly all of the land. In 1892 the people took out a new ditch on the east side of the river, the old one having been on the west side, and are now reclaiming and cultivating their old land.

The changes of acreage since 1880 have been so many in the Mesilla Valley that I append to the list of ditches for the district a table showing the probable acreage watered each year since 1880 by the individual ditches.

Table 14 shows Follett's estimates of acreages irrigated between San Marcial and El Paso for the years ending with 1896.

Follett's description of El Paso Valley (the Texas part of which roughly corresponds to the portion of the Rio Grande project below El Paso) was as follows:

This valley was occupied by the Spaniards over 300 years ago. In 1600 Paso del Norte (now called Juarez) was an important town, and records are in existence over 280 years old which refer to the Acequia Madre of Paso del Norte as being then in use.

Owing to the limited time at our disposal, and also to the fact that the use of water which had supposedly injured this valley was all, of course, above it, we did not extend our detailed examination below El Paso. From all I could learn, however, from old inhabitants, I should judge that in former years some 40,000 acres of land were tilled in this valley, more than half of which was on the Mexican side of the river. * * *

* * * I am unable to give you an estimate as to the acreage now cultivated in this valley, but can safely say that it is considerably less than the amount formerly tilled. * * *

Previous discussions in this report have shown early Federal census statistics for Dona Ana County, which now includes the greater part of the area in New Mexico

TABLE 14.—*Areas irrigated in Rio Grande drainage basin from San Marcial, N. Mex. to El Paso, Tex., as reported by Follett (20)*

[In acres]

Year:	Area
Prior to 1880	37,350
1880	34,850
1881	34,850
1882	34,850
1883	34,450
1884	34,390
1885	27,690
1886	27,290
1887	27,340
1888	27,440
1889	27,590
1890	28,140
1891	28,190
1892	28,990
1893	30,390
1894	32,490
1895	35,600
1896	36,800

below Elephant Butte Dam. Ignoring changes of boundaries, they were, for improved land in farms: 1860, 14,490 acres; 1870, 17,184 acres; 1880, 25,786 acres (24,246 acres "tilled, including fallow and grass in rotation, whether pasture or meadow", and 1,540 acres "permanent meadows, permanent pastures, orchards, and vineyards"). In 1890 approximately 15,550 acres was reported as "improved" in Dona Ana and Sierra Counties. The two counties reported 29,906 acres improved and 19,890 acres irrigated (in 1899). Corresponding figures for 1910 were 37,415 acres and 35,869 acres, respectively; for 1920 the acreages were 49,876 and 60,756. The census total for irrigated land in the two counties in 1929 was 81,726 acres; in 1934 the census reported 67,543 acres in "irrigated land from which crops were harvested."

The early census figures for El Paso County farms were as follows: 1860, improved land, 4,456 acres; unimproved, 7,150 acres. In the 1870 census report, only 50 acres of improved land is shown. In 1880 the "improved" total was 14,024 acres, comprised of 10,587 acres "tilled, including fallow and grass in rotation whether pasture or meadow", and 3,437 acres "permanent meadows, permanent pastures, orchards, and vineyards." Texas was not included in the 1890 and 1900 irrigation censuses, but in 1910 El Paso County reported 16,772 acres of improved land in farms and 23,308 acres irrigated (in 1909). The corresponding 1920 figures were 30,119 acres and 20,259 acres. The irrigated acreage for 1929 was 65,442 acres, and in that census Hudspeth County reported 14,010 acres irrigated. "Irrigated land from which crops were harvested" in 1934 was 51,518 acres for El Paso County, and 12,093 acres for Hudspeth County.

Bureau of Reclamation estimates for areas irrigated in Hudspeth County for the years 1920 to 1926 are a

TABLE 15.—*Irrigated areas in Rio Grande project, New Mexico, and Texas, as reported by United States Bureau of Reclamation, 1922 to 1935*

[In acres]

Year	New Mexico irrigated area					Texas irrigated area					Rio Grande project irrigated area				
	Alfalfa	Cotton	Miscellaneous	Not cropped	Total	Alfalfa	Cotton	Miscellaneous	Not cropped	Total	Alfalfa	Cotton	Miscellaneous	Not cropped	Total
1922	18,546	2,633	24,703	3,114	48,996	14,766	7,278	11,119	2,003	35,224	33,312	9,909	35,822	5,177	84,220
1923	18,768	12,961	16,652	4,014	52,415	12,932	17,115	8,546	1,363	39,956	31,700	30,096	25,198	5,377	92,371
1924	14,462	26,599	12,942	5,390	59,393	10,990	32,122	6,000	7,486	56,598	25,452	58,721	18,942	12,876	115,991
1925	13,141	38,960	12,066	3,291	67,458	10,018	42,413	5,201	5,821	63,453	23,159	81,373	17,267	9,112	130,911
1926	14,652	41,864	13,953	6,995	77,464	11,181	41,473	5,735	6,670	65,059	25,833	83,337	19,658	13,665	142,523
1927	15,140	40,229	16,534	2,139	74,042	13,550	38,686	9,592	1,683	63,511	28,690	78,915	26,126	3,822	137,553
1928	10,929	55,048	10,334	1,351	77,662	9,622	49,121	4,544	2,375	65,662	20,551	104,169	14,878	3,726	143,324
1929	11,236	56,942	9,754	843	78,775	9,109	48,463	4,250	3,580	65,422	20,345	105,425	14,004	4,423	144,197
1930	13,730	50,610	13,267	842	78,449	11,904	44,255	5,941	4,058	66,158	25,634	94,865	19,208	4,900	144,607
1931	16,017	43,922	17,696	1,579	79,214	12,753	39,416	7,573	5,333	65,075	28,770	83,338	25,270	6,912	144,290
1932	15,988	40,110	21,520	1,684	79,302	14,792	30,946	11,175	1,234	58,147	30,780	71,056	32,695	2,918	137,449
1933	13,960	40,140	23,895	1,562	79,557	12,712	32,514	13,288	1,135	59,649	26,672	72,654	37,183	2,697	[1] 139,206
1934	14,269	33,880	20,643	3,593	72,385	13,007	30,038	11,985	1,677	56,707	27,276	63,918	32,628	5,270	[2] 129,092
1935	12,326	32,004	17,087	4,008	65,425	13,910	28,640	10,691	1,409	54,650	26,236	60,644	27,778	5,417	[3] 120,075
1936	15,476	44,513	14,290	4,163	78,444	14,822	36,832	5,710	2,994	60,358	30,300	81,345	20,000	7,157	138,802

[1] Cropped area includes 13,038 acres of cotton that was plowed up after having been planted, as a result of U. S. Government cotton reduction program.
[2] 28,093 acres of cotton land rented to U. S. Government under cotton reduction program; of this area 11,946 acres was planted in other crops and the remainder was left idle.
[3] 29,663 acres of cotton land rented to U. S. Government under cotton reduction program; of this area 9,992 acres was planted to other crops and the remainder left out of production.

follows: 1,011 acres in 1920, 1,120 acres in 1921, 6,153 acres in 1922, 6,126 acres in 1923, 8,964 acres in 1924, 10,800 acres in 1925, and 12,540 acres in 1926.

Irrigated area statistics for the Rio Grande project have been assembled yearly since 1922 by the Bureau of Reclamation, and figures pertinent to this discussion, as supplied by Project Superintendent Fiock, appear in table 15.

Especially notable in table 15 is the statistical history of cotton and alfalfa, the heavy preponderance of those crops in the project's agriculture, and the agreement of their acreage figures with the corresponding Federal census figures. The alfalfa acreage has been fairly constant, but the cotton acreage, while in 1935 substantially lower than its 1930 peak, has assumed an advanced lead over all other crops since as recent a year as 1922. In fact, only 5 years before that date cotton was unimportant in its proportion of the project's cropped acreage. While showing by no means the stable position held by alfalfa—its fluctuations being, in fact, emphatic—cotton, nevertheless, has been the project's characteristic crop for the past dozen years, and while the alfalfa acreage supports a local hay and dairy industry, much of it now has its principal importance in the crop rotation program built around cotton, and its migrations have accorded, in some degree, with those of cotton.

The close agreement between Bureau of Reclamation acreage statistics for Rio Grande project and census figures for Sierra, Dona Ana, and El Paso Counties appears in the following comparison. The figures are acres.

Crop and source of data	1924	1929	1934
Cotton			
Bureau of Reclamation	58,721	105,425	63,918
Bureau of the Census	62,019	107,532	64,231
Alfalfa			
Bureau of Reclamation	25,452	20,345	27,276
Bureau of the Census	25,634	22,541	25,634

As in the case of the Rio Grande project, the preponderant crop in Hudspeth County is cotton. Thus three-fourths of the 1934 acreage in "irrigated land in which crops were harvested" (12,093 acres) was in cotton; 10 percent was alfalfa, and most of the remainder was in other hay and forage crops. In 1929 almost the whole irrigated acreage was in cotton.

Irrigation Works

The irrigation plan of the Rio Grande project involves the storage of flood waters of the Rio Grande in a reservoir controlled by Elephant Butte Dam, about 12 miles west of Engle, N. Mex., and the diversion of water from the river about 24 miles below for watering lands in Rincon Valley; about 60 miles below for the irrigation of the upper Mesilla Valley under the Leasburg diversion dam; about 80 miles below for the irrigation of the lower Mesilla Valley under the Mesilla Dam; and about 120 miles below for supplying water to lands in El Paso Valley and furnishing 60,000 acre-feet per annum for use on land in El Paso Valley on the Mexican side of the river. The United States claims all waste, seepage, spring, and percolating water arising within the project. All irrigation works required for Palomas and Rincon valleys were new; those for the Mesilla Valley include a diversion dam and several miles of old canals, as well as a diversion dam 5½ miles southwest of Las Cruces and many miles of reconstructed canals leading from it. The distributaries in El Paso Valley likewise supplemented and improved previously existing canals. (Plates 1, 18–21, incl.)

Under construction is a new storage unit below Elephant Butte Dam, which will submerge the area now farmed between the dam site at Caballo and Elephant Butte Dam. Caballo Dam has several purposes in addition to that of storage of previously uncontrolled flood waters, among them being regulation of present storage to the possible future extent of permitting the use of that storage for power development. (Pl. 18.)

Also about to be constructed is a new diversion dam above the present international boundary dam, and the necessary appurtenant canals, by which the 60,000 acre-foot delivery to Mexico will be made more accurately than is possible with the structure now used. (Pl. 20.)

An extensive system of drains was constructed between 1916 and 1920, to serve practically the entire area. Drainage and waste waters leaving the project are delivered to the Hudspeth County district, co... stituting the principal agricultural supply for that enterprise notwithstanding their high salinity. (Plates 19–22, incl.)

An elaborate channel-straightening program betw... El Paso and Fort Quitman, in progress for several years under the direction of the International Boundary Commission, is expected to be extended to the Mesilla Valley section. In the section below El Paso this will involve some shifting of jurisdiction between the two nations, and has already had the effect, although in a relatively unimportant degree, of removing or withholding certain lands from productive use in order to facilitate the Commission's operations. This status is temporary, the expectation being that such of these areas as are of agricultural value will be put to use as soon as the progress of the Commission's program permits. (Plates 21–22.)

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PART III

SECTION 2.—SOME CONDITIONS AFFECTING USE OF WATER

Several factors influence the use of water in irrigation besides evaporation and the moisture requirements of plants which have separate attention elsewhere in this report. Difficulties of distribution, vagaries of climate, soil characteristics, and differing methods of applying water are among them. In the following paragraphs these conditions are described in such detail as seems necessary to provide a general understanding of irrigation needs.

San Luis Valley

Large-scale farming is a striking feature of the agriculture in San Luis Valley. In 1930 the average size of the irrigated farms[1] in the seven counties which include the Colorado portion of the Valley was almost 400 acres (398 acres), and more than half this average area was irrigated. The list below shows how the irrigated farms of the Valley counties were grouped in the 1930 census reports:

	Number of irrigated farms
Under 3 acres	19
3 to 9 acres	197
10 to 19 acres	181
20 to 49 acres	435
50 to 99 acres	427
100 to 174 acres	948
175 to 259 acres	296
260 to 499 acres	556
500 to 999 acres	204
1,000 to 4,999 acres	131
5,000 to 9,999 acres	11
10,000 acres and over	5

Thus the predominant size (100 to 174 acres) is less than the average size (398 acres), and there are more farms of less than 100 acres each than there are in the predominant size group; conversely, however, there are almost as many larger than the predominant size, and the group next in number to that size group is the one inclusive of farms ranging from 260 to 499 acres each.

Such large farms require capacious distributaries and liberal heads of water. Farming operations are typified by the extensive use of machinery, although horses are also widely used.

[1] A "farm", for census purposes, is all the land which is directly farmed by one person, either by his own labor alone or with the assistance of members of his household or hired employees. In 1930 the enumerators were instructed not to report as a farm any tract of less than 3 acres unless its agricultural products in 1929 were valued $250 or more.

Climate

San Luis Valley's climate is marked by almost continuous sunshine, small rainfall, extremes of temperature, and a high wind movement. Precipitation varies widely from season to season and at different places. On the basis of long-time averages farmers can depend upon only about 7 inches of precipitation, but the records producing this average include figures more than twice its amount, as well as others of less than half. However, the heaviest rainfall of the year occurs in July and August, when it is most needed by crops. In the usual summer these rains are of little direct benefit to the crops, but the streams are flooded by run-off from adjacent hills and so sometimes provide water for irrigation for a few days. In exceptional years such as 1936, the summer precipitation in the Valley itself may be heavy enough at times to benefit the crops directly.

The least agreeable feature of the Valley's climate is the high winds occurring in the spring. Their general direction is northeastward, and they blow steadily for days at a time. In some of the lightest soils, newly planted crops may be damaged severely by winds of this nature.

Table 16 shows that over a period of 37 years the average growing season at the Garnett station was only 95 days. July 7 was the latest date of killing frost in the spring and August 13 the earliest date of killing frost in the autumn. The average length of growing season, for the four stations shown in the table, was 108 days, with the average date of last killing frost in the spring, May 30, and average date of first killing frost in autumn, September 19.

TABLE 16.—*Dates of killing frost and length of growing season as recorded at various United States Weather Bureau stations in San Luis Valley, Colo.*

Station	Length of record in years	Average date of last killing frost in spring	Average date of first killing frost in autumn	Average length of growing season, days	Latest date of killing frost in spring	Earliest date of killing frost in autumn
Del Norte	14	May 28	Sept. 24	119	June 19	Sept. 8
Garnett	37	June 9	Sept. 12	95	July 7	Aug. 13
Manassa	29	June 6	Sept. 13	99	June 20	Aug 2
Saguache	35	May 28	Sept. 25	120	June 26	Aug. 28

Table 17 shows, from all records available, that the maximum temperature is 102° (at Saguache Weather

Bureau station) and the lowest temperature —41° (at Garnett station). The seasonal precipitation was 15.64 inches in 1923 at Saguache station; but in 1917 only 2.64 inches was recorded at Manassa station, to set the minimum record.

TABLE 17.—*Mean annual temperatures and precipitation as recorded at various United States Weather Bureau stations in San Luis Valley, Colo.*

Station	Length of temperature record in years	Temperature in degrees Fahrenheit					Length of precipitation record in years	Seasonal precipitation in inches		
		Average maximum	Average minimum	Mean	Maximum	Minimum		Maximum	Minimum	Average
Del Norte	14	58.1	26.0	42.5	85	−26	13	12.39 (1929)	4.76 (1934)	8.19
Garnett	35	59.0	23.0	41.0	92	−41	45	10.37 (1895)	3.54 (1900)	6.77
Manassa	30	58.3	25.1	41.7	92	−33	30	11.57 (1914)	2.64 (1917)	6.81
Saguache	37	60.7	27.1	43.0	102	−27	37	15.64 (1923)	2.88 (1896)	8.89

7.66"

Soils

The soils of part of the Valley have been described as follows by the United States Bureau of Chemistry and Soils (77):

All the upper part of San Luis Valley was at one time a great lake, and the soils must therefore be classed as derived from lacustrine deposits. Since the subsidence of this lake the immediate surface has in many places been modified by the streams issuing from the mountains onto the plain and by the action of the winds, while moisture and irrigation have done much to decompose the coarse sands, wherever standing water has accumulated or moisture has been continuously present in the soil.

As a result of these changes, five types of soil are found in the area. The following table names these soils and gives the area of each:

Areas of different soils

Soil	Acres	Percent
San Luis sandy loam	196,992	49.0
San Luis sand	136,960	34.2
Rio Grande sandy loam	35,776	8.9
Rio Grande loam	23,104	5.7
San Luis loam	9,088	2.2
Total	401,920	

All the types, except the Rio Grande sandy loam, are gravelly. Even this soil is underlain at from 2 to 4 feet by gravel, and this deposit outcrops in places to form small gravel patches. Thus the soils of the valley may in a general way be called coarse, gravelly, sandy soils to distinguish them from soils which have a high clay content or are free from gravel or very coarse sand.

The San Luis sandy loam covers an extensive area. This is a coarse, reddish-brown soil. It carries considerable gravel and is underlain at depths of 1 to 3 feet by a coarse gravelly subsoil. It irrigates readily and drains well except on the lower lands.

As indicated by the foregoing quotation, San Luis Valley sand represents a little more than one-third of the entire area. It is a light, porous, incoherent lea. soil consisting mainly of disintegrated volcanic rock. At depths ranging from 2 to about 4 feet it is underlai by a gravelly porous subsoil. It drains well, does : puddle nor become sticky when wet, and requi frequent irrigation to produce crops. The lower lands of this type are waterlogged.

The river bottom soils vary from a sandy loam to a heavy clay loam, and all are underlain at depths of a few feet by a coarse gravelly subsoil. The sandy loam occurs widely along the river bottom and is one of the best of the Valley soils. These soils are largely given over to hay meadows, the yearly flooding of which has kept them fairly free of alkali. All but the heaviest drain readily.

Agricultural Practice [1]

In most of the water districts of the valley, little system is necessary in handling the water. The spring flood rises rapidly but it also recedes rapidly and the stream is soon dry at most headgates. When this stage is reached, the commissioner divides the available water among the few early priorities which can be satisfied, and watches the gates above to see that no water is diverted unlawfully.

On some of the streams the flood recedes more slowly and the headgates must be closed, but it is customary to shut even these streams off in blocks including priorities of from 1 to 5 years. There is often consid able daily fluctuation in the flow of the Rio Gran during the flood period.

Natural conditions are so good that the cost of maintaining ditches is relatively low. Most ditches are built on straight lines. There is almost no sidehill construction and very little fluming. Breaks are rare, water seldom being carried in the ditches above the level of the adjacent land. Ditches which must pass through marshes on low gradients are subject to loss of capacity through plant growth, and no satisfactory way has been found to cope with this condition.

When water is plentiful in the spring its distribution after it is in the canal does not present difficulties. When it becomes scarce some form of rotation is resorted to, either between laterals or between "divisions" of the ditch. On ditches where division boxes are used the supply is prorated officially until exhausted,

[1] Discussion under this heading is largely an abstract and condensation of descriptions by R. G. Hemphill, corrected to reflect present conditions. Mr. Hemphill, now deceased, in 1912 and 1913 made an exhaustive survey of irrigation conditions and practices in San Luis Valley for the Department of Agriculture. (The irrigation work of the department, then conducted under the supervision of the Office of Experiment Stations, was designated "Irrigation Investigations". Later this and other agricultural engineering activities were grouped in a division of agricultural engineering which, at first established in the Bureau of Public Roads, in 1931 became the Bureau of Agricultural Engineering. The irrigation studies now are conducted by the Bureau's Division of Irrigation, and in this report, to avoid confusion, the Bureau is considered to have had an existence concurrent with that of the continuous irrigation investigations.)

though the farmers frequently make exchanges among themselves to get usable heads.

The length of the irrigation season varies with the [illegible] water is available. Under ditches which may divert at all times irrigation usually begins about April 15 and continues until the middle of October, making a season of approximately 180 days. Fall irrigation is not widely practiced. Under ditches holding late rights the season is from May 1 to July 1, or an average of 60 days which may be lengthened a few days by later floods. However, along Saguache Creek where hay must be cut about July 1 to avoid foxtail, irrigation is begun as early as March 15 to thaw the soil and give the meadows a quick start, and where fall irrigation is practiced water is carried as late as November 1 in a number of ditches.

Methods of Irrigation.—Various methods are used in applying water to the land. Flooding is most widely used, with subirrigation the next most extensive method. However, subirrigation is confined largely to areas under ditches diverting from Rio Grande. The furrow method is also used widely but principally for potatoes, sugar beets, vegetables and crops on land too steep for flooding. Borders and checks are employed on a limited acreage.

Subirrigation consists in raising the ground-water level by seepage from small ditches placed at intervals over a field so that the surface soil will be moistened by capillarity.

The soil best adapted to this method is the porous sandy loam which is underlain by an impervious stratum. Heavy soils are not porous enough to be subirrigated successfully. Best results are obtained where the slope of the land is from 5 to 10 feet per mile. The method has been successful with most crops.

The seed bed is prepared in the usual manner and the crop planted. The field ditches are made immediately either with plow and V, or with a ditching plow, which is the more economical and makes an even, loose ditch through which water seeps readily. The proper location of the ditches can be determined only by trial. Most of the land in the Valley has a uniform, gentle slope, and the custom is to run the ditches parallel to the section lines in the direction having the least slope. They are spaced at intervals varying from 50 to 250 feet according to the character of the soil, the depth of the normal water table, and the amount of irrigation in the neighborhood affecting the water table.

At the proper time, which is usually when the ditches are finished or when the water becomes available, irrigation is begun by filling the field ditches as full as possible without flooding at any point or wasting over the blind lower end. The flow turned into each ditch is then regulated to compensate the amount of seepage from it. This seepage water flows downward rapidly and fills the subsoil to the point where moisture is drawn to the surface. When the surface becomes moist the flow in the field ditches is cut down so that only enough water flows to maintain the moist condition of the surface soil. The time required to "raise the sub" varies from 10 days to 6 weeks. The cost of subirrigation is very low.

There are many modifications of the method. Where the soil is thin, or leveling is impracticable for any reason, the field ditches are carried along the ridges. In the river bottoms, sloughs or old channels are dammed and kept full of water during the season. Drains are also dammed during the irrigation season to raise the water level. In other cases small reservoirs have been built to catch excess water, which is then allowed to seep from them.

Under ideal conditions, this method of irrigation could hardly be improved upon, but actual practice has developed a number of faults. The greatest objection is that frequently the farmer on the lower lands is drowned out. Control of the moisture in the surface soil within narrow limits is impossible. Under this system irrigation becomes a community, rather than a private, affair. It concentrates alkali on the surface quicker than any other system of irrigation.

Its chief advantages are simplicity and cheapness. The ease with which large fields can be irrigated by one

FIGURE 67.—Subirrigation ditch in potato field near Monte Vista, Colo.

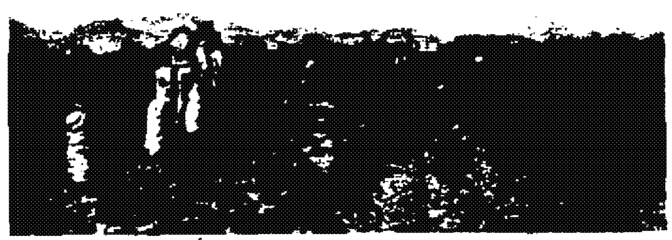

FIGURE 68.—Digging potatoes near Monte Vista, Colo.

FIGURE 69.—Stacking native hay in San Luis Valley.

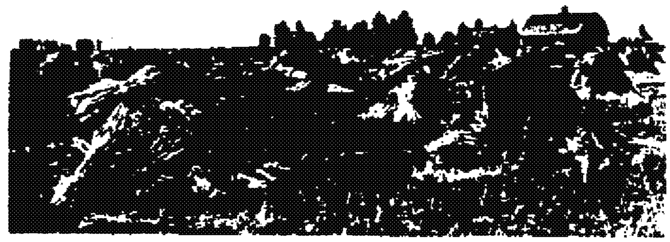

FIGURE 70.—Grain field in San Luis Valley.

man is another advantage. Under ditches with doubtful water supplies crops are often carried through to maturity by the water in the subsoil when the ditches fail early.

Most of the land reclaimed by drainage was once subirrigated; much of it is now being flooded. Many farmers in the subirrigation districts are convinced that better crops are raised by that method than any other, but facts upon which a comparison can be based are few. A number of ranches in the Valley are either flooded or subirrigated and as a general thing subirrigation is preferred to flooding. However, the question of cost enters here and the chances are that cheapness and a minimum of trouble are the factors which determine the use of subirrigation.

The condition of much of the subirrigated land which is feeling the effects of the gradual rise of the water table and the collection of alkali on the surface, could probably be improved by a change to surface irrigation.

The popular way of irrigating the large areas of pasture and native hay is the "wild flooding" method common throughout the Rocky Mountain States. Water is taken to the high point in the field and turned loose, and to direct it small ditches are thrown up at various positions in the field. The general custom is to keep the water running as long as it is available; or if hay is to be made, it is turned off a week or 10 days before the time for cutting. This method is primitive and wasteful. It is fortunate much of the water used in this manner soon finds its way back to the streams.

The method of flooding from field ditches used in the Valley does not differ from the practice elsewhere. Small ditches are plowed in the fields at intervals of 50 to 150 feet and water is turned on the field from them by cutting the banks. In a few cases permanent ditches equipped with wooden check boxes and gates are maintained, but on most farms the field ditches are plowed out each year and then filled in before the harvest. Dirt dams and canvas dams are used to check the water up to the cut-out.

Where potatoes and beets are not subirrigated they are watered by the common furrow method. In localities around the edge of the Valley where the land slope is too high for effective flooding, furrow irrigation is used for all crops except hay. Furrows are plowed about 3½ feet apart and a small head is run in each for from 12 to 36 hours. The length of the furrows varies from 200 feet to ¼ mile. Sometimes in irrigating crops in rows only alternate furrows are used.

Other methods of irrigation are used only to a limited extent. A few examples of the border method and the square and contour check methods may be found, but most of the checks were built for washing alkali out of the soil.

Middle Valley

Marked differences appear in a comparison of New Mexico farms and farming with those of San Lu Valley.

Size of Farms

Such differences are emphatic in the matter of size of farms. Whereas large-scale farming is the common type in San Luis Valley, small farms are the rule in Middle Rio Grande Valley. The average size of the San Luis irrigated farm is 398 acres; the corresponding average for the entire group of Rio Grande Basin counties above San Marcial is 95 acres.

Size of farms	Number of irrigated farms	
	Rio Arriba, Taos, and Santa Fe Counties	Bernalillo, Sandoval, Socorro, and Valencia Counties
Under 3 acres	3	7
3 to 9 acres	1,280	1,196
10 to 19 acres	930	943
20 to 49 acres	703	632
50 to 99 acres	223	213
100 to 174 acres	172	100
175 to 259 acres	47	31
260 to 499 acres	30	30
500 to 999 acres	25	30
1,000 to 4,999 acres	38	13
5,000 to 9,999 acres	7	3
10,000 acres and over	3	8
Total	3,461	3,209

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Even this comparison is misleading, however, as the N. Mexico average is distorted in somewhat greater e than is the case with the San Luis figure, by atively few ranches of great size, some of them in sections of the counties not strictly within the Valley area. The facts are brought out more effectively by the list above, which is based on the 1930 census reports.

From the foregoing list it appears that in the northern group of counties more than one-third (37 percent) of the farms are less than 10 acres in size; nearly three-fifths (58 percent) have less than 20 acres. Somewhat more than four-fifths are smaller than the 95-acre Valley average. The predominant size, in fact, is represented by the 3-to-9-acres group.

In the four lower counties, which include the Middle Rio Grande Conservancy District, the comparisons are similar. Nearly two-fifths (38 percent) of the total number of irrigated farms have less than 10 acres each. More than two-thirds (67 percent) have less than 20 acres. Probably more than nine-tenths are smaller than the 95-acre Valley average. As in the case of the upper counties, the predominating size is represented by the 3-to-9-acres group.

Climate

While the climate continues distinctly arid through- the New Mexico portion of the Valley, and in the hern part of the State retains the general characteristics described for the San Luis region, the reducing altitudes introduce modifications, so that a new set of conditions mark the Middle Valley areas. There the growing season averages 190 days. Frequent rains occur in the hot summers, producing an average precipitation of 5 inches between April 1 and September 30. Humidity is low. Prevailing winds are from the west and southwest.

Table 18 shows the pertinent facts relating to temperature and precipitation at four stations in the Middle Valley.

TABLE 18.—*Mean annual temperatures and precipitation in the Middle Rio Grande Valley, N. Mex.*[1]

Station	Length of temperature record in years	Temperature in degrees Fahrenheit					Length of precipitation record in years	Annual rainfall in inches		
		Mean maximum	Mean minimum	Mean	Maximum	Minimum		Maximum	Minimum	Average
Albuquerque	33	69.3	41.8	55.5	104	−10	65	16.30	3.29	8.21
Bernalillo [2]	6	70.7	39.6	55.3	102	−13	13	11.49	5.64	8.16
Los Lunas	63	71.6	37.4	54.5	106	−26	44	16.37	2.15	8.62
Socorro	44	73.8	40.8	57.3	108	−16	46	22.40	4.12	10.27

[1] Based on U. S. Weather Bureau records.
[2] Station discontinued in May 1924.

In table 19, the length of growing season is shown for three stations in the Middle Valley area.

TABLE 19.—*Length of growing season, Middle Rio Grande Valley, N. Mex.*[1]

Station	Length of record, years	Average date of last killing frost in spring	Average date of first killing frost in fall	Average length of growing season, days	Latest date of killing frost in spring	Earliest date of killing frost in fall
Albuquerque	39	Apr. 13	Oct. 26	196	May 1	Sept. 17
Los Lunas	43	Apr. 18	Oct. 19	184	May 13	Sept. 22
Socorro	34	...do...	Oct. 21	186	May 6	Sept. 27

[1] Based on U. S. Weather Bureau reacords.

Surveys have not been made by the Bureau of Chemistry and Soils in the Valley areas above Cochiti, but the following paragraphs, abstracted from a report by that bureau (79), describe the soils of "the Middle Rio Grande Valley area":

The soils of the area are classed in three distinct groups according to their topographic position—those representing the material of the uneroded mesas or upland desert plains, those occupying the mesa slopes along the valley margin, and those of the valley floor. * * *

The soils of the mesa slopes have been identified as members of the Anthony series. They occur along the eroded slopes of the high plains bordering the valley, and are usually separated from the higher uplands by bluffs or an eroded escarpment. * * *

The material forming this group of soils consists predominantly of reworked material of the upland formation which has been assorted to some extent and deposited by surface waters as alluvial and colluvial fan and foot-slope deposits over the slopes below. To this in some localities there has been added a small amount of wind-blown material, removed from the Rio Grande bed during periods of low water. * * * The soils of the Anthony series are grayish brown or light brown to reddish brown in color, a reddish tint usually being perceptible. The subsoils to a depth of 3 feet or more are generally similar in color and character to the surface material. * * *

The series is distinctly arid and supports only a stunted growth of scrubby mesquite and other characteristic desert vegetation. * * *

The soils forming the valley floor have with two exceptions been recognized under the Gila series. The material giving rise to the Gila soils consists mainly of sediments brought down from regions to the north by the Rio Grande and deposited over the valley during periods of high water. It is derived from a wide variety of rocks, including sandstones, limestones, and metamorphic altered and igneous rocks, which may or may not contain conspicuous amounts of quartz-bearing minerals. * * *

To this has been added small amounts of alluvial wash and of wind-blown material from the mesa slopes. * * *

Numerous old abandoned river channels occur throughout the valley. Sometimes clay deposits several feet deep occur over limited areas of these channels, but most frequently the coarser material forming the old river beds is covered with only a few inches of heavy soil. The alluvial soils of the valley are thus still in process of formation. * * *

Considerable sedimentary material is also deposited each year over the entire irrigated portion of the valley by irrigation water. During the long periods of irrigation these deposits have increased until in places they are several feet deep.

Table 20 names and shows the relative extent of each of the several soil types in the Middle Rio Grande area. The distribution shown is believed to be fairly suggestive of that applying to the entire Middle Valley as considered in this report, although many variations are to be found throughout the larger areas.

TABLE 20.—*Areas of different soils in the Middle Rio Grande area, New Mexico*

Soil	Acres	Percent
Gila fine sandy loam	46,336	26.4
Anthony gravelly sand	24,576	14.0
Gila loam	24,384	13.9
Riverwash	18,688	10.7
Gila clay	14,272	8.1
Gila clay loam	11,584	6.6
Anthony fine sand	11,072	6.3
Anthony sand	10,944	6.2
Anthony silty clay loam	4,160	2.4
Anthony fine sandy loam	2,944	1.7
Gila sand	2,752	1.6
Brazito fine sand	2,048	1.2
Tijeras fine sandy loam	1,600	.9
Total	175,360	----------

Agricultural Practice and Crop Adaptability

Throughout the successive Valley areas from the Colorado line to San Marcial, agriculture still centers, as it has for many years, upon the hay and cereal (including corn) crops. The 1929 Federal census returns showed these as comprising by far the greater part of the cropped areas in both the section ending approximately at White Rock Canyon, and the Middle Valley area from Cochiti to San Marcial; in both cases the position of each of these two leading groups of cropped acreages was not greatly different, the cereals holding a slight advantage in each.

The preponderance of these crops does not mean that others are not important. In point of acreage, the legumes—mostly beans—are distinctly prominent, although not as much now as 10 or 15 years ago. Vineyards and orchard fruits, such as apples, pears, peaches, European and native plums and sour cherries, are raised throughout the area, and while of limited and localized importance as commercial crops, have nevertheless a well-established place in the Valley's agriculture. Truck gardening is rapidly becoming a profitable industry, especially around Albuquerque.

Water for irrigation from ditches is available between March 1 and November 15, so that no winter irrigation is practiced. The irrigation methods used are the flooding, border, and check methods for alfalfa; flooding for vega (meadow) land; and border, check, furrow and flooding methods for the other crops. Approximately 310,000 acre-feet of water is used annually in the Middle Rio Grande Conservancy District.

Lower Valley

Farms in the counties which include the Rio Grande project and the irrigated lands below it average somewhat larger (151 acres) than those above it in New Mexico, but are somewhat smaller than the San Luis Valley farms. As in the case of both other Valley tions, however, the average size is misleading, as size-group which includes that average comprises only about 9 percent of the total number of farms. The predominating size-group in each of the four counties (Sierra, Dona Ana, El Paso, and Hudspeth) is the one ranging from 20 to 49 acres, and the farms which are smaller than those inclusive of the average size comprise more than four-fifths (83 percent) of the total number.

The 1930 distribution of the irrigated farms in the Lower Valley is shown in detail below:

	Number of irrigated farms
Under 3 acres	90
3 to 9 acres	634
10 to 19 acres	711
20 to 49 acres	1,015
50 to 99 acres	508
100 to 174 acres	318
175 to 259 acres	101
260 to 499 acres	75
500 to 999 acres	42
1,000 to 4,999 acres	37
5,000 to 9,999 acres	6
10,000 acres and over	6

Climate

The climate of the Lower Valley is characteristica arid, with cool nights but high temperatures during day. The mean relative humidity is low. There a very few cloudy days and but little rainfall. These factors contribute to a high evaporation rate.

The average annual rainfall is only 8 to 10 inches per year, about two-thirds of this coming during the growing season. Only a relatively small proportion of this rainfall becomes of value for crop production, however, since so much of it comes in numerous light showers that cannot penetrate far into the soil and is soon lost by evaporation.

Records taken over a period of 43 years to 1936 exclusive at State College give an average length of growing season of 200 days as shown in table 21, where frost data for three different locations along this section of the Rio Grande over a long period of years are summarized.

TABLE 21.—*Length of growing season, Lower Rio Grande Valley, New Mexico, and Texas*

Station	Length of record, years	Average date of last killing frost in spring	Average date of first killing frost in fall	Average length of growing season, days	Latest date of killing frost in spring	Earliest date of killing frost in fall
Elephant Butte Dam, N. Mex.	33	Apr. 2	Nov. 8	218	May 28	Oct. 17
State College, N. Mex.	43	Apr. 10	Oct. 28	200	May 13	Oct.
El Paso, Tex.	48	Mar. 20	Nov. 15	241	Apr. 28	Oct

In table 22 long-time records are averaged to January 1, 1936, for temperatures and precipitation at three stations. Average annual evaporation is over 10 times the average annual precipitation and irrigation is an absolute necessity to produce good crops.

TABLE 22.—*Mean annual temperatures and precipitation at Elephant Butte Dam and State College, N. Mex., and El Paso, Tex.*

Station	Length of temperature record in years	Temperature in degrees Fahrenheit					Length of precipitation record in years	Annual rainfall, in inches		
		Mean maximum	Mean minimum	Mean	Maximum	Minimum		Maximum	Minimum	Average
Elephant Butte Dam, N. Mex.	38	73.88	45.00	59.77	109	−2	47	16.89	3.53	9.92
State College, N. Mex.	37	76.14	43.98	60.10	106	−8	50	17.09	3.49	8.58
El Paso, Tex.	50	76.2	50.8	63.7	106	−5	57	18.29	2.22	8.90

Soils

The soils of the valley are almost entirely of alluvial deposit classed as of the Gila series, previously described. The exceptions are numerous small and scattered areas of wind deposit described as Brazito fine sand. Bordering the valley the soils are classed as of the Anthony series. Much of the material in the valley has been carried over long distances by the Rio Grande. The fall of the stream is not great so that very little gravelly material is transported, making the soils of the valley particularly free of very coarse material except along the margins where the Anthony gravelly loam is sometimes carried out into the valley a short distance by local cloudbursts.

The valley soil is extremely variable in texture and in other properties as well. Many factors are responsible for this. The Rio Grande drains a very extended area. In this area there are a number of different types of parent material that contribute to the river burden. Even some of the Spanish names of tributary arroyos indicate this variability as Rio Puerco (Muddy), Tierra Blanca (White Earth) Creek, and Rio Colorado (Red River). Rio Grande also flows through a territory where the rainfall is very erratic, local areas occasionally being visited by torrential downpours that carry great quantities of soil into the river. The localized character of the rainfall together with the fact that it might come in quantity sufficient to raise the river to flood volume often meant the deposition of a predominant amount of sediment from a particular locality at one time and from an entirely different locality and type of parent material at some other time.

The highly variable flow of the river had a great influence on the texture of the material being deposited at a particular spot. The ever-changing channel of the stream also had a large influence on the character of the deposit. The result on the soils of the valley has been to make it not uncommon to find five or six variations in texture in a 6-foot depth of sample. The action of the river has been largely controlled in recent years by regulating the flow at Elephant Butte Dam. Besides the variability in texture, there are also abrupt and somewhat unaccountable variations in the productivity of the soil in certain places, giving the crop a distinctly nonuniform appearance.

Agricultural Practice

The following discussion, by Dean W. Bloodgood, associate irrigation engineer, Bureau of Agricultural Engineering, describes the agricultural practice followed in raising the principal crops of Mesilla Valley. Mr. Bloodgood for many years was in charge of the irrigation investigations conducted by the Bureau in cooperation with the New Mexico Agricultural Experiment Station at State College.

Although describing practices in Mesilla Valley specifically, the description is generally applicable also

FIGURE 71.—Irrigation of cotton in Mesilla Valley.

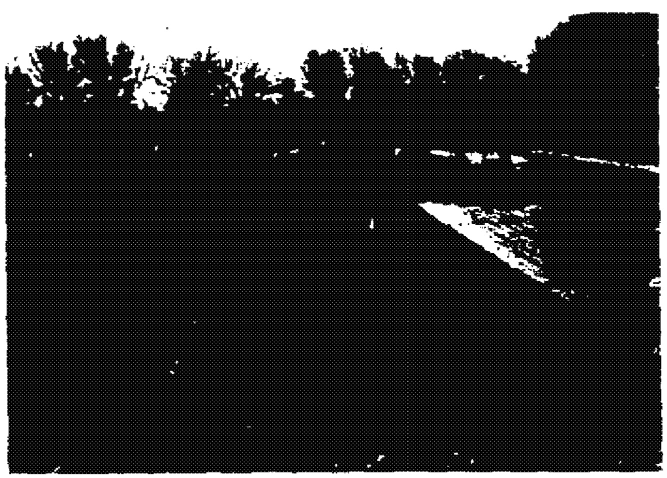

FIGURE 72.—Starting an onion crop in Mesilla Valley.

to customary methods in Rincon and Palomas Valleys and to the important areas below El Paso.

After the completion of the Elephant Butte Dam, farming and irrigation conditions changed rapidly. About this time service by the old community ditch systems was discontinued and distribution of water was taken over by the Bureau of Reclamation. By reason of its retention at Elephant Butte the water contained only some fine sand instead of being somewhat heavily laden with silt, as had been the case immemorially. Farmers did not realize the significance of the change until it was noticed that the ground water was rising rapidly. This realization did not come until about 2 years after the completion of the dam. In that interval the ground water rose so fast that it ruined many acres of highly productive land and damaged much property before remedial measures could be made effective.

The condition described was brought about largely by the use of too much water. In former days when silty water was used the irrigation lands or runs were long and small heads of water were used. These small heads of the now-clarified water took several times as long as formerly to reach the lower ends of the plots. Consequently the runs had to be cut shorter and larger heads of water used in order to irrigate the plots effectively. Before this could be accomplished, however, the entire ditch system had to be reconstructed. The main canals were straightened and enlarged for greater capacity. Many new laterals were constructed about this time, the losses from which also contributed to seepage conditions. Farm ditches were also enlarged and straightened, and modern structures were installed to prevent water losses.

The clear water involved a drainage and alkali problem which materially affected the use of water. High fluctuations of the water table prevented growth of the deeper-rooted plants and the accumulation of alkali in the surface soils damaged good fields. In order to leach out the alkali preparatory to bringing the land back into cultivation, large quantities of water were required; and to assist in the alkali reclamation additional drainage facilities were needed. Hence the alkali problem increased the use of water by reason of the reclamation program.

The systems of cost and delivery were changed so that the farmer paid for the amount of water he used instead of a flat rate for all he wanted. He became more careful in its use, and presently began to use less, paying a fixed flat rate an acre for 2 acre-feet and a sliding scale for amounts over that minimum. Water was delivered on a strictly rotation basis and no favoritism was shown; all farmers using water shared it equally.

As much of the alfalfa land was replaced with cotton, the water requirements for the valley decreased, because alfalfa used from 4 to 5 acre-feet per acre annually, whereas cotton used from 1.5 to 3 acre-feet per acre. Hence cotton was an important factor in increasing the duty of water for the Mesilla Valley and its influence is still felt.

Since cotton became an important commercial crop (about 1920) the use of water for other crops has been nearly constant with little change in irrigation requirements and agricultural practices. The acreage of alfalfa and cotton has averaged about the same over a period of years, and as those crops are the largest users of water, the water requirements of the valley do not change very much from year to year.

Cotton is usually irrigated by the flooding-border method from May to September, and during this time, four to six irrigations are applied. For good results, 18 to 30 acre-inches of water per acre is used for the heavier soils and 24 to 36 acre-inches for the lighter soils.

The border method of irrigation is almost universally used for the irrigation of alfalfa in Mesilla Valley, where larger heads of water are available and the land is comparatively level with a fairly uniform slope. The fields are divided into strips of lengths varying from a few hundred feet to 800 feet or more, the reason for this irregularity being that the farm boundaries are not on section lines and the farms are irregular in shape. The larger tracts or grants which have been broken up into smaller farms are more regular in shape and easier to farm and irrigate. The width between borders varies from 35 or 40 feet up to 100 feet or more, depending on local conditions. The border between strips of land is usually high enough to keep the water within the borders and from 8 to 10 feet wide, this width, which is flat, permitting economical harvesting. Alfalfa is planted on the borders; hence there is no idle land. The land between the borders is graded level from one to the other so that a her water will spread across it to a uniform depth.

The use of water by established alfalfa (second year's growth or more) varies from 34 to 60 acre-inches per acre, applied in 8 to 14 irrigations. The average use, as determined from experimental data, is about 48 acre-inches of water per acre. The first year's growth of alfalfa requires more frequent irrigations and possibly a slightly greater amount of water.

The grain fields of Mesilla Valley are generally irrigated immediately after the planting and from then until the crop approaches maturity. Depending upon the season, about four to six irrigations are ordinarily given and from 18 to 24 acre-inches of water per acre is usually applied.

FIGURE 73.—Irrigating grapes in Mesilla Valley.

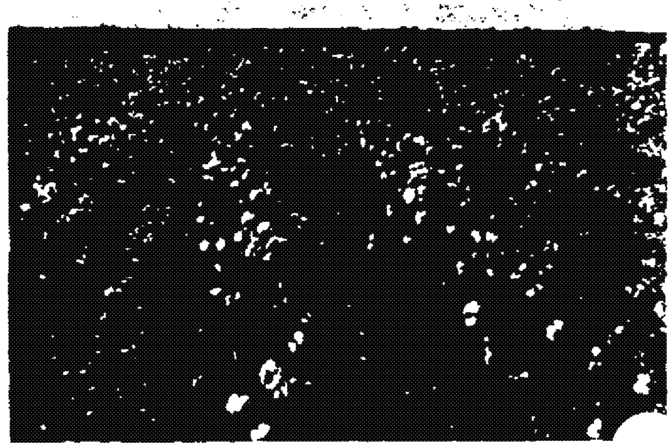

FIGURE 74.—Acala cotton field in Hudspeth County, Tex.

The water requirements for vegetables vary considerably in the amount of water used and frequency of irrigations.

Cabbage is usually irrigated from the middle of March to the er part of June, and from 18 to 24 acre-inches of water per .re is applied in 10 to 12 irrigations.

The irrigation season for chile and tomatoes is from the middle of May to the middle of September. From 24 to 30 acre-inches of water per acre is applied in 12 to 14 irrigations.

Potatoes have an irrigation season extending from March 15 to June 30. During this time 18 to 24 acre-inches of water per acre is applied in 5 to 7 irrigations.

Cantaloups are usually planted about the middle of May and the irrigation season extends to about August 10. During this time about 20 to 30 acre-inches of water per acre is applied in 8 to 10 irrigations.

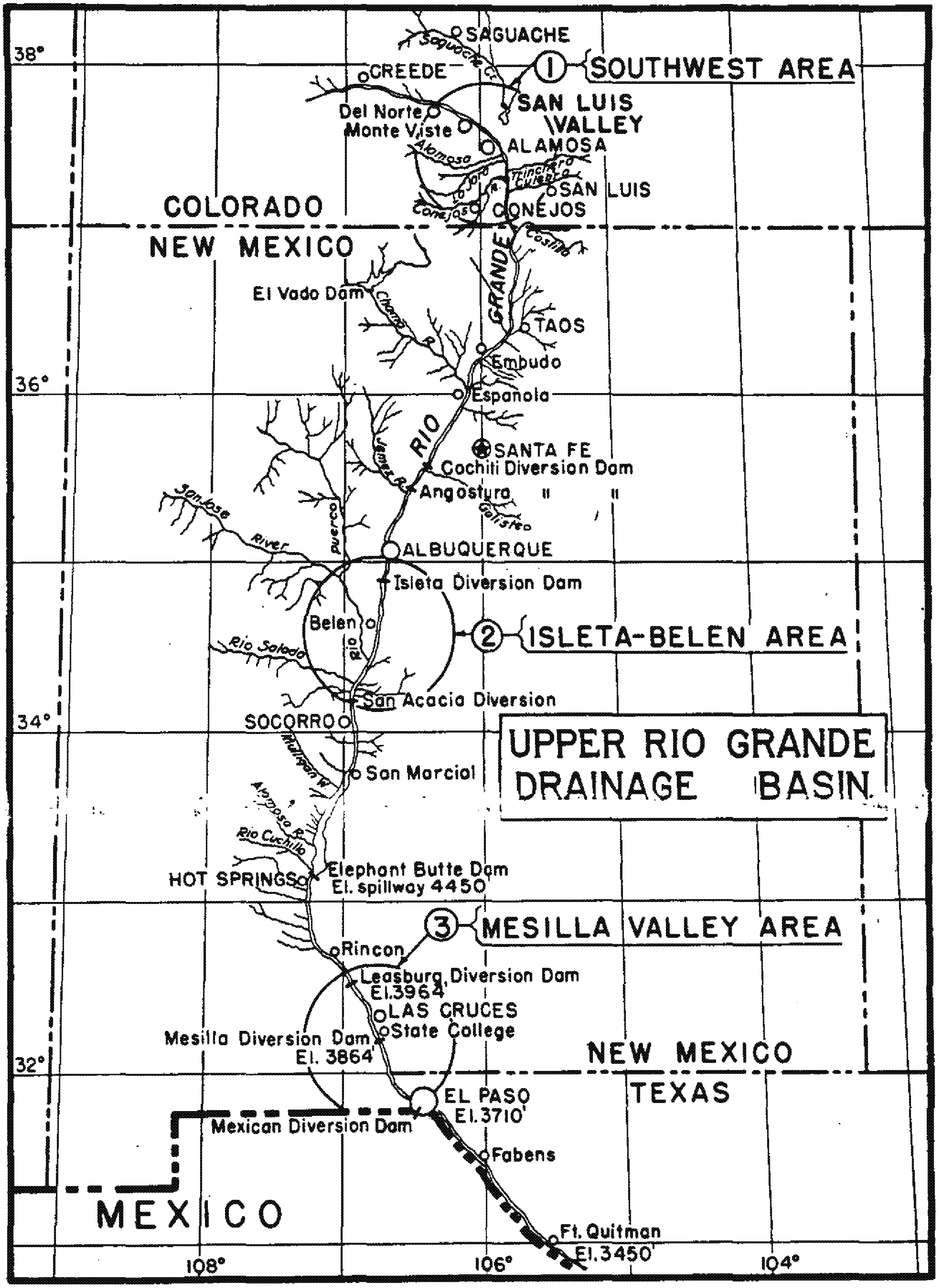

FIGURE 75.—General location of intensive study areas. For details see figures 83, 86, and 89.

PART III

ᐧTION 3.—PREVIOUS STUDIES OF CONSUMPTIVE USE OF WATER

The waters of the Rio Grande above Fort Quitman are largely consumed by native vegetation and irrigated agricultural crops in Colorado, New Mexico, Texas, and Mexico. In the usual year, only a small portion of the total water production of the Upper Rio Grande Basin escapes from it unconsumed, and that small part consists mostly of unusable return flow and flood-peak flows originating below Elephant Butte Reservoir (pl. 1).

The precipitation on the mountain watershed above the San Luis Valley contributes a large portion of the annual water yield of the upper river basin. Therefore, the amount of water available each year for irrigation in the Middle Rio Grande Valley depends in part on the amount consumed in San Luis Valley; and likewise the amount available to Mesilla Valley and other areas below Elephant Butte Reservoir depends in part on the amount consumed both in San Luis Valley and Middle Rio Grande Valley.

This chapter consists of a review of previous studies b ious investigators of the consumptive use of w in the San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley. A report on the studies made by the Bureau of Agricultural Engineering during 1936 follows in section 4. The Bureau's investigation was divided into two parts: (1) Consumptive use of water studies on large representative areas (see fig. 75); (2) evapo-transpiration measurements by means of tank and soil moisture experiments.

One of the main objectives of the irrigation experimental work of the United States Department of Agriculture and the agricultural experiment stations of the Western States during more than one-third of a century just past, has been to find the net water requirements and the irrigation requirements of various crops under different climatic and soil conditions. The terms "net water requirements" and "consumptive use in a basic sense", though probably not identical in meaning, are very closely related. A review of the literature on net water requirements is beyond the scope of this report; suffice it to say that many of the references herein to published writings, concern this important topic. Noteworthy among these are the following: (7), (8), (14), (21), (22), (23), (24), (33), and (84).

Some Interpretations of "Consumptive Use"

Most writings concerning the consumptive use of water are in the form of unpublished engineering reports. Among the very few published writings dealing directly with the consumptive use, a report of a committee of the American Society of Civil Engineers entitled "Consumptive Use of Water in Irrigation" (25) is noteworthy.

The committee proposed certain definitions for consumptive use of water in a basic sense, and for the farm, the project, and the valley. It also reviewed previous estimates of consumptive use for large river systems and made citations to 24 articles, published and unpublished dealing with net water requirements and consumptive use.

One of the definitions suggested by the committee of the American Society of Civil Engineers (25) follows:

Consumptive Use in a Basic Sense.—The consumptive use, U, is here defined as the quantity of water, in acre-feet per cropped acre per year, absorbed by a crop and transpired or used directly in the building of plant tissue, together with that evaporated from the crop-producing land.

The Bureau of Agricultural Engineering in a report on Rainfall Penetration and Consumptive Use of Water (4) defines "consumptive use" as "the sum of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from that area."

The committee on "absorption and transpiration" of the hydrology section, American Geophysical Union, has proposed the following definition: (47)

Consumptive use.—The quantity of water per annum used by either cropped or natural vegetation in transpiration or in the building of plant-tissue, together with water evaporated from the adjacent soil, snow, or from intercepted precipitation. It is sometimes termed "Evapo-transpiration."

The definition offered by the American Society of Civil Engineers is silent concerning the area involved, therefore implying that the area from which consumptive use occurs is coincident with and equal to the area covered by "cropped and natural vegetation." For experimental studies of consumptive use of water by the use of tanks or of small field plots, the foregoing

45—38——22

definitions are sound and adequate. However, for large tracts of land and entire valleys which include appreciable areas of bare land, native vegetation and of water surfaces, these definitions need to be amplified.

The definition of the "consumptive use of water in a basic sense" proposed by the society committee is in harmony with the basic concept of the Bureau of Agricultural Engineering in the Rio Grande studies. Amplifications have been made in this report in the application of the basic definition to the consumptive use on a large tract of land or in an entire valley.

Bureau of Agricultural Engineering Definitions

As a general definition of consumptive use applied to the Rio Grande Basin problem, the following definitions have been adopted by the Bureau of Agricultural Engineering:

Consumptive use (evapo-transpiration).—The sum of the volumes of water used by the vegetative growth of a given area in transpiration or building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time. If the unit of time is small, such as a day or a week, the consumptive use is expressed in acre-inches per acre or depth in inches, whereas, if the unit of time is large, such as a crop growing season or a 12-month year, the consumptive use is expressed as acre-feet per acre or depth in feet.

Valley consumptive use.—The sum of the volumes of water absorbed by and transpired from crops and native vegetation and lands upon which they grow, and evaporated from bare land and water surfaces in the valley; all amounts measured in acre-feet per 12-month year on the respective areas within the exterior boundaries of the valley.[1]

As defined by the Bureau of Agricultural Engineering, the valley consumptive use (K) is equal to the amount of water that flows into the valley during a 12-month year (I) plus the yearly precipitation on the valley floor or project area (P) plus the water in ground storage[2] at the beginning of the year (G_s) minus the amount of water in ground storage at the end of the year (G_e) minus the yearly outflow (R); all amounts measured in acre-feet. The consumptive use of water per acre of irrigated land is equal to (K) divided by irrigated area (A_i); and consumptive use per acre of entire valley floor is equal to (K) divided by entire valley area. The unit is expressed in acre-fe[et per] acre or depth in feet.[3]

It has been considered essential, because of extending the definition of the society committee to include the 12-month year, and also in order to analyze the Rio Grande problem in sufficient detail, to introduce and use a new set of symbols. For instance, the symbol K is used to represent the consumptive use in acre-feet on an entire tract or valley; K_c, the consumptive use by crops; and K_n, the consumptive use by native vegetation.

Stream-flow depletion.—The amount of water which annually flows into a valley, or onto a particular land area (I), minus the amount which flows out of the valley or off from the particular land area (R) is designated "stream-flow depletion" (I–R) and is usually less than the consumptive use and is distinguished from consumptive use in the Rio Grande studies.

Résumé of Previous Studies

The following résumé relating to previous studies of consumptive use in Rio Grande Basin is designed to give only a general view of the work done and to designate the public agencies which did it. It is not an exhaustive list of efforts to estimate consump[tive] use; rather it lists only the more comprehensive re[search] efforts and sources of experimental data on the pro[blem].

The first noteworthy investigation of the effect of irrigation in Colorado on stream flow in the lower valleys was that made by W. W. Follett in 1896 (20). He concluded that irrigation in San Luis Valley had substantially decreased the annual yield of the river in the lower valleys. Follett estimated the use of water from 1880 to 1896 and made "allowances of water per acre" on "irrigated land" along the Rio Grande above El Paso. His allowance (or annual use) in San Luis Valley varied from 0.7 to 4 acre-feet per acre; in the Middle Rio Grande Valley from 1 to 4 acre-feet per acre; and in the Mesilla Valley from 1.5 to 4 acre-feet per acre. Referring to these allowances he asserts:

> * * * that the amount of water I have estimated as used each year is not supposed to be all actually applied to the beneficial irrigation of a growing crop, but it is intended to show the approximate amount diverted by the ditches and lost to the drainage, being either dissipated by evaporation or by transpiration through the growing crops, or held in the soil but not quickly returned to the drainage.

[1] For the case of maximum crop production the consumptive use will probably exceed that for the case of average crop production. This definition is general and therefore applicable to either case. It is essential to observe also that water used beneficially for crop production, and nonbeneficially by native vegetation, in evaporation from bare land and water surfaces, is included in this definition.

[2] The expression "ground storage" includes both gravitational and capillary water. (See equation 1, p. 347.) However, in the Bureau studies of consumptive use for years prior to 1936 there are no data available concerning capillary water in storage, and therefore this item has been neglected. (See equation 4, p. 347.)

[3] Detailed consideration is given definitions and symbols in the section of this report entitled "Bureau of Agricultural Engineering Studies", particularly on pp. 345 to 347. Understanding of these symbols, especially with respect to inflow (I), outflow (R) and stream-flow depletion (I–R) is essential to an understanding of the r[esumé] of previous studies.

In cooperation with the Colorado Agricultural Ex-
periment Station and the Costilla Estates Development ., the Bureau of Agricultural Engineering conducted irrigation experiments in San Luis Valley on three tracts near San Acacio, Colo., in 1912, 1913, and 1914. The amounts of water used each month and during the irrigation season were measured for different types of soil producing alfalfa, the grains, beets, peas, and potatoes (24).

The Bureau of Agricultural Engineering, in cooperation with New Mexico Agricultural Experiment Station, studied the water requirements of many crops in Mesilla Valley and ground-water fluctuations in Middle Rio Grande and Mesilla Valleys. Results of these studies, which continued from 1905 to 1930, were published by the New Mexico Agricultural Experiment Station (5), (6), (7), (8), (61), and the United States Department of Agriculture (24).

The Rio Grande project of the Bureau of Reclamation has gathered the data necessary for consumptive use estimates in Mesilla Valley each year since 1919. Bureau of Reclamation engineers have also made estimates of consumptive use in the Middle Valley (12), (17), (18), based on a 2-year study (1927–28). Data collected by the Bureau are reviewed in some detail at a later place in this report in the discussion of consumptive use for each of the valleys.

In 1919 Conkling and Debler (12) in a study of water supply, irrigation, and drainage on the Rio Grande gave particular attention to the consumptive use of water, although of necessity they made many assumptions. That they considered the study of consumptive use of special importance is clearly evident in their statement which follows:

> There is also a paucity of data on consumption of irrigation water. The basis of the entire report is the consumption of water. Not only does the supply for the Rio Grande project depend on the consumption in the Middle Rio Grande and the San Luis Valley but on each project conditions are favorable for re-use of return flow by the acreage on the lower end.
>
> Although there is a lack of extensive data concerning consumptive use in field conditions, yet such as do exist point to a much greater uniformity for this than for diversions. That is, consumptive use with any ordinary economical method of irrigation appears to be independent of diversion. Above a certain amount, sufficient to supply consumption, each acre-foot diverted will, if drainage is perfect and water does not stand on the surface, cause an additional acre-foot of return flow.

From 1922 to 1928 the Colorado State engineer's office made many studies of Rio Grande irrigation problems (36 to 44).

During 1925 and 1926 that office made extensive land surveys looking to the determination of consumptive use of water in certain parts of San Luis Valley, in 1930 it completed a report of the consumptive use in the major valley divisions (67). From 1930 to 1932, inclusive, it conducted experiments on a tract of some 17,300 acres for the special purpose of finding the consumptive use (70), (71), (72).

In 1915 the Colorado Agricultural Experiment Station published a bulletin based on its cooperative work with the United States Department of Agriculture during the years 1912, 1913, and 1914 (11). It conducted climatic studies also, the results of which were published in 1917 (53).

During the period 1924 to 1932 the State engineer's office of New Mexico and the Rio Grande Valley Survey Commission conducted survey work in the Upper Rio Grande Basin relating to net irrigated areas and consumptive use of water (26), (27), (32), (49), (50), (51), (52), (78), (79).

New Mexico Agricultural Experiment Station, in cooperation with the Bureau of Agricultural Engineering, has done much experimental work on the net duty of water. Most of the results of these studies have been published by the station (7), (8), (61). Some are used in this report as a basis for estimating the consumptive use.

Results of studies of the various phases of the Rio Grande irrigation problems by the Bureau of Reclamation and by the State engineer's offices are presented largely in unpublished engineering reports. Most of the engineering reports include discussions on water requirements which are of necessity based largely on assumptions as to the consumptive use of water in the different valleys. Brief reference is here made to some of the noteworthy reports and their authors, and also to the variability in consumptive use estimates.

In addition to the Conkling-Debler report (1919) hereinbefore mentioned, R. I. Meeker, consulting engineer for Colorado, in a series of reports from 1922 to 1930 (36 to 45) made numerous computations based on assumed values of consumptive use; R. J. Tipton, special engineer for the State of Colorado, made many reports from 1924 to 1935 (65 to 69) relating to Rio Grande water problems and most of them include consumptive use estimates and analyses. E. B. Debler, Bureau of Reclamation hydraulic engineer, has done much work relating to consumptive use in the Rio Grande Upper Basin as evidenced in his reports of 1924, 1927, and 1932 (15, 17, 18); Charles R. Hedke, engineer for New Mexico, made a special report on consumptive use in 1924 (26); E. P. Osgood, engineer for New Mexico and Texas, considered it in 1928 (50 to 52); R. G. Hosea, New Mexico engineer, made brief reference in 1928 (32) to the lack of reliable data, and later in the water requirement studies of Middle Valley (9) he made extended application of consumptive use estimates based on comparisons with Mesilla Valley data. A. W. Newcomer (49), D. C. Henny (30) and others also recognized the importance of consumptive use data. Herbert W. Yeo and R. F. Black (86) in 1931 made a 3-volume confidential report for New Mexico based on E. P. Osgood's San Luis Valley work of 1927–28. Consumptive use is given prominent consideration in the Yeo-Black report.

There is considerable variability in the estimates made by engineers and others for unit values of consumptive use in each of the three major valleys. This is not unusual. It is difficult to make precise estimates because there are so many variable factors influencing the consumptive use. However, some variability in estimates is attributable to lack of specific definitions.

San Luis Valley

Most estimates[4] for San Luis Valley are in reality estimates of stream-flow depletion $(I-R)$ rather than of consumptive use as defined by the Bureau of Agricultural Engineering to include annual precipitation and draft on ground-water supplies. (See p. 326.)

However, for the San Luis Valley, there seem to be two types of estimates—one being those estimates that have been based on comparative data from other localities, and the other, those based on direct measurements of inflow, outflow, and precipitation in the valley, which in substance accord with the Bureau of Agricultural Engineering (inflow-outflow) method A. (See p. 345.) Most of the estimates based on comparisons with other valleys were made in the earlier years, and the estimates based on direct measurements during the later years, with but little overlapping.

Chronology is considered an important factor in the study of consumptive use of water; therefore the following estimates for San Luis Valley are presented as nearly as practicable in the order of the time when they were made.

A condensed outline of the plan and order of presentation follows: (1) Early estimates by engineers, based largely on comparisons of the Valley conditions with other valleys in which stream-flow depletion measurements had previously been made. (2) Estimates based on measurements of inflow and outflow, and in some cases also on precipitation, thus applying method A.

Early Estimates by Engineers

Most of the early estimates of "consumptive use" for San Luis Valley are really estimates of stream-flow depletion, that is $(I-R)$ of equation 4, page 347. When given in acre-feet per year per acre of irrigated land, they are considered in this report as unit irrigated area stream-flow depletion, i. e., $\left(\frac{I-R}{A_i}\right)$.[5]

The annual precipitation (P) and the change in the amount of gravitational ground water (G_s-G_e) are usually not included for San Luis Valley. Therefore, in reality, the quantity which is usually reported is $\frac{I-R}{A_i}$.

It should be observed, however, that $I-R$ (stream-flow depletion) results in part from consumptive use by crops, and in part by native vegetation, together with evaporation from water surfaces and from bare land surfaces. In valleys in which the ratio of irrigated area to the total area (A) is small, say two-thirds or less, it may be misleading to debit $(I-R)$ to irrigated area alone, especially if the valley water surface and native vegetation areas are large.

Estimates made by engineers heretofore are reported as acre-feet per acre irrigated in terms of stream-flow depletion regardless of rainfall, that is $\frac{I-R}{A_i}$, and also as stream-flow depletion plus the annual rainfall divided by the irrigated area, or as $\frac{I+P-R}{A_i}$. In attempting comparisons of past estimates, special effort is necessary to see that the estimates are comparable.

Conkling-Debler.—In 1919 Conkling and Debler, Bureau of Reclamation engineers, on the basis of results of 2 years' observations of consumptive use in the Boise Valley, Idaho, and 9 years in the Cache La Poudre Valley, Colo., estimated the "beneficial consumptive use" in San Luis Valley, exclusive of rainfall, at about 1.25 acre-feet per irrigated area; for the mountain valleys tributary to San Luis they placed the estimate at 1.0. They found the stream-flow depletion to be 1,041,000 acre-feet per year, of which they estimated 460,000 acre-feet was beneficial consumptive use. The balance was considered as wasted evaporation (12).

Meeker.—R. I. Meeker first made an estimate for the San Luis Valley in May 1924 (37) of 0.9 acre-foot per irrigated acre of drained lands.

In August 1924 (38) he estimated the unit stream-flow depletion as 2.1 excluding rainfall, and attributed the high value to incomplete drainage in parts of the Valley.

In June 1926 (40) he estimated the San Luis Valley stream-flow depletion as 2 acre-feet per acre of irrigated land.

[4] The term "estimate" is applied to all consumptive use observations for large areas because of the many variable factors which influence consumptive use and because it is impractical to measure them all.

[5] Inflow (I); outflow (R); irrigated area (A_i). See pp. 345 to 347 for complete list of symbols and for derivation of equation 4.

In 1928 (43) he wrote that the beneficial consumptive ...e in San Luis Valley should be about 1.0 acre-foot acre of irrigated land.

Large Area Studies

In the past studies of "consumptive use" of water in San Luis Valley different tracts of land have been used. A brief description of four of the tracts is given in the following paragraphs:

1. R. J. Tipton's measurements for the Conejos area, the southwest area minus Conejos Basin, the north area for the years 1921 to 1929. (Data from Tipton's 1930 confidential report (67), Appendix I, tables 3 and 11. Inflow and outflow data based on Colorado State measurements—areas irrigated measured by Tipton in 1925 and 1926 under direction of Meeker.)
2. Tipton-Hart experiments on Bowen-Carmel area of some 17,300 acres of which the "average area irrigated" is 12,760 acres. (Data from three Tipton-Hart reports (70), (71), (72), 1930, 1931, and 1932.)
3. Yeo-Black report (86) regarding tracts in water districts 20, 21, 22, and 26 and for the entire valley. (Inflow and outflow data largely from water commissioners records as quoted by Osgood. Areas irrigated based on Osgood's 1927–28 surveys.)
4. Hedke-Bliss entire valley estimates for the 24-year period 1900–1923, inclusive. (Inflow and outflow data from Hedke's January 1925 report (27). Irrigated areas based on surveys of Osgood, 1927–28; Bliss, 1932; and Dallas, 1934. The results of their surveys were used by J. H. Bliss, August 1936, to find a correction factor for the Colorado water commissioners' area ...es.)

...pton.—Extensive and detailed estimates of past "consumptive use" of water in three major divisions of the San Luis Valley were made by R. J. Tipton in his report dated March 1930 (67). These estimates are based on details of water inflow and outflow measurements together with measurements of irrigated areas which are reported fully in tables and illustrated in part in graphs. The report was made for the State engineer of Colorado, and was of a confidential nature. References to it in the following paragraphs and pages of this report are made solely upon the responsibility of the Bureau of Agricultural Engineering, the State engineer of Colorado reserving the right to revise and correct the data as later study and experimentation may require.

Tipton concludes that the "consumptive use" in parts of the San Luis Valley—notably in the Conejos area—is appreciably higher than it would be if water were held in storage reservoirs until late season when needed, rather than applied in excessive amounts during April and May to effect storage in the soil in an attempt to alleviate shortages during July and August.

Measurement of areas of land actually irrigated is vital to the accuracy and the reliability of estimates of st...m-flow depletion in terms of acre-feet per acre. As ...een shown in preceding parts of this report, areas reported by the water commissioners of divison no. 3 may be appreciably higher than the actual areas irrigated. Tipton says (66) that the water commissioners' reports are invariably high, because the tendency of the farmer is to report a high acreage in order to get a maximum of water.

The special field surveys of irrigated areas in San Luis Valley by Tipton in 1925–26 under the direction of R. I. Meeker are the first such surveys in San Luis Valley of which the Bureau is informed. They appear to be more accurate and reliable than the water commissioners' estimates. He found the total irrigated area for the Valley to be 494,200 acres, which is 80 percent of the 621,836 acres reported by the water commissioners for 1925, and 76 percent of the 653,564 acres reported for 1926.

Tipton's stream-flow depletion measurements, as reported in 1930, are summarized as tables 23 and 24 and consolidated in table 50.

For the Conejos Basin (table 23), he used a round number of 75,000 acres irrigated, as compared to 71,280 given in his 1935 report (69). Based on the area of 75,000 acres, assumed constant for the years 1921 to 1929, Tipton found the average stream-flow depletion equal to 2.58 acre-feet per acre. The minimum was 1.16 in 1924 and the maximum was 3.22 in 1929—nearly three times the minimum.

Table 24 represents the "southwest area minus the Conejos area" for 1921–29, being 115,890 acres of irrigated land, of which 33,000 acres is drained. It shows that the average stream-flow depletion per irrigated

TABLE 23.—*Water consumption in Conejos Basin, San Luis Valley, Colo.*

[75,000 acres irrigated]

Year	Inflow in 1,000 acre-feet				Outflow in 1,000 acre-feet			Consumption	
	Conejos (Mogoto)	Los Pinos (Ortiz)	San Antonio (Ortiz)	Total	Conejos mouth	La Jara drain	Total	Total in 1,000 acre-feet	Per acre in acre-feet
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1921	260	90	15	365	154	4	158	207	2.76
1922	311	107	22	440	254	6	260	180	2.40
1923	392	139	42	523	296	10	306	217	2.89
1924	284	98	17	399	304	8	312	87	1.16
1925	233	76	9	318	91	8	99	219	2.92
1926	249	98	25	372	185	6	191	181	2.42
1927	345	120	27	492	246	5	251	241	3.20
1928	192	73	15	280	110	[1] 5	115	165	2.20
1929	323	101	26	450	199	[1] 8	207	243	3.22
1930	306	93	16	315	130	7	137	178	2.37
1931	137	37	5	179	34	7	41	138	1.84
1932	369	148	23	540	305	7	312	228	3.04
1933	214	73	17	304	113	7	120	184	2.45
1934	110	29	3	142	25	7	32	110	1.47

[1] Estimated.

NOTES.—Data for the years 1921 to 1929, inclusive, taken from table 11 of R. J. Tipton's 1930 report. The 1929 figures represent nine months only. Data for the years 1930 to 1934, inclusive, computed by the Bureau of Agricultural Engineering on the basis of water measurement records of the Colorado State engineer.

All the results shown in column 10 are based on the constant area of 75,000 acres which was used by Tipton for the years 1921 to 1929.

acre for the period is 1.92 acre-feet, the minimum 1.05 acre-feet, and the maximum 2.50 acre-feet.

For the north area of 179,170 acres and the same period of years the average stream-flow depletion is 2.06 acre-feet per acre, the minimum 1.87, and the maximum 2.40.

In August 1933, in his "Synopsis of Engineering Report on Interstate Phases of Rio Grande and Proposed 'Sump' Drain and State Line Reservoir", Tipton estimated (68) the "beneficial consumptive use" in the "dead", or closed, area irrigated from the Rio Grande as 1.2 acre-feet per acre, excluding rainfall; and for the portion of the closed area irrigated from streams other than the Rio Grande he estimated the consumptive use as 1.5 acre-feet per acre.

TABLE 24.—*Water consumption in southwest area minus Conejos Basin, San Luis Valley, Colo.*

[115,890 acres irrigated, of which 33,000 acres is drained]

Year	Inflow in 1,000 acre-feet							Outflow[1] in 1,000 acre-feet	Consumption[2]	
	Diversions from Rio Grande	Rock Creek	Alamosa River	La Jara Creek	Rio Grande (At Alamosa)	La Jara drain	Total		Total in 1,000 acre-feet	Per acre in acre-feet
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1921	165	8	105	16	636	4	934	713	221	1.91
1922	191	10	125	23	355	6	710	428	282	2.44
1923	136	12	110	28	338	10	636	400	236	2.04
1924	138	18	91	23	304	8	582	449	133	1.05
1925	169	[3] 8	86	14	156	8	441	232	209	1.81
1926	160	[3] 9	78	18	163	6	434	241	193	1.67
1927	218	[3] 10	113	18	406	5	770	481	289	2.50
1928	163	[3] 8	64	15	153	[3] 5	408	215	193	1.67
1929	215	[3] 12	96	16	221	[3] 8	568	219	249	2.15
1930	62	4	73	13	163	7	322	231	91	.80
1931	102	1	50	7	67	7	234	108	126	1.09
1932	243	8	119	16	177	7	570	268	302	2.61
1933	119	6	71	10	77	7	290	137	153	1.32
1934	96	3	36	5	58	7	205	94	111	.96

[1] Rio Grande at State line, minus Conejos.
[2] The equivalent, in this table, of stream-flow depletion.
[3] Estimated.

NOTES.—Data for the years 1921 to 1929, inclusive, taken from table 11 of R. J. Tipton's 1930 report.
Data for the years 1930 to 1934 inclusive computed by the Bureau of Agricultural Engineering on the basis of water measurement records of the Colorado State engineer.
Rock Creek figures for 1930-34 are not exactly comparable with Tipton's figures.
All the data in column 11 are based on the constant area of 115,890 acres, which was used by Tipton only for the years 1921 to 1929.

Bowen-Carmel area studies.—Tipton-Hart Experiments.—Consumptive use experiments were conducted in the Bowen-Carmel area in San Luis Valley by the State of Colorado under the direction of the State engineer during the years 1930, 1931, and 1932 (70), (71), (72). The field work was done under the immediate supervision of R. J. Tipton, special engineer, reporting to M. C. Hinderlider, State engineer, F. C. Hart, special hydrographer, made the measurements and kept the experimental records. All inflows to and outflows from the Bowen-Carmel tract below the Monte Vista canal and above the Empire canal were measured. Automatic stage registers were maintained except for the smaller ditches in 1930, when staff gages only were used. It is probable that the error of inflow-outflow measurements does not exceed 10 percent.

The area of land actually irrigated in the two consumptive-use experimental tracts was measured with a fair degree of precision in 1930, but in 1931, becau inadequate financial support for the work and consı able variation in use of land caused by the serious drought, there was uncertainty as to the area of land irrigated. More reliable area measurements were made in 1932.

The area included within the exterior boundaries of the experimental tract was 17,300 acres and the irrigated area for each of the 3 years was 13,360, 8,703, and 12,399, respectively, making an average of 11,488 acres irrigated, or 66 percent of the gross area. Measurements of the irrigated area were probably less accurate than the water measurements; nevertheless they are considered reliable and accurate in comparison with the water commissioners' estimates.

Both the Bowen and Carmel lands are well drained. The feeder lines of both drainage systems are of tile, and the lower and outlet lines are open ditches.

Results of these San Luis Valley consumptive use experiments are recited by Tipton and Hart in three annual reports (70, 71, 72), which include many details related to water measurements, climatic data, drain discharges, and monthly amounts of consumptive use. There were no observations of depths to water table; hence the quantity $(G_s - G_e)$ of consumptive use equation 4 (p. 347) cannot be evaluated (70).

The Bowen-Carmel experimental tract is wholl the "live" area of the Valley. (See fig. 78.) Of the gross area of the experimental tract as measured from the map (17,300 acres), the water surface and bare land areas are considered negligible.[6] Therefore the gross area minus the irrigated area gives approximately the area of native vegetation, namely, 4,540 acres.

Results of Experiments.—A résumé of the results of the 3 years' work is given in table 25.

TABLE 25.—*Résumé of use of water in the Bowen-Carmel area in San Luis Valley for the years 1930, 1931, and 1932, based on Tipton-Hart studies*

Year	Total stream-flow depletion $(I-R)$, acre-feet	Area irrigated (A_i), acres	Stream-flow depletion $\left(\frac{I-R}{A_i}\right)$, acre-feet per acre	Total consumptive use $(I+P-R)$,[1] acre-feet	Consumptive use in irrigated area $\left(\frac{I+P-R}{A_i}\right)$, acre-feet per acre	Consumptive use in entire area $\left(\frac{I+P-R}{A}\right)$, acre-feet per acre
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1930	15,141	13,360	1.13	26,252	1.96	1.52
1931	10,924	8,703	1.25	21,096	2.42	1.22
		[2] 12,530	[3] .87	[3] 21,096	[3] 1.68	[3] 1.22
1932	22,301	12,399	1.88	31,296	2.52	1.81
Average	16,455	----------	1.42	26,215	2.30	1.52

[1] Precipitation (P) computed on the basis of entire area of tracts, 17,300 acres.
[2] Total cropped acreage.
[3] Not included in average.

[6] There is practically no free water surface within the tract, it being bounded on each side by two major canals. Estimating the bare land in roadways as a str feet wide and 18 miles long, shows that the area it occupies is only one-half o cent of the gross area and therefore negligible.

Column 2 shows the net stream-flow depletion; that is, the inflow minus the outflow for the combined Bowen-Carmel areas. Column 3 shows the irrigated ·a, which in 1930 was measured with a fair degree of :uracy. With reference to this, Tipton and Hart said:

A cruise was made of the land in both districts. Most of the tracts were regular and followed land lines, except in the case of some of the pasture lands. All pasture land upon which water was actually used, either waste or direct irrigation, was included in the irrigated acreage, but brush pasture was not, unless there were areas of grass on which water was used, in which cases the acreage of grass was included. A small compass was used for obtaining directions and distances were paced, in making the determination of irregular grass acreage.

Early in the season each farmer was visited and questioned as to the acreage he had planted of the various crops, and other land on which water was being used. The figures thus obtained were subsequently found to be high upon comparison with the areas determined by the cruise.

The 1931 area measurements were less accurate than those of 1930, largely because the extreme dryness of the season complicated the determinations of areas. Concerning the 1931 areas Tipton and Hart said:

In the determination of the irrigated area, the dryness of the season made an accurate determination of the land irrigated impracticable. As a result, the area irrigated, and the consumptive use also, must lie between two limits. (1) One limit is defined by the area of cropped land, the (2) other by the area of land to which water was known to have been applied.

The values of these two areas were obtained from the individual ɩers, and checked against the area determined by the 1930 ʂe of irrigated acreage. The crop production, and the acreage, however, were also obtained from the farmers themselves.

Tipton and Hart made the following statement concerning 1932 irrigated areas:

The crop acreage, area irrigated, and production figures were all gathered from personal interview of the farmers in the area, as limited time and funds made it impracticable to again cruise the area. The acreage irrigated was checked against the cruise of 1930 and the results from 1931 in each individual case, and is considered to be fairly accurate.

For 1931, because of the uncertainty in the measurements of irrigated area, both the 8,703 acres to which water was applied and the cropped area of 12,530 acres are reported in table 25. These areas may be considered as "minimum" and "maximum" for the season. Certainly the stream-flow depletion (column 4), and consumptive use (column 6), based on the maximum area of 1931, are too low because the water used was not enough to mature ordinary crops on this area.

It is believed that the quantities 1.13 and 1.25 of column 4, representing stream-flow depletion per irrigated acre, and the quantities 1.52 and 1.22 of column 7 representing consumptive use per acre in entire area, lower than the amounts for the area normally essential to satisfactory crop production. Both the years 1930 and 1931 were adverse to crop growth. Concerning 1930, Tipton and Hart wrote as follows:

The season of 1930 was not normal. The first part of the season was very dry, with high winds and cold nights prevailing. After the middle of July ample water was available due to copious rains. Although the season was not normal, yet, in general, crop production over the area investigated was about normal. * * *

The results of any consumptive-use determination for a single season cannot be considered as conclusive. This is especially true when the season is not a normal one, as was the case in 1930.

The early part of the season was characterized by high winds of sustained duration and cold nights, the last killing frost of the spring occurring on June 23. The weather after that was dry and warm, with considerable wind.

During June and the early part of July the demand for irrigation water far exceeded the supply.

That 1931 was a year of unusual and serious drought is well known. The figures for 1932 are probably more nearly representative of consumptive-use requirements than those for either 1930 or 1931—indeed, more nearly representative than the average results for the 3 years. It is probably conservative to conclude that the average of the 3 years is representative of the minimum use for normal years on the area studied, and that the figures for 1932 are more nearly representative of the maximum. In column 4 the 1930 magnitude of stream-flow depletion per irrigated acre is 80 percent of the average; for the 8,703-acre area of 1931 it is 88 percent, and for the 1932 area it is 132 percent. Perhaps it is not extravagant to say that the average is subject to a variation of plus or minus 20 percent.

Yeo and Black.—In 1931 Herbert W. Yeo, State engineer of New Mexico, assisted by R. F. Black, completed their voluminous report on Water Supply, Irrigation and Drainage in the San Luis Valley and Adjacent Northern Areas (86), which contains many data on "consumptive use" of water in San Luis Valley gathered by E. P. Osgood in 1927–28. Lack of funds in 1929 delayed the completion of the report of Osgood's findings, hence his data were later examined and classified by R. F. Black and transmitted to Herbert W. Yeo, State engineer.

The Yeo and Black report, in addition to containing the results of Osgood's 1927–28 area surveys, included descriptions and discussions of irrigation conditions in each of the Colorado State water districts nos. 20 to 27, inclusive, and 35. For each water district, wherever practical, an estimate of the stream-flow depletion ("consumptive use") was made and details for the bases of the estimates presented. The entire report was of a confidential nature and was not published. References to it in the following paragraphs and pages of this report are made solely upon the responsibility of the Bureau, the State engineer of New Mexico reserving the right to revise and correct the data as later study and experimentation may dictate.

Yeo and Black say concerning water district no. 20 that data presented demonstrate an average use, from measured inflow since 1912, of 1.99 acre-feet of water per irrigated acre during the irrigation season and 2.04 acre-feet for the year.

One of their tables shows that for the period 1915 to 1928, inclusive, the minimum stream-flow depletion for water district no. 20 lands was 1.68 acre-feet per acre of land irrigated in 1921. The maximum of 2.43 came in 1916 and again in 1922. For this 14-year period, according to Yeo and Black's table, the average stream-flow depletion for district no. 20 was 2.01 acre-feet per acre of irrigated land.

However, certain corrections of these estimated amounts were made, after which Yeo and Black concluded that a summary of the tabulation showed a mean use of water, or depletion from the stream system, since 1912, amounting to 2.29 acre-feet per acre per year in water district no. 20. This figure did not include water derived from artesian wells.

For district no. 21 data were available to Osgood, Yeo, and Black for the year 1927 only. On the basis of these data and the assumption "that all outflow through Alamosa River is derived from water district no. 20, as calculated in the estimate of depletion in that district", they found that the stream-flow depletion ("consumptive use") was 2.6 acre-feet per acre irrigated per year.

On the basis of Osgood's 1927 field studies the irrigated area in water district no. 22 was taken by Yeo and Black as 76,000 acres. State of Colorado inflow measurements for the years 1921 to 1927 inclusive at the following stations were used (Pl.11):

Conejos River at Mogote.
San Antonio River at Ortiz.
Los Pinos River above Ortiz.
McIntyre Springs estimated.

The outflow measurements were:

Conejos River at mouth.
San Luis Valley Drainage District No. 1, estimated on basis of 1927 measurements.

The average stream-flow depletion, based on measurements and estimates as above for the years 1921 to 1927, was found to be 2.67 acre-feet per acre of irrigated land (86).

Yeo and Black asserted that there were no available data on which to estimate the stream-flow depletion in water districts nos. 24 and 25 (86).

For water district no. 26 there was no surface outflow; the inflow was 2.9 acre-feet per irrigated acre, which is considered as the stream-flow depletion for the district.

The Entire Valley.—Considering San Luis Valley as a whole, Yeo and Black estimated that the stream-flow depletion for the years 1918 to 1927, inclusive, averaged 2.10 acre-feet per acre for 570,000 acres of irrigated land, the area which they assert had been found by Osgood in 1927.[7] The minimum stream-depletion was 1.92 acre-feet per irrigated acre and maximum was 2.30. It should be noted that the area 570,000 acres which was considered constant for the period 1918 to 1927 is 73 percent of the 779,671 acres reported as irrigated in 1927 by the Colorado division engineer for division no. 3. It is 131 percent of the 435,790 acres reported by Colorado division engineer for 1918, and 94 percent of the average irrigated area for the period 1918–27 as reported by Colorado division engineer, namely, 607,970 acres.

Yeo and Black estimated the San Luis Valley area on which water might be applied if available as 1,065,000 acres, and by including all the annual rainfall, estimated as 7 inches average, they found the average consumptive use to be 3.17 acre-feet per irrigated acre.

Yeo and Black concluded their discussion of "consumptive use" for certain parts of San Luis Valley with the following estimates:

	Acre-feet per irrigated acre per year
Rio Grande Drainage District	1.40
Southwestern area range 1.71 to 2.15 and average	1.85
Entire Valley	2.10

They suggested that with complete drainage for the entire valley the depletion might be reduced to 1.50 to 1.75 acre-feet per irrigated acre per year.

Other estimates for entire valley.—Efforts have been made by several engineers to estimate, as far as practical, the annual amounts of stream-flow depletion for the entire San Luis Valley both in terms of total acre-feet and acre-feet per acre irrigated. The major difficulty in making these estimates is the fact that not all the tributaries have been measured. Therefore certain assumptions regarding inflow must be made. Another uncertainty is as to the area of land actually irrigated. The outflow from the Valley is of record since 1890 and the measurements of it are considered relatively reliable.

Irrigated Land Surveys.—In 1932 John H. Bliss and Russell Dallas surveyed the irrigated lands of San Luis Valley. They measured distances by automobile and plotted all irrigated lands on township plats having a scale of 1 inch equals 1 mile. On the basis of these surveys Bliss prepared a large map of the valley on a

[7] There is lack of harmony in the Valley area reported as based on Osgood's 1927–28 surveys. In the collection of data designated "Report on Water Supply, Irrigation and Drainage in San Luis Valley, Colorado" (51) by Osgood, the first table giving areas for 8 water districts of water division no. 3 shows Osgood's total as 507,471 acres. In the Yeo-Black report, this area is used as a basis for estimating net depletion for the years 1926, 1927, and 1928, which is 2.67 acre-feet per acre per year. Apparently the Yeo-Black estimate of the valley area as 570,000 acres at another page of their report is in error, and all the stream-flow depletion estimates on that page shou' multiplied by the ratio $\frac{570}{507}$ to be correct, thus making the average for th 1918–27 equal 2.36 instead of 2.10.

scale 1 inch equals 2 miles. The map was in five sheets and showed the location and extent of the irrigated lands.

The results of the surveys by Bliss are presented in table 26 which shows areas in eight classifications for each of eight water districts. Columns 2, 3, and 4 show the areas of irrigated land which are cultivated, used for production of wild hay and pasture, respectively. Column 5 gives the total irrigated area for the valley and for each of the water districts. The non-irrigated lands as distributed into five classes by Bliss are shown in columns 6 to 10 and the total of non-irrigated areas is shown in column 11. The grand total of all land areas listed in table 26 is probably less than 40 percent of the area of the valley floor. Bliss did not cover all the nonirrigated valley area but only such part as was necessary to find and map the irrigated land.

Area Résumé.—The results of the Osgood, Bliss, and Dallas surveys are summarized in table 27. From the table it appears that the sum of the area irrigated in 1934, 428,737 acres, plus 70,184 acres irrigated in 1932 but not in 1934 because of water shortage, was 498,921 acres. This total is probably nearly representative of the area that would have been irrigated in 1934 if the water supply had been normal. With this interpretation of the 1934 areas, the average irrigated area for the years 1927, 1932, and 1934 would be 513,733 acres, and the respective irrigated acreages would be 99 percent, 104 percent, and 97 percent of the average. This suggests that the area irrigated during the period 1927 to 1934, as found by the New Mexico engineers, was substantially constant.

TABLE 26.—*San Luis Valley lands classification in 1932 by John H. Bliss*

[In acres]

Water district	Irrigated				Nonirrigated					
	Cultivated	Wild hay	Irrigation pasture	Total	Swamp and tule	Lakes	Grasses	Cultivated dry	Bottom land	Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
No. 22	48, 051	16, 465	7, 614	72, 130	403	......	1, 696	86	6, 334	8, 521
No. 21	47, 627	12, 465	4, 239	64, 331	383	119	3, 845	......	2, 516	6, 663
No. 20	177, 677	29, 694	27, 041	234, 412	2, 582	253	14, 458	140	10, 232	27, 665
No. 35	9, 143	6, 776	5, 004	21, 023	243	2, 956	1, 338	......	491	5, 028
No. 27	13, 252	11, 018	11, 035	35, 305	......	28	6, 444	......	......	6, 472
No. 26	6, 052	18, 514	5, 659	30, 225	118	201	7, 924	......	367	8, 610
No. 25	4, 126	30, 543	10, 104	44, 773	168	22	3, 459	78	110	3, 837
No. 24	26, 391	2, 572	3, 644	32, 607	......	1, 699	1, 388	......	585	3, 672
Total	332, 319	128, 047	74, 440	534, 806	3, 917	5, 278	40, 554	304	20, 635	70, 688

TABLE 27.—*Irrigated area, San Luis Valley, Colo., reported by surveys of Osgood, Bliss, and Dallas*

Authority	Year	Area, in acres			
		Cultivated	Hay	Pasture	Total
Osgood	1927	328, 005	[1] 179, 466	....	507, 471
Bliss	1932	332, 319	128, 047	74, 440	534, 806
Dallas	1934	291, 278	94, 686	42, 773	428, 737
		[2] 9, 938	27, 222	33, 024	70, 184

[1] Includes pasture.
[2] Irrigated in 1932 but not in 1934 because of water shortage.

The irrigated areas reported by the Colorado State engineer for the San Luis Valley as a whole each year from 1890 to 1925 are shown in the upper dotted curve of figure 76. The upper heavy line curve of figure 76 shows 70 percent of the areas reported by the Colorado State engineer.

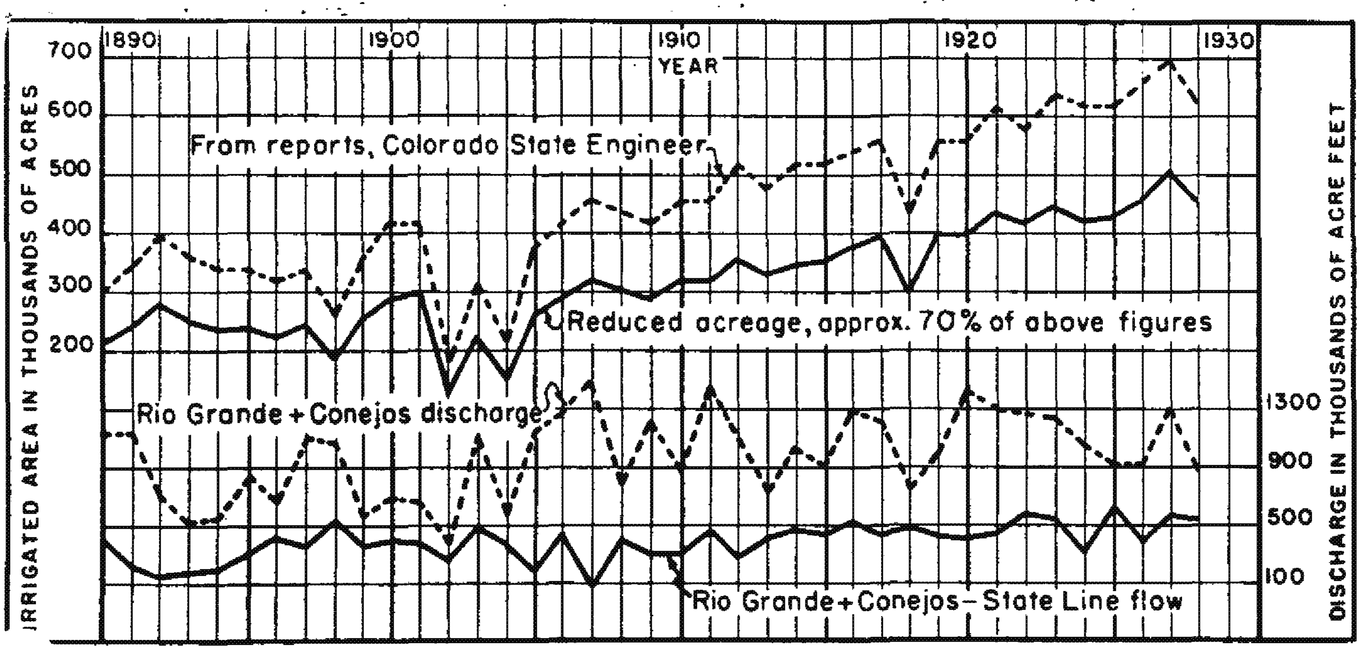

FIGURE 76.—Irrigated area and stream flow depletion for San Luis Valley, 1890 to 1928. (After John H. Bliss.)

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Valley Stream-flow Depletion.—The Bureau of Agricultural Engineering has endeavored to use stream-flow estimates by Hedke with land area estimates by Osgood and by Bliss, with results briefly shown in the following paragraphs.

The total annual inflow to the valley has been estimated by Charles R. Hedke for New Mexico for the years 1900 to 1923, inclusive (27). His inflow estimates are given in table 28, column 2, and the outflow measurements he reported are in column 3. Column 2 minus column 3 shows that the minimum depletion was 374,500 acre-feet in 1902; the maximum was 1,078,000 acre-feet in 1923, and the average for the 24-year period was 793,800 acre-feet.

On these bases column 6 shows that the minimum per acre stream-flow depletion was 1.82 feet in 1907; the maximum was 4.14 feet in 1903; and the average for the 24-year period was 2.52 feet.

TABLE 28.—*Stream-flow depletion for the years 1900 to 1923, entire San Luis Valley, Colo., based on irrigated area*

Year	Inflow (I) in 1,000 acre-feet	Outflow (R) in 1,000 acre-feet	Stream-flow depletion ($I-R$) in 1,000 acre-feet	Irrigated area (A_i) in acres	Stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$ in acre-feet
(1)	(2)	(3)	(4)	(5)	(6)
1900	1,003.1	304.0	699.1	289	2.42
1901	938.6	284.0	654.6	298	2.20
1902	473.2	98.7	374.5	131	2.86
1903	1,567.0	627.0	940.0	227	4.14
1904	777.2	188.0	589.2	148	3.98
1905	1,660.0	986.0	674.0	265	2.54
1906	1,728.5	842.0	886.5	289	3.07
1907	2,014.9	1,436.0	578.9	318	1.82
1908	1,053.2	356.0	697.2	311	2.24
1909	1,690.5	933.0	757.5	295	2.57
1910	1,187.0	556.0	631.0	326	1.94
1911	2,077.4	1,037.0	1,040.4	[illegible]28	3.17
1912	[illegible]590.5	349.0	[illegible]41.5	[illegible]64	[illegible]
1913	375.0	[illegible]93.0	[illegible]82.0	[illegible]42	[illegible]
1914	1,409.6	591.0	818.6	369	2.22
1915	1,261.8	471.0	790.8	359	2.20
1916	1,824.4	762.0	1,062.4	376	2.82
1917	1,670.8	779.0	891.8	393	2.27
1918	1,057.0	263.0	794.0	305	2.60
1919	1,412.8	612.0	800.8	391	2.05
1920	2,028.7	1,041.0	987.7	398	2.48
1921	1,678.7	863.0	815.7	431	1.89
1922	1,724.9	674.0	1,050.9	412	2.55
1923	1,775.2	697.0	1,078.2	450	2.40
Average	1,440.8	647.0	793.2	326	2.52

NOTE.—Columns 2, 3, and 4 after Hedke, column 5 from chart by Bliss, and column 6 computed by the Bureau of Agricultural Engineering.

Experimental Studies

Table 29 reports some results of experimental work conducted by the Bureau of Agricultural Engineering and the Colorado Agricultural Experiment Station, in cooperation with the Costilla Estates Development Co., on three tracts near San Acacio, Colo. (24). Each crop was grown on a group of plots, the groups including from 2.1 to 11.1 acres. Three farms were involved in the experiments. The soil of one farm was one of the heavy types of sandy loam, cut up by gravel deposits; the soil of the second was much heavier, in some places almost adobe, with a few gravel deposits and on one side some sand; the soil of the third was sandy.

Tank Experiments

Meeker has given the results of tank experimen[illegible] near Monte Vista on use of water by meadow grass as follows (43): The consumptive use of water from May

TABLE 29.—*Irrigation water applied monthly, rainfall, and total water received on experimental tracts near San Acacio in San Luis Valley, Colo. (24)*

Year	Irrigations, number	Monthly application of water in acre-feet per acre: May	June	July	August	September	October	Total quantity of water received by crop in acre-feet per acre: Irrigation	Rainfall	Total
ALFALFA										
1913	3	0.77		0.30		0.28		1.35	0.49	1.84
1913	4	.82	0.31		0.41		0.19	1.73	.49	2.22
1913	3	.39	.45		.59			1.43	.49	1.92
1914	3	.62	1.16	.99				2.77	.70	3.47
1914	4	.21		.92	.90			2.03	.70	2.73
1914	3	.65		.87	.45			1.97	.70	2.67
1914	3	1.31	.61	.97				2.89	.70	3.59
BARLEY										
1913	2	0.42		0.44				0.86	0.38	1.24
1913	3	.39	0.45		0.53			1.37	.38	1.75
1913	3		.59	.42	.45			1.46	.45	1.91
OATS										
1913	2	0.51		0.47				0.98	0.38	1.3[illegible]
1913	3		0.41	.12	0.19			.72	.45	1.[illegible]
1913	3	.42		.42	.62			1.46	.45	[illegible]
1914	2		.46	.74				1.20	.70	1[illegible]
1914	2		.54	.85				1.39	.70	2.[illegible]
PEAS										
1913	2		0.42	0.44				0.86	0.42	1.28
1913	2	0.61		.46				1.07	.49	1.56
1913	3	.55		.20	0.24			[illegible]	.49	[illegible]
1914	[illegible]		1.02					1.02	.70	1.72
1914	4		.52	.99				1.51	.70	2.21
PEAS AND BARLEY										
1914	3		1.18	0.71				1.89	0.70	2.59
1914	3		.85	.44				1.29	.70	1.99
1914	4		.52	.99				1.51	.73	2.24
PEAS AND OATS										
1913	3	0.42		0.42	0.62			1.46	0.45	1.91
1913	3	.42		.42	.62			1.46	.45	1.91
1914	3		1.24	1.05				2.29	.70	2.99
1914	3		.89	.98				1.87	.70	2.57
1914	3		.70	.89				1.59	.70	2.29
1914	4		.52	.99				1.51	.70	2.21
POTATOES										
1913	2			0.27	0.33			0.60	0.45	1.05
1913	2		0.30		.24			.54	.45	.99
WHEAT										
1913	2	0.43		0.28				0.71	0.42	1.13
1913	2		0.66	.80				1.46	.42	1.88
1913	3	.61		.19	0.19			.99	.49	1.48
1913	3	.42		.42	.62			1.46	.45	1.91
1914	3	.33		.78				1.11	.73	1.8[illegible]

to October 1927, inclusive, was 1.49 acre-feet per acre, of which 0.67 acre-foot was supplied by precipitation. The depth to water table was about 8 inches during the summer months and 18 inches in October. For the period April 19 to September 14, 1928, the use was 2.17 acre-feet per acre, of which 0.44 acre-foot was precipitation. Two cuttings of hay per year were made and the irrigation season was from about May 1 to September 1.

Tipton and Hart, for the State engineer of Colorado, conducted studies of the use of water by salt grass from tanks, and of evaporation, for several years at Garnett, in San Luis Valley. The results for 1927, 1928, 1930, and 1931 are set out in unpublished reports (70), (71).

The evaporation and transpiration laboratory was established at Garnett in 1927 and continued in 1928. The station was rehabilitated and placed in operation again in April 1930 by Hart. No change was made in the apparatus or in the depth at which the water table was maintained in the various tanks. An additional salt grass tank was installed to maintain the water table at a depth of about 40 inches, but this tank did not begin to function properly until late in the season. Micrometer hook gages were installed on the free water surface tanks. Charles Speiser, United States Weather Bureau observer at Garnett, again was retained as observer. Readings of all apparatus were made two to three times a week. Daily temperature, wind movement, precipitation, evaporation, and evapo-transpiration records were kept.

Tanks nos. 1, 2, 3, and 4 were 3 feet in diameter and 3 feet deep, sunk in the ground nearly flush with the rim and filled with sandy loam soil. The soil was placed in these tanks in the spring of 1927; therefore the soil, together with the vegetation on it, was well stabilized in 1930. Tanks nos. 1, 2, and 3 had a growth of salt grass with water levels maintained at approximate depths of 4, 12, and 24 inches, respectively, and Tank no. 4 held saturated bare soil. The water table was maintained below the surface by means of Mariotte apparatus. Tank no. 4A was similarly installed in 1930 except that it was 4 feet deep with the water level kept at about 40 inches below the surface. Tank no. 5 was 3 feet in diameter and 3 feet deep, sunk in the ground nearly flush with the rim and filled with water. The water level was maintained about 2 inches below the rim. Tank no. 6 was a standard Weather Bureau land pan.

The results of these experiments are summarized in tables 30 and 31. The investigation was divided into two periods, separated by the year 1929 during which no records were obtained. Although the Mariotte apparatus was designed to hold the water table in the soil tanks at constant levels, fluctuations of 2 to 3 inches occurred. Total consumptive use during the growing season is influenced by the depth to water, plants located where water is near the surface showing the greater consumptive use because of more luxuriant growth and increased soil evaporation. Fluctuation of two or three inches is, however, too small noticeably to influence the quantity of water used by the plant.

The effect of differences in predetermined depths is apparent in the salt grass tanks. During the seasons 1927 and 1928 with consumptive use measurements from June to October, inclusive, the average use of water per season, when the water table was 4 to 5 inches below the surface, was 1.57 acre-feet per acre. In the tank having depth to water of approximately 15 inches, the grass used 1.48 acre-feet per acre, and in the tank having a water table at 24 inches the grass used only 1.20 acre-feet per acre. Such tests, however, do not give conclusive evidence of consumptive use at depths greater than those in the soil tanks. The data obtained do not plot as a straight line but as a curve which becomes unreliable when produced to represent depths of more than three feet. During the seasons of 1930 and 1931 consumptive use records were obtained for the period May to October, inclusive, instead of June to October as during the first year of the investigation, and the use of water was consequently greater for the longer season. The increase was partly attributable, however, to the long period (several years) in which the salt grass plants had fully developed their root systems.

Averaging the total use of water during the 4-year period, regardless of the length of season, shows that salt grass in tank no. 1 used 1.78 acre-feet per acre with

TABLE 30.—*Results of tank experiments on consumptive use of water by salt grass and evaporation, Garnett, San Luis Valley, Colo., 1927 and 1928*

Month	Consumptive use in feet (acre-feet per acre), salt grass						Evaporation in feet					
							Soil		Water			
	Tank number and year											
	1		2		3		4[1]		5[1]		6[2]	
	1927	1928	1927	1928	1927	1928	1927	1928	1927	1928	1927	1928
April	-----	0.23	-----	0.21	-----	0.16	-----	0.27	-----	0.32	-----	0.32
May	-----	.31	-----	.29	-----	.23	-----	.39	-----	.39	-----	.43
June	0.38	.46	0.38	.46	0.26	.32	0.47	.47	0.48	.55	0.49	.60
July	.32	.53	.33	.44	.23	.42	.37	.53	.44	.47	.45	.52
August	.33	.36	.34	.29	.29	.24	.41	.44	.35	.42	.34	.44
September	.25	.23	.27	.19	.22	.19	.29	.36	.29	.33	.28	.34
October	.14	14	.17	.10	.11	.13	.22	.26	.22	.27	.22	.27
June to October	1.42	1.72	1.49	1.48	1.11	1.30	1.76	2.06	1.78	2.04	1.78	2.17
Mean depth to water (in inches)	6	4½	15	14	25	24	0	0	-----	-----	-----	-----

[1] Evaporation has been reduced to field conditions by applying coefficient 0.85 to original data.

[2] Evaporation has been reduced to field conditions by applying coefficient 0.67 to original data.

NOTE.—Tanks nos. 1, 2, 3, 4, and 5, 3 feet in diameter and 3 feet deep sunk in ground. Tank no. 6 standard U. S. Weather Bureau land pan.

TABLE 31.—*Summary of results of tank experiments on consumptive use of water by salt grass and evaporation at Garnett, San Luis Valley, Colo., 1930 and 1931*

Month	Consumptive use in feet (acre-feet per acre) by salt grass								Evaporation in feet					
									Soil		Water			
	Tank number and year													
	1		2		3		4A		4 [1]		5 [1]		6 [2]	
	1930	1931	1930	1931	1930	1931	1930	1931	1930	1931	1930	1931	1930	1931
April	....	0.25	....	0.14	....	0.07	....	0.13	....	0.47	....	0.36	....	0.35
May	0.39	.30	0.22	.25	0.22	.16	....	.14	0.52	.56	0.52	.47	0.52	.47
June	.57	.44	.36	.52	.35	.35	....	.33	.53	.58	.56	.54	.53	.58
July	.45	.48	.43	.56	.36	.47	....	.38	.44	.55	.44	.51	.44	.53
August	.43	.40	.34	.49	.28	.38	....	.33	.32	.42	.35	.46	.38	.44
September	.25	.25	.29	.29	.25	.27	0.12	.25	.31	.32	.35	.33	.33	.33
October	.17	.15	.11	.13	.11	.12	.11	.12	.16	.26	.24	.27	.24	.26
November 1-16	....	.04	....	.02	....	.01	....	.01	....	.08	....	.07	....	.07
May to October	2.26	2.02	1.75	2.24	1.57	1.75	....	1.55	2.28	2.69	2.46	2.58	2.44	2.01
Mean depth to water (in inches)	4	3.3	9.5	11.8	23.1	25.4	39.1	37.5	0.25	0	....	....	....	....

[1] Evaporation has been reduced to field conditions by applying coefficient 0.85 to original data.
[2] Evaporation has been reduced to field conditions by applying coefficient 0.67 to original data.

NOTE.—Tanks nos. 1, 2, 3, 4, 4A, and 5 were 3 feet in diameter and 3 feet deep sunk in ground. Tank no. 6 standard U. S. Weather Bureau land pan.

an average depth of 4.5 inches to the water table. Tank no. 2 consumed 1.74 acre-feet per acre with an average depth of 12.6 inches to water—practically the same as the tank with a higher water level. Tank no. 3 used 1.43 acre-feet per acre, with the water table 24.4 inches below the surface. The slight difference in consumptive use between the first two tanks indicates a nearly uniform use of water for all depths to 15 inches; small differences within this range probably were caused by soil evaporation rather than actual use of water by plant growth.

Middle Rio Grande Valley

There are no complete crop-area records for Middle Valley like the records for Mesilla Valley, but various estimates of consumptive use have been made by engineers, as follows.

Conkling-Debler

Water losses in the Valley and annual water demand are considered in part III of the Conkling-Debler report of 1919 (12), from which the following estimates are taken.

On the basis of a study of available records of flow at Buckman and at San Marcial for the period 1895 to 1918, supplemented by records and estimates of arroyo inflow, the "actual loss" is calculated as 508,400 acre-feet per year, the minimum estimated for the period being 260,000 and the maximum 680,000 acre-feet.

Conkling and Debler point out that these estimates covered a period in which the river was low at San Marcial for 9 years, and that if irrigation had been fully practiced the losses would have been greater. Their estimate for new conditions after irrigation is extended allows for 15,000 acre-feet of additional loss, making a total of 523,000 acre-feet, exclusive of rainfall.

Land surveys.—The New Mexico State engineer made a preliminary survey of the Middle Valley lands in 1918. His classification of areas and the meaning of each class are quoted by Conkling and Debler (12) as follows:

Land areas.—The total gross area of the valley, as determined by the survey, including all areas from the foot of the slopes as nearly as may be determined, is 206,012 acres, classified as follows:

	Acres
Cultivated (class I)	40,063
Cultivated (class II)	8,732
Alkali and salt grass	51,977
Swamp	6,517
Timber	37,594
River and river wash	27,536
Other valley	33,593
Total	206,012

In cultivated (class I) of this classification is included all areas that are being cultivated and, by a superficial examination, do not show that crops are being impaired by a too high water table. It does not mean that the land is not suffering from a high water table or even endangered, nor that it will grow all crops without injury, but that there are no surface indications of a shallow soil.

In cultivated (class II) are included those cultivated areas which do show indications of a high water table either by evident saturated soil or the presence of alkali or by affected crops.

In alkali and salt grass are included those areas which are not being farmed, have visible quantities of alkali or are overgrown with salt grass. It is usual that such areas have the water table within a very few inches of the surface and during periods of high water table it may be at, or even above, the ground surface.

The swamp areas are those that have the ground water exposed and are indicated by the water surface, marsh and rushes. This class is very closely related to alkali and salt grass areas as the two may oscillate to a certain extent with fluctuations of the ground water within the same year or from year to year.

The timbered areas are those overgrown with timber or brush, ually cottonwoods, willows, or thorn bushes.

In the river and river wash areas are those actually occupied by the river or the washed channels through which the water flows at a higher river stage. These latter are usually free from vegetation and consist of washed sand or gravel.

In the other valley areas are included all lands that do not come under the other classifications and may be sand wastes or sand dunes or sage brush either above or below ditches, and village or town areas.

Integration method estimates.—Table 32, which is taken from the Conkling and Debler report (12), shows the assumed acreages and total use of water for each class of land in the Valley.

TABLE 32.—*Loss in Middle Rio Grande* [1]

Land classification	Acres, from State engineer's report	Assumed evaporation or use of water in acre-feet per acre	Total, 1,000 acre-feet
Cultivated, class I	40,100	2.5	100.2
Cultivated, class II	8,700	3.0	26.1
Salt grass and alkali	52,000	3.3	171.6
Swamp	6,500	5.0	32.5
Timber	37,600	1.4	52.7
River and river wash	27,500	4.5	123.8
Other valley	33,600	.5	16.5

[1] After table 25 of the Conkling and Debler report (12).

In a consideration of the water demand for the lley, Conkling and Debler said:

As the consumptive use is the criterion on this project as in the San Luis Valley, *the actual diversions are quite unimportant so long as the excess over consumptive use does not exceed drainage capacity and cause excessive evaporation from the ground surface.*[8]

[8] Italics by Bureau of Agricultural Engineering.

Hedke

In January 1925, Hedke, in his report for the Rio Grande Valley Survey Commission (27), estimated the "present normal stream depletions" as 565,000 acre-feet. His estimates are based on the State engineer's area distribution of the Valley lands into eight classes as reported by Conkling and Debler. However, Hedke used different assumed unit amounts of use for each class of land, with two exceptions.

The details of Hedke's tabulation are reproduced in these pages as table 33, from which it appears that alkali land, swamps, and river bed caused an estimated stream-flow depletion of nearly 330,000 acre-feet. This is 58 percent of the total depletion estimated by Hedke as 565,000 acre-feet.

In his report Hedke says: "The depletion under full development and with drainage, is calculated to be about 500,000 acre-feet,[9] a saving in water of 65,000 acre-feet." The basis of the latter estimate has not been found by the Bureau of Agricultural Engineering. It is noteworthy that Conkling and Debler estimated irrigation expansion would increase the annual use 15,000 acre-feet, where Hedke estimated that under full development and with drainage it would be decreased 65,000 acre-feet per year.

Debler-Elder

On December 15, 1927, E. B. Debler and C. C. Elder, of the Bureau of Reclamation, completed a "Preliminary Report on Middle Rio Grande Investigation—New Mexico" [10] (18), which contains an extended

[9] Conkling and Debler estimated 523,000 acre-feet.

[10] A final report of the Middle Rio Grande investigation was made by E. B. Debler in 1932.

TABLE 33.—*Normal stream-flow depletions with monthly distribution* [1] *Middle Rio Grande Valley, N. Mex., for the year 1925, by classified areas (after Hedke (27))*

	(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)	
Class (acres)	Total, 206,000		Alkali, 52,000		Timber, 37,600		River bed, 27,500		Cultivated, class 1, 40,100		Swamps, 6,500		Cultivated, class 2, 8,700		Miscellaneous, 33,600	
Use (acre-feet per acre)	2.75		3.6		3.1		4.0		2.0		5.0		2.5		0.5	
Depletion, total (acre-feet)	565,000		187,200		116,500		110,000		80,200		32,500		21,800		16,800	
Month	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet	Percent	1,000 acre-feet
January	1.0	7.1	2	3.7	1	1.2	1	1.1	------	------	2	0.6	1.5	0.3	1.5	0.2
February	3.0	17.4	5	9.4	2	2.3	1	1.1	2	1.6	5	1.0	3.5	.8	3.5	.6
March	6.0	36.0	8	15.0	6	7.0	5	5.5	4	3.2	8	2.6	7.0	1.5	7.0	1.2
April	10.0	54.6	11	20.6	8	9.3	10	11.0	8	6.4	11	3.6	9.5	2.1	9.5	1.6
May	15.5	86.6	14	26.2	12	14.0	25	27.5	14	11.3	14	4.5	13.0	2.9	13.0	2.2
June	17.0	94.4	14	26.2	14	16.3	25	27.5	18	14.4	14	4.6	14.0	3.1	14.0	2.3
July	14.0	78.8	12	22.4	16	18.6	12	13.2	19	15.3	12	3.9	14.0	3.0	14.0	2.4
August	12.0	68.3	10	18.7	16	18.6	9	9.9	16	12.8	10	3.3	13.0	3.8	13.0	2.2
September	9.0	51.4	9	16.9	12	14.0	5	5.5	10	8.0	9	2.9	10.5	2.3	10.5	1.8
October	6.5	36.9	7	13.1	8	9.4	4	4.4	6	4.8	7	2.3	7.5	1.6	7.5	1.3
November	4.0	21.9	5	9.4	4	4.6	2	2.2	3	2.4	5	1.6	4.5	1.0	4.5	.7
December	2.0	9.6	3	5.6	1	1.2	1	1.1	------	------	3	1.0	2.0	.4	2.0	.3
Total	100	565.0	100	187.2	100	116.5	100	110.0	100	80.2	100	32.5	100	21.8	100	16.8

[1] Monthly distribution based as follows: Columns 3 and 5, thermal consumptive use; columns 2 and 6, free water evaporation; columns 7 and 8, mean of the above 2; column 4, evaporation and quantity. Seasonal distribution: Nonirrigation, 92,000 acre-feet; high water, 238,000 acre-feet; low water, 235,000 acre-feet.

discussion of the water supply for Middle Rio Grande Conservancy District, including estimates of valley stream-flow depletion and consumptive use. On the basis of comparison of the Middle Valley stream-flow depletion with that of Mesilla Valley for the years 1923–25, inclusive, they concluded that, on the whole, the Middle Valley use will be 10 percent higher than the Mesilla Valley use; hence it was estimated that the future irrigation-season use of the Middle Valley would be 570,000 acre-feet.

Debler and Elder contemplated Valley losses under conditions then existing from two aspects, namely, those of (1) stream-flow losses, and (2) experimental determination of evaporation and transpiration losses for typical conditions. They placed their chief reliance on stream loss determinations, preliminary data only being available in December 1927 for the evaporation and transpiration estimates.

Two methods were used to determine Valley losses from stream-flow records: "(a) By an estimate of surface inflow to the Middle Valley from tributaries entering Rio Grande between Buckman and San Marcial with such tributary inflow plus the difference in Rio Grande flow at Buckman and San Marcial representing Valley losses, all by annual amounts, and (b) by estimates of monthly losses based on seepage runs in periods of negligible inflow between Buckman and San Marcial."

The Valley loss according to Debler and Elder is a function of the annual flow at Buckman (18). Their report gives in tabular form estimated losses in Rio Grande discharge from Buckman to San Marcial for the years 1895 to 1926 based on conditions of 1927 and also based on discharges at Buckman. The average for the period is 510,000 acre-feet per year. The year 1904 showed the minimum of 310,000 acre-feet and 1907 the maximum of 694,000 acre-feet. Adding an estimated annual rainfall contribution of 0.71 feet on a valley area of 206,000 acres, equal to 146,000 acre-feet, plus an estimated "gain from deep percolation in the upper portion of the Valley, between Buckman and Bernalillo of 72,000 acre-feet" (subsurface inflow F_i), they estimated the total annual Valley loss to be 728,000 acre-feet.

Expressed in the terms of the Bureau of Agricultural Engineering's equation 1 on page 347 (neglecting capillary storage C_s-C_e and subsurface outflow F_o), the Debler-Elder estimate of 1927 is as follows[11]:

$$K=(G_s-G_e)+(I-R)+F_i+P$$

hence

$$K=0+510{,}000+72{,}000+146{,}000=728{,}000 \text{ acre-feet}$$

Debler and Elder showed in detail the bases of their estimates of evaporation and transpiration losses for 1927 undrained-land conditions. The total annual estimated loss on their bases was 755,900 acre-feet.[12] This is 4 percent higher than the result of the inflow-outflow method computation—728,000 acre-feet. A cording to Debler and Elder, the difference may rep sent subsurface (deep percolation) inflow from Bernalillo to San Marcial.

Use of water in the Middle Rio Grande Valley under future conditions of drainage and irrigation was estimated as 570,000 acre-feet for the irrigation season, March to October, in years of normal run-off, when a full irrigation supply is available for diversion. A nonirrigation season return flow correction factor of 35,000 acre-feet, based upon Mesilla Valley experience, was applied, thus making a "net loss from surface waters of 535,000 acre-feet annually." Hence their inflow minus outflow $(I-R)$ average of 510,000 acre-feet is only 5 percent lower than the estimate based on Mesilla Valley experience for 3 years.

Hosea

In 1929 then Chief Engineer J. L. Burkholder, of the Middle Rio Grande Conservancy District, submitted to the district's board of commissioners a plan for flood control, drainage, and irrigation, which contained a detailed study of water requirements of the district made by R. G. Hosea under the direction of the late D. C. Henny.

Hosea reported the consumptive use (stream-flow depletion) in Mesilla Valley for the years 1924 to 19 as 3.1, 3.3, 3.4, 3.5, and 3.8 acre-feet per acre, respe tively, the average being 3.42.

Alfalfa and grains are the major Middle Valley crops, whereas cotton (which requires less water than alfalfa) is the dominant crop in Mesilla Valley. Hosea therefore estimated the Middle Valley river depletion requirement as 15 percent higher than that of Mesilla Valley, or 3.9 acre-feet per irrigated acre. On this basis and taking the irrigated area as 123,265 acres, the average annual river depletion of the Middle Valley would be 480,740 acre-feet.

Consumptive use (rainfall deducted) computations made by the integration method on assumed unit amounts for agricultural and other lands, as tabulated by Hosea, are here reproduced as tables 34 and 35, because of their relation to the Bureau of Agricultural Engineering's studies. Table 99 shows that the average crop consumptive use in Mesilla Valley during the 17-year period 1919–35, as estimated by the Bureau of Agricultural Engineering, was 173,082 acre-feet. Dividing this amount by 65,814, the average area of irrigated land, shows a crop consumptive use of 2.63 acre-feet per acre. In table 34 Hosea used an average of 3 acre-feet per acre of irrigated land. Mesilla Valley experience appears to indicate that this is a liberal estima

[11] It should be noted that the quantity K is equal to the sum of $K_s+K_f+K_a+E_w+E_i$ in equation 1.

[12] From another computation the total was shown as 753,900 acre-feet.

TABLE 34.—*Estimated annual consumptive use of river water in Middle Rio Grande Valley, N. Mex.*[1]

[In acre-feet]

Classification	Division				Total use
	Cochiti	Albuquerque	Belen	Socorro	
Conservancy district lands, 123,267 acres at 3.0 acre-feet	39,000	111,615	172,197	46,989	369,801
Other irrigated lands, 1,200 acres at 3.0 acre-feet				3,600	3,600
River channel evaporation losses, 24,836 acres at 3.9 acre-feet	16,575	23,400	33,930	22,963	96,868
Excluded areas, 2,757 acres at 2.9 acre-feet				8,000	8,000
Rights-of-way, etc., 17,798 acres at 3.0 acre-feet	3,000	19,518	16,860	14,016	53,394
Total project	58,575	154,533	222,987	95,568	531,663
Excluded areas between project and San Marcial, 13,385 acres at 2.9 acre-feet					38,817
River channel between project and San Marcial, 1,963 acres at 3.9 acre-feet					7,656
El Vado Reservoir evaporation					9,000
Total Valley					587,136
Less drainage return (Socorro division entire year; Cochiti, Albuquerque, and Belen division, November to February					94,849
Net annual consumptive use entire Valley					492,287

[1] After table 30 of Hosea's report (9).

TABLE 35.—*Estimated future losses of water, Middle Rio Grande Valley,*[1] *N. Mex.*

Classification	Average depth to water table in feet	Area in acres	Loss in acre-feet per acre	Total loss in acre-feet per year
Irrigated area	6	123,600	3.0	370,800
River banks and bars	0-2	18,920	3.8	71,900
River open water	0	10,000	4.6	46,000
Unbenefited area (Pueblito, Bosquecito, Val Verde and San Marcial), irrigated	2-4	2,200	3.0	6,600
Unirrigated:				
Bosque	3-4	5,600	3.6	20,100
Salt grass	1-3	[illegible],500	3.5	[illegible],250
Swamp	0	70	7.0	500
Sand dunes	0	200	1.0	200
Other areas [2]	(3)	43,910	3.0	131,730
Total for Valley		206,000		653,080
Deduct rainfall of 0.71 inch over 206,000 acres equals				146,000
Estimated loss				507,080

[1] After table 31 of Hosea's report (9).
[2] Including sand bars, mesa or upland, fallow, unirrigated homesites, road and ditch rights-of-way, areas above ditches and below foot of mesa slopes, etc.
[3] Variable.

Debler (1932)

The results of only one season's work at the Los Griegos Experiment Station (p. 340) were available when the Debler-Elder report was prepared, whereas all the data from that station were used by Debler in his 1932 report (17). The relative maturity of the 1932 report and its direct bearing on the stream-flow depletion and consumptive use problem in the Middle Valley justify liberal reference to it in this report.

Debler again used Mesilla Valley data as a basis of estimating Middle Valley water needs. He gave particular attention to the Mesilla Valley quantity stream-flow depletion plus change in ground-water storage for the years 1926 to 1929, inclusive, and found that it averaged 257,200 acre-feet. The average irrigated area was 75,579 acres. Thus the average consumptive use, excluding precipitation, was 3.40 acre-feet per acre irrigated. As was done in the Debler-Elder report of 1927, 10 percent was added to allow for extra water needs of alfalfa in the Middle Valley, thus making the estimates for Middle Valley 3.74 acre-feet per irrigated acre and 430,500 acre-feet for an irrigated area of 115,000 acres. With the addition of 49,500 acre-feet net losses in river channel, use by salt grass, bosque, swamp, and miscellaneous uses, the total Valley use, exclusive of rainfall, would appear to be 480,000 acre-feet. No allowance was made for arroyo inflow.

TABLE 36.—*Estimated future Valley losses, Middle Rio Grande Valley, N. Mex.*[1]

Classification	Area in acres	Rate of loss in feet of depth per year	Total annual loss in 1,000 acre-feet
Irrigable land:			
Net irrigated	115,000	3.2	368.0
Fallow, etc	9,475	1.0	9.5
River channel:			
Free water	10,000	4.6	46.0
Banks and bars	16,800	3.4	57.1
Non-irrigable areas in excluded tracts [2]	16,142	3.4	54.9
Rights-of-way, towns, roads, flood channels	18,298	3.0	54.9
Other lands [3]	24,285	0.71	17.2
Total	210,000		607.6
Less rainfall	210,000	0.71	149.1
Net use river water	210,000		458.5

[1] After table 20 of Debler's 1932 report (17).
[2] Bottom lands excluded as unworthy of development and taken as one-half bosque and one-half salt grass with average water table depths of 3 feet and 1 foot, respectively.
[3] Largely high lands above proposed high line canals.

Approaching the problem of estimating future Valley losses by the integration method and assuming unit rates of loss from each of the several classes of land and river water surface, Debler estimated the annual future Middle Valley loss for the 210,000 acres at 607,600 acre-feet. After deducting rainfall he calculated the "net use of river water" at 458,500 acre-feet (table 36).

In applying the integration method Debler used a rate of loss of 3.2 acre-feet for the irrigated land area of 115,000 acres, basing the assumption on a comparison of Middle Rio Grande Valley with the Boise project, Idaho, for which "consumptive use" had been determined by Paul and Steward.

The 1932 report contains detailed data concerning depths to water table, classification of valley land, and estimates of losses based on assumed unit losses for different classes of land and different depths to the water table. The unit loss taken for agricultural lands is again 3.2 acre-feet per acre and it is not varied for different water-table depths. For sand dunes, mesa land, gravel, and embankments, the unit loss is taken as equal to the annual rainfall. The annual per acre loss used for free water surface is 4.6 acre-feet, for tule swamps 5.6 acre-feet, and for salt grass with water table within 1 foot of the surface, 4.0 acre-feet. (See table 37.)

TABLE 37.—*Present Valley losses, Middle Rio Grande Valley, N. Mex.*[1]

Classification	Area in acres	Depth to water table, feet	Rate of loss, feet per year [2]	Total annual loss, 1,000 acre-feet
River channel:				
Free water	10,000	0	4.6	46.0
Banks and bars	16,822	0-2	3.4	57.2
Rights-of-way:				
Free water	1,000	0	4.6	4.6
Tule swamps	2,000	A. G.[3]	5.6	11.2
Embankment	3,158	Variable	[4] 0.71	2.2
Irrigated homesites, orchards, and gardens	2,114	Over 6	3.2	6.8
	2,114	4 to 6	3.2	6.8
Alfalfa and grain	5,985	Over 6	3.2	19.1
Do	16,284	4 to 6	3.2	52.1
Do	17,732	2 to 4	3.2	56.7
Pasture and hay	1,355	2 to 4	3.2	4.3
Salt grass	1,696	2 to 4	0.9	1.5
Do	22,778	1 to 2	2.7	61.5
Do	20,129	0 to 1	4.0	80.5
Do	4,000	A. G.[3]	4.5	18.0
Bosque	32,821	2 to 4	3.5	114.9
Do	5,000	1 to 2	4.0	20.0
Swamp and lake:				
Free water	715	0	4.6	3.3
Tules	2,609	A. G.[3]	5.6	14.6
River and arroyo wash	1,290	0 to 2	3.4	4.4
Barren alkali	275	A. G.[3]	4.0	1.1
Sand dunes, mesa, and gravel	4,400	Over 6	[4] 0.71	3.1
Fallow land and nonirrigated homesites.	8,566	Variable	3.0	25.7
Total for lands under present ditches.	182,845			615.6
Other areas:				
High land above canals	[5] 24,285	Over 6	[4] 0.71	17.3
Seeped and swampy	2,870	A. G.[3]	5.0	14.3
Total	210,000			647.2

[1] After table 46 of Debler's 1932 report (17).
[2] Inclusive of rainfall.
[3] A. G. equals average above ground, although below the surface during parts of the year.
[4] Assumed equal to average annual rainfall.
[5] Area taken from table 24, 1928 report by Burkholder (9).

On the basis of these estimates and others similar, together with the land classification made by the appraisal section of the conservancy district and the numerous observations of depth to water table (with resulting classification of land areas having water table at different depths), Debler estimated the total annual loss to be 547,200 acre-feet from a 210,000-acre valley area. This is 88.5 percent of the 733,000-acre-feet loss estimated from stream-flow records. Debler says the difference "may be largely accounted for by the approximations necessary in arriving at the estimates."

Résumé

For convenience of reference the estimates by different engineers, of stream-flow depletion, precipitation and other water losses in the Middle Valley are brought together in table 38. It is evident from the remarks in column 7 that the quantities in column 4 designated $(I-R)$ are not rigorously comparable. However, in spite of the estimated differences between present and future losses the greatest departure of any one esti from the average of the 10 estimates, namely 505, acre-feet, is only 12 percent. Four-fifths of the esti mates are within 10 percent of the average. Neverth less, stream-flow depletion $(I-R)$ for any one year ma depart widely from the average. (See Conkling and Debler (12), table 22.)

TABLE 38.—*Résumé of estimates of stream-flow depletion $(I-R)$, precipitation (P), and sub-surface losses (F_i) for the Middle Rio Grande Valley, N. Mex.*

Authority and year	Method of estimating	Period covered	Estimated amounts in 1,000 acre-feet			Remarks
			$(I-R)$	P	F_i	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Conkling and Debler (1919).	Inflow-outflow.	1895-1918	508			River dry part time.
	do		523			New conditions.
Hedke (1925)	Integration	Present normal.	565			Present normal depletion.
	do	Future	500			Future.
Debler	Inflow-outflow.	1895-1926	510	146	72	
Elder (1927)	Comparison [1]		535			
Hosea (1929)	do. [2]		481			
Debler (1932)	do. [3]		[4] 480			
	Integration		458	149		Future losses.
	do		498	149		Present losses.

[1] Taken as 10 percent higher than Mesilla Valley average for years 1923-25, inclusive.
[2] Taken as 15 percent higher than Mesilla Valley average for years 1924-28, inclusive.
[3] Taken as 10 percent higher than Mesilla Valley average for years 1926-29, plus difference in ground-water storage at beginning and end of year (G_s-G_e).
[4] Includes 49,500 acre-feet for nonagricultural lands.

Tank Experiments

An experiment station was established by Debler . the Bureau of Reclamation in cooperation with the Middle Rio Grande Conservancy District and the Weather Bureau, in August 1926 near Los Griegos, about 5 miles northwest of Albuquerque, to determine evaporation and transpiration losses (9), (17). The station was located in a salt grass pasture, the soil, vegetation, and surroundings being typical of the low-lying undrained lands of the Valley.

Stock tanks of 4.0 feet diameter were ordered but the actual diameter of pan no. 2 was 48¼ inches and that of all others approximately 45½ inches. Pan no. 1, open water, 2.0 feet deep, was set 1.75 feet in the ground with the water level maintained 3 inches below the rim. A pointed meter gage was fixed in the center of the pan and the water surface was brought to this level daily by adding or removing water with a rated cup. The pan was more nearly like a floating pan than an ordinary ground pan, as the ground-water table was close to the surface, its depth varying from 8 inches to 20 inches during the period of observation.

Pan no. 2, 48 inches diameter, 10 inches deep, was filled to a depth of 8 inches. This was an open water standard Weather Bureau pan mounted on timber grillage and subject to free circulation of air. A regulation gage [illegible] not available and evaporation was measured in the same manner as with pan no. 1.

Pans nos. 3 to 7 were set in the ground with approximately a 3-inch rim inside and out. The bottom of each was filled with 6 to 8 inches of coarse gravel. Soil was then replaced in pans nos. 4, 5, and 6, which were of 4-foot, 3-foot, and 2-foot depths, respectively, and planted with salt grass sod. Pans nos. 3 and 7, of 4-foot and 2-foot depths, respectively, were filled with river wash material, hauled from a sand bar on the bank of the Rio Grande, composed of rather fine sand with traces of silt. The water table depths in the pans were maintained at predetermined depths by use of Mariotte apparatus, the equipment being similar to that used at the Fort Collins laboratory of the Bureau of Agricultural Engineering.

The results of measurements at the Los Griegos station are shown in tables 39 and 40. Data on soil evaporation and consumptive use by salt grass and tules are given in table 40. There was some difference in water use by salt grass during the 2 years, the greater use occurring during 1927–28. Use by salt grass

TABLE 39.—*Evaporation and meteorological records 1926–28 at Los Griegos station, Middle Rio Grande Valley, N. Mex.*[1]

Period	Evaporation, feet		Mean monthly air temperature, °F.	Monthly precipitation, inches	Mean wind velocity, miles per hour[2]	Relative humidity, percent
	Ground pan no. 1	Weather Bureau pan no. 2				
1926						
September	0.465	0.585	67.2	1.04	2.7	59
October	.314	.417	57.3	1.03	2.4	64
November	.240	.330	44.2	T	3.5	50
December	[3].075	[3].106	35.4	1.01	2.4	75
1927						
January	.384	.121	38.9	T	2.0	64
February	.196	.269	44.0	.34	3.6	56
March	.384	.519	46.5	.50	4.7	50
April	.470	.697	53.9	.17	4.0	45
May	.768	1.103	61.8	T	4.6	30
June	.569	.850	67.9	1.00	3.1	45
July	.650	.937	74.7	.80	2.7	55
August	.555	.760	71.3	1.62	2.5	60
September	.406	.558	66.3	1.34	2.8	62
October to September	4.717	6.673	55.2	7.81	3.2	54.7
1927						
October	.322	.462	54.7	.19	2.2	48
November	.213	.282	46.6	.04	2.5	55
December	.089	.121	31.5	.06	3.2	68
1928						
January	.090	.168	33.5	.00	2.6	33
February	.158	.242	38.2	.32	3.6	44
March	.359	.514	47.1	.06	3.6	31
April	.500	.718	52.0	.75	5.1	29
May	.445	.676	61.5	1.38	3.3	39
June	.720	1.060	68.5	.00	3.8	22
July	.617	.917	73.5	1.43	2.4	43
August	.614	.699	70.2	2.65	2.6	62
September	.444	.611	63.6	.15	2.3	43
October to September, inclusive	4.571	6.470	53.4	7.03	3.1	43.1

[1] Station located ½ mile east of Rio Grande, about 5 miles northwest of Albuquerque, elevation 4,970 feet. Records by E. B. Debler and C. C. Elder, United States Bureau of Reclamation. After table 35 Debler's 1932 report (17).
[2] Anemometer 2 feet above ground surface.
[3] Ice-covered during most of December and to Jan. 9, 1927.

appears to be in direct ratio to depth to water table; that is, it plots as a straight line. This becomes more evident as depth to the water table increases and consumptive use decreases. For instance, with the water table at 2 feet in depth, consumptive use was [illegible].6 acre-feet per acre during the first year, and 2.1 acre-feet per acre during the second year. However, as ground water approached the surface consumptive use increased to nearly 4 acre-feet per acre per year and was practically the same for each year of the investigation.

Debler's estimated losses for the Middle Rio Grande Valley have been previously set forth. (See table 37.)

Lower Valley

Not all the estimates by engineers, of use of water in Mesilla Valley, are strictly comparable with each other. Some include the entire Rio Grande Project, while others are concerned specifically and alone with the Mesilla Valley portion of the project; but they are so closely related as to justify comparisons even though they can be only approximate. However, in addition to the various studies by engineers, investigation of the use of water by crops in Mesilla Valley has been carried on by the New Mexico Agricultural Experiment Station, much of it in cooperation with the Bureau of Agricultural Engineering. Specific references are made to both sources of data in the following paragraphs:

Estimates by Engineers

A few of the Mesilla Valley and related estimates made by engineers representing the different interested States are reviewed below.

Meeker.—In May 1922 Meeker estimated the "ultimate net" consumptive use for the Rio Grande Project (150,000 acres) as 2.5 acre-feet per acre (36), exclusive of river channel or reservoir losses. In August 1924 he estimated that the actual water consumption from San Marcial to Fort Quitman was 5.7 acre-feet per acre of irrigated land (38). The losses and uses were not segregated in the 1924 analysis; hence the estimate is not comparable to those which preceded and followed it.

On June 8, 1926 the same investigator estimated the consumptive use for irrigated land on the Rio Grande Project above El Paso as 2 acre-feet per acre (40). This figure is roughly comparable to the Bureau of Agricultural Engineering's use by crops per acre irrigated (K_c/A_i) for Mesilla Valley, which for the 17-year period 1919–35, as determined by method B, is 2.7 acre-feet per acre of irrigated land.

On June 20, 1928 Meeker analysed the Bureau of Reclamation's records for Mesilla Valley for the years 1923 to 1927 and reported the consumptive use figures given in table 41 (42).

TABLE 40.—*Evaporation and transpiration losses and depth to water table below ground surface, in feet, Los Griegos station, 1926–28, ...lle Rio Grande Valley, N. Mex.*[1]

Period	Sand and river wash				Salt grass								Ca (t
	Pan no. 3		Pan no. 7		Pan no. 4		Pan no. 5		Pan no. 6		Pan no. 8		Pan no. 9
	Evaporation	Average depth	Evaporation	Average depth	Evaporation and transpiration	Average depth	Evaporation and transpiration	Average depth	Evaporation and transpiration	Average depth	Evaporation and transpiration	Average depth	Evaporation and transpiration
1926													
October	0.19	2.42	0.26	0.37	0.10	2.07	0.18	1.35	0.29	0.48			
November	.10	2.32	.23	.25	.01	2.32	.06	1.15	.06	.40			
December	.12	2.10	.08	.20	.09	2.06	.09	.96	.07	.20			
1927													
January	.02	2.11	.12	.19	.01	1.84	.01	1.17	.03	.26			
February	.10	2.33	.20	.35	.04	1.82	.07	1.24	.07	.39			
March	.17	2.36	.40	.28	.05	1.67	.11	1.10	.14	.40			
April	.17	2.38	.47	.45	.01	1.67	.12	1.23	.26	.47			
May	.16	2.49	.68	.41	.05	2.30	.20	1.22	.59	.37			
June	.16	2.40	.57	.36	.23	2.23	.36	1.28	.59	.41			
July	.11	2.50	.63	.39	.29	2.25	.51	1.27	.75	.41			
August	.20	2.43	.54	.34	.35	2.28	.61	1.12	.67	.40			
September	.14	2.24	.40	.34	.28	2.30	.35	1.06	.49	.39			
October to September	1.64	2.34	4.58	.33	1.51	2.07	2.77	1.18	4.03	.38			
1927													
October	.12	2.38	.32	.20	.16	2.16	.27	1.34	.29	.47	0.04	3.06	0.23
November	.08	1.86	.18	.42	.18	2.02	.10	1.16	.09	.45	.02	3.08	.15
December	.13	1.59	.11	.19	.05	1.89	.05	1.18	.05	.39	.02	3.10	.08
1928													
January	.03	2.10	.13	.33	.01	2.17	.01	1.10	.03	.39	.01	3.07	.10
February	.08	2.22	.17	.23	.04	2.17	.03	1.19	.05	.40	.03	3.04	.14
March	.09	2.38	.35	.31	.03	2.10	.05	1.62	.09	.49	.01	3.04	.30
April	.10	2.17	.43	.31	.10	2.10	.16	1.30	.17	.40	.07	3.09	.43
May	.16	1.78	.44	.28	.22	2.09	.32	1.30	.40	.42	.13	3.09	.44
June	.06	2.18	.58	.42	.18	2.17	.45	1.41	.74	.53	.02	3.09	.89
July	.15	2.26	.57	.34	.32	2.33	.60	1.43	.84	.51	.16	3.09	1.09
August	.20	1.90	.47	.25	.41	2.27	.56	1.41	.64	.48	.28	3.04	.89
September	.13	2.02	.37	.25	.19	2.25	.33	1.41	.48	.51	.05	3.07	.65
October to September	1.33	2.07	4.12	.29	1.89	2.14	2.93	1.32	3.87	.45	.84	3.07	5.39

[1] After table 36 of Debler's 1932 report (17).

TABLE 41.—*Consumptive use of water, Mesilla Valley, N. Mex. and Tex., 1923–27*

What the consumptive use includes	Use in acre-feet per cropped acre				
	1923	1924	1925	1926	1927
River depletion plus annual rain plus arroyo inflow	6.25	3.67	4.12	5.18	4.13
River depletion only	4.48	2.90	3.02	3.32	2.93

Meeker recorded his opinion briefly concerning the above amounts of consumptive use as follows: "Some question about accuracy of records at Leasburg: Irrigated area, which is greater than cropped area, should have been used. The above values are too high and higher than they will be in the future when river conditions are stabilized and water economy practiced. A study of consumptive use between Elephant Butte Reservoir and El Paso by Meeker for past 5 years shows a much smaller consumptive use of reservoir water."

Meeker and Burgess.—In November 1928 Meeker and Burgess reported use for irrigated lands from Elephant Butte Reservoir to El Paso (Courchesne Station) for the years 1920 to 1927, inclusive (44). Their estimate, including river evaporation losses, is 3.23 acre-feet based on the "gross area of irrigated land." They considered the average width of river surface as 400 feet, thus making a water surface area of 50 acres per mile, or 7,000 acres of water surface in all. Using 5.35 feet as the average annual water surface evaporation and deducting the annual water surface loss from the river depletion, they found the consumptive use to be 2.68 acre-feet per acre for the gross area of irrigated land, not including rainfall. If 85 percent of the gross area of land were actually irrigated, then the consumptive use based on the net area would be 3.15 acre-feet per acre. For future conditions Meeker and Burgess estimated the average consumptive use from Elephant Butte Reservoir to El Paso as 2.4 acre-feet per "gross acre of irrigated land" exclusive of rainfall, as compared to 2.68 for the years 1920 to 1927. For the area between El Paso and Fort Quitman they found, on the basis of the 5 years 1923 to 1927, after deducting estimated river and evaporation losses of 88,000 acre-feet per year, a consumptive use of 2.8 acre-feet per acre and an estimated future consumptive use of 2.6 acre-feet per gross acre.

Considering Mesilla Valley only, for the 5-year period 1923 to 1927, Meeker and Burgess found a ...

sump··.e use of 3.5 acre-feet per acre of irrigated land, c.. · ..of arroyo inflow and of rainfall (44).

..od.—In 1928 E. P. Osgood made a report (52) .e consumptive use of the Rio Grande project from ..ephant Butte Reservoir to Fabens, Tex. He seems to have charged all the water loss between Elephant Butte and Fabens against the irrigated land, thus including water losses from water surface and bare land, evaporation losses, and use by native vegetation as consumptive use. His results are roughly comparable, it seems, with the sum of $K_c+K_n+K_f+E_w+E_l$ divided by A_i or, more briefly, to the ratio $I-R/A_i$, provided precipitation and ground water storage are ignored. (See p. 346 for symbols.) The Bureau of Agricultural Engineering's results apply to Mesilla Valley only; whereas the results obtained by Osgood represent the larger area including Rinçon Valley, some Mexico lands and parts of El Paso Valley.

Because Osgood's graph (fig. 77) shows the uses below Elephant Butte Reservoir for each month of the year, it is of special interest. During the years 1919 to 1922, as shown in figure 77, the outflow measurements were at Fabens Bridge, Tex., but during the years 1923 to 1927 they were at Fort Quitman. The "consumptive" use at any time is equal to the vertical distance between the plotted flows at that time.

The results of estimates by Osgood appear in table 42. ^C^lumn 2 shows areas of land irrigated between the ..hant Butte Reservoir and Fabens, Tex.; column 3 ..s the stream-flow depletion comparable to the quantity $(I-R)$ as used in this report, and column 4 shows the stream-flow depletion in acre-feet per acre of irrigated land.

For comparison with Mesilla Valley stream-flow depletion during the same period of years, the inflow at Leasburg as given in column 2 of table 92, less the outflow at Courchesne, divided by the irrigated areas, given in column 7 of table 93, are shown in column 5, table 42. It will be noted that stream-flow depletion results by Osgood have an average for 1919 to 1927 inclusive of 4.0 acre-feet per acre as compared to 3.4 for the Mesilla Valley studies by the Bureau of Agricultural Engineering, thus showing an excess of 18 percent in the Osgood estimates.

TABLE 42.—*"Consumptive use" of water estimates by E. P. Osgood for the lands irrigated between Elephant Butte Dam, N. Mex., and Fabens, Tex., with comparisons to Mesilla Valley stream-flow depletion computations by the Bureau of Agricultural Engineering for the years 1919 to 1927*

Year	Elephant Butte to Fabens; area irrigated in acres	Reservoir water consumed, in acre-feet	Elephant Butte to Fabens; "consumptive use" in acre-feet per acre	Mesilla Valley, stream-flow depletion $\left(\frac{I-R}{A_i}\right)$ in acre-feet per acre [1]
(1)	(2)	(3)	(4)	(5)
1919	92, 238	417, 200	4. 5	3. 4
1920	95, 605	491, 000	5. 1	1. 9
1921	97, 994	404, 700	4. 1	2. 5
1922	98, 062	544, 100	5. 5	4. 5
1923	126, 958	511, 700	4. 0	4. 8
1924	154, 948	629, 500	4. 1	3. 1
1925	173, 978	547, 800	3. 2	3. 3
1926	192. 173	494, 300	2. 8	3. 5
1927	187, 373	656, 980	3. 5	3. 6
Average			4. 0	3. 4

[1] Column 5 has been computed by the Bureau of Agricultural Engineering on the bases of inflow (I) at Leasburg, outflow (R) at Courchesne, and Mesilla Valley irrigated areas (A_i) as reported by the Bureau of Reclamation.

Records of Use of Water

The Bureau of Reclamation keeps records of water distribution for Rincon, Mesilla, and El Paso Valleys. These include monthly amounts of water diverted, main canal waste, main canal losses, and water delivered to farms. E. B. Debler in a report on use of water on Federal irrigation projects gives a summary of records for the Rio Grande project from 1912 to 1926 inclusive (16).

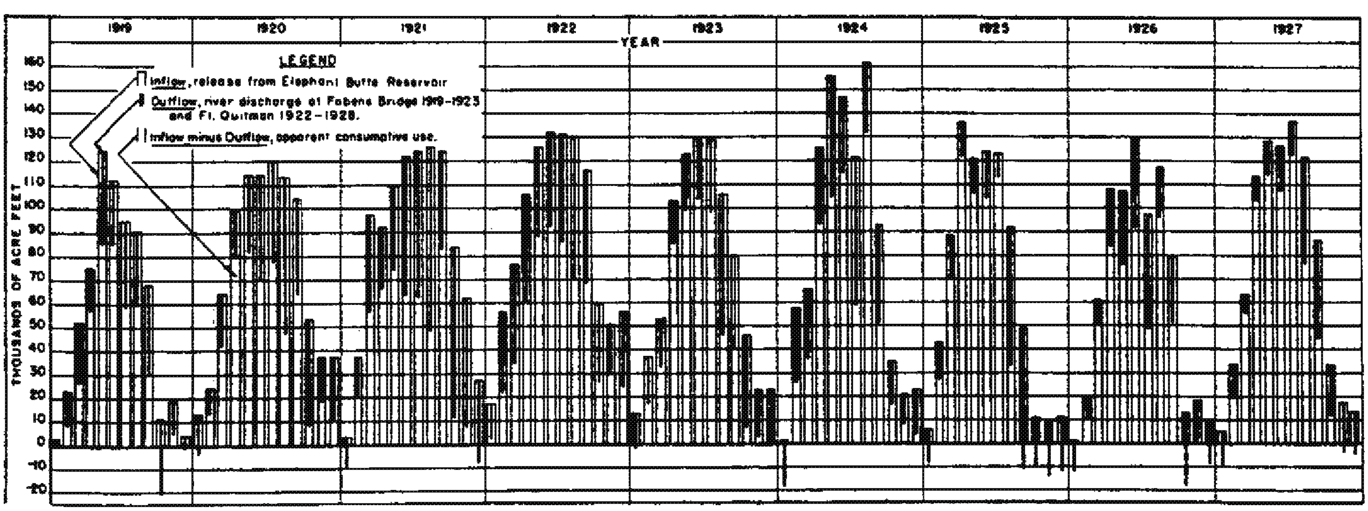


FIGURE 77.—Monthly inflow, outflow, and apparent consumptive use of irrigation water—Rio Grande project. (After E. P. Osgood.)

Experimental Studies

Investigations on the use of water on crops have been conducted by the New Mexico Agricultural Experiment Station and the Bureau of Agricultural Engineerin... many years. Some of the results are reproduced ... tables 43 and 44, inclusive, from United States Depa... ment of Agriculture report (24). Other studies Dean W. Bloodgood, associate irrigation engineer o... the Bureau of Agricultural Engineering, and Albert S. Curry, in charge of irrigation department of the New Mexico Agricultural College, have been published by the college (7), (8), (14).

TABLE 43.—*Irrigation water applied, rainfall, total water received by experimental plots in Mesilla Valley, N. Mex.*[1]

Year	Area irrigated, acres	Irrigations, number	Crop	Total quantity of water in acre-feet received by crop per acre		
				Irrigation	Rainfall	Total
1905	(²)	9	Alfalfa	2.62	0.82	3.44
1905	(²)	9	do	3.38	.82	4.20
1905	3.4	12	do	5.12	.82	5.94
1913	24.4	7	do	3.08	.64	3.72
1913	29.95	7	do	3.04	.64	3.68
1913	6.37	4	do	2.00	.67	2.67
1914	24.4	11	do	3.71	.98	4.69
1914	6.37	7	do	3.18	.50	3.68
1914	14.5	9	do	2.68	.51	3.19
1923	.580	13	do	5.11	.50	5.61
1923	.581	13	do	4.88	.50	5.38
1923	.596	13	do	3.97	.50	4.47
1923	.499	13	do	5.72	.50	6.22
1923	.503	13	do	5.10	.50	5.60
1923	.513	13	do	4.43	.50	4.93
1923	.338	13	do	4.70	.50	5.20
1923	.332	13	do	4.27	.50	4.77
1923	.353	13	do	3.50	.50	4.00
1913	10.10	3	Corn	1.85	.51	2.36
1915	.55	6	do	2.09	.22	2.31
1915	.40	6	do	1.88	.22	2.10
1915	.42	6	do	2.03	.22	2.25
1915	.63	6	Sorghum	1.99	.22	2.21
1915	.47	6	do	2.67	.22	2.89
1915	.43	6	do	2.77	.22	2.99
1915	.49	6	do	2.10	.22	2.32
1915	.45	6	do	2.39	.22	2.61
1915	.46	6	do	2.46	.22	2.68
1915	.43	5	do	1.77	.22	1.99
1915	.27	7	Sudan grass	2.67	.44	3.11
1915	.26	7	do	2.51	.44	2.95
1915	.30	7	do	2.64	.44	3.08
1915	.27	7	do	2.67	.44	3.11
1915	.29	7	do	2.68	.44	3.12
1915	.28	7	do	2.78	.44	3.22
1915	.29	7	do	2.62	.44	3.06
1915	.26	7	do	2.46	.44	2.90
1915	.29	7	do	2.58	.44	3.02
1915	.28	7	do	2.37	.44	2.81
1926	(²)	11	Seed cotton	4.00	.47	4.47
1926	(²)	11	do	3.41	.47	3.88
1926	(²)	5	do	2.00	.47	2.47
1926	(²)	5	do	1.81	.47	2.28
1926	[illegible]	6	do	[illegible]	.47	2.57
1926	[illegible]	6	do	2.16	.47	2.63
1926	(²)	6	do	2.43	.47	2.90
1926	(²)	6	do	2.18	.47	2.65
1926	(²)	11	do	3.52	.47	3.99
1926	(²)	11	do	3.44	.47	3.91
1926	(²)	5	do	2.20	.47	2.67
1926	(²)	5	do	2.26	.47	2.73

[1] Abstract of table 12, Bureau of Agricultural Engineering report (24).
[2] Plot.

TABLE 44.—*Use of water on alfalfa, water applied at each irrigation, rainfall, total water received in Mesilla Valley, N. Mex.*[1]

Year	Irrigations, number	Depth applied each irrigation, inches	Total quantity of water received by crop per acre		
			Irrigation, acre-feet	Rainfall acre-feet	Total, acre-feet
1916	12	5	5.00	0.56	5.56
1916	19	2	3.17	.56	3.73
1916	14	4	4.67	.56	5.23
1916	16	3	4.00	.56	4.56
1916	15	3	3.75	.56	4.31
1916	13	4	4.33	.56	4.89
1916	10	5	4.17	.56	4.73
1916	18	2	3.00	.56	3.56
1916	19	4	6.33	.56	6.89
1916	12	5	5.00	.56	5.56
1917	12	5	5.00	.44	5.44
1917	14	3	3.50	.44	3.94
1917	13	3	3.25	.44	3.69
1917	10	4	3.33	.44	3.77
1917	9	5	3.75	.44	4.19
1917	11	4	3.67	.44	4.11
1917	10	4	3.33	.44	3.77
1917	15	3	3.75	.44	4.19
1917	18	2	3.00	.44	3.44
1917	15	3	3.75	.44	4.[illegible]
1918	14	3	3.50	.29	
1918	11	5	4.58	.29	
1918	12	4	4.00	.29	
1918	17	3	4.25	.29	
1918	19	2	3.17	.29	3.46
1918	11	5	4.58	.29	4.87
1918	11	4	3.67	.29	3.96
1918	15	3	3.75	.29	4.04
1918	17	2	2.83	.29	3.12
1918	12	5	5.00	.29	5.29
1919	15	4	5.00	.58	5.58
1919	[illegible]	[illegible]	[illegible]	.58	[illegible]
1919	[illegible]	[illegible]	[illegible]	.58	[illegible]
1919	12	3	3.00	.58	3.58
1919	12	3	3.17	.58	3.75
1919	10	5	4.08	.58	4.66
1919	10	4	3.25	.58	3.83
1919		3	3.17	.58	3.75
1919	16	2	2.67	.58	3.25
1919	11	5	4.58	.58	5.16

[1] Abstract of table 14, Bureau of Agricultural Engineering report (24).

PART III

SECTION 4.—BUREAU OF AGRICULTURAL ENGIN… ING STUDIES OF CONSUMPTIVE USE OF WATE…

T… consumptive use of water studies conducted by the …ureau of Agricultural Engineering in San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley may be considered as having two parts:

(1) Analysis of climatic data, water supply and irrigation records as a basis of estimating consumptive use on large representative tracts or areas. These include studies of past records and the results of field work during 1936.

(2) Evapo-transpiration and evaporation measurements by means of tanks and soil moisture studies. These include both native vegetation and irrigated agricultural crops.

Unfortunately funds to start the investigation were not available until April 1936, and many of the field studies could not be gotten fully under way until the latter part of May. Thus, in addition to being of limited significance because of representing only a single year, the 1936 field studies are properly subject to criticism because they are not completely representative even to that extent. With full realization of their limitations, the results of the 1936 field studies are nevertheless believed to be of value, and accordingly are set out at the proper place in this report.

In most of the early studies of the consumptive use water in the West, needs for irrigation have been the major motivating element. Naturally, therefore, the approach has been from the point of view of irrigated agriculture and the basic units of time and of area used have been the crop year and the crop area. These units were used in the report of the committee of the American Society of Civil Engineers in a report on Consumptive Use of Water in Irrigation (25).

However, for the Bureau's Rio Grande studies it was decided to use the 12-month year instead of the crop year as used by the society's committee, and the geographical unit of area as well as the irrigated area within each geographical unit. Moreover, the consumptive uses of water by native vegetation and by bare land and water surfaces are important factors of the Bureau's Rio Grande studies. It has therefore been necessary to add new definitions and symbols to those used by the committee. Methods of procedure heretofore used have been extended in the Bureau's studies.

Methods of Estimating Valley Consumptive Use

Three methods have been used by the Bureau of Agricultural Engineering to estimate valley consumptive use. These methods are designated as follows:

A. *The inflow-outflow method*, which is the measurement of the amount of water flowing into and out of a given area, including precipitation, and change in ground-water storage. Thus Valley consumptive use (K) is equal to the amount of water that flows into the Valley during a 12-month year (I) plus the yearly precipitation on the valley floor (P) plus the water in ground storage at the beginning of the year (G_s) minus the amount of water in ground storage at the end of the year (G_e) minus the yearly outflow (R); all amounts measured in acre-feet.

B. *The Integration method*, which is the summation of the products of consumptive use for each crop times its area, plus the consumptive use of native vegetation times its area plus water surface evaporation times water surface area plus evaporation from bare land times its area.

C. *The Hedke heat-consumption method*, which is the application of a linear relation between the consumptive use of water and the heat available for production of crops each month, and for the season (25) (26).

More than any other method, the inflow-outflow method of estimating consumptive use of water for large areas has been applied by engineers; but definitions are essential in order to segregate Valley consumptive use into its component parts, such as use by crops, native vegetation, and evaporation from bare and fallow land and from water surfaces. Methods B and C have been used primarily in Mesilla Valley.

Combinations of methods A and B have in some cases seemed fruitful and the results of such combinations are also presented.

Definitions, symbols, equations used, and essential details of procedure in estimating consumptive use are presented below.

Bureau of Agricultural Engineering Usage

1. *Time period.*—A 12-month period beginning January 1 is used as the unit of time.

2. *Precipitation used.*—*All* the precipitation during the *entire year* is considered as water consumptively used whenever precipitation is included in the computations. The product of the area (acres) within the exterior boundaries and the annual precipitation in feet is taken as the acre-feet contribution.[1]

[1] It is recognized that some of the rain comes in such small showers that it is of but little, if any, benefit to crops. Yet such rain is "consumed" very soon after falling. Rainfall thus consumed is designated "nonbeneficial" consumptive use. Probably the major value of the precipitation, as suggested by Hedke (26), is in the substitution of the moisture thus made available for soil moisture provided by irrigation, to supply the evaporation from the area.

Evaporation loss after a rainstorm is influenced by many factors such as temperature, wind movement, soil type, kind of vegetation, interception, and periods between storms. Observations made in southern California by the Bureau of Agricultural Engineering indicate that the average evaporation loss from the top soil is about one-half acre-inch per acre after each rainstorm (4).

The Bureau does not have available sufficient experimental data relative to rates of evaporation from soils following rains in the Upper Rio Grande Basin to constitute a basis for estimating the effectiveness of the rainfall. Therefore, all the annual precipitation has been designated as a part of the consumptive use, it being recognized, however, that knowledge of the amount of stream-flow depletion (heretofore designated consumptive use by some writers) is of vital practical importance in the solution of Rio Grande water use problems.

3. *Volume of soil considered.*—Consumptive use is considered within a volume of soil; that is, the product of a multiplication of the valley area in acres by the depth of soil which needs to be considered—usually a depth greater than the maximum depth to the water table.

4. *Water in storage.*—Water storage is considered as being in two forms: (a) Gravitational water and (b) capillary water.

5. *Gravitational water in storage.*—The essential quantity is the change in the amount of gravitational water in the soil during the period under consideration. This is the product of the mean difference in feet in water table elevation at the beginning and end of the period, the area in acres of the valley floor and the mean specific yield of the soil.[2]

6. *Capillary water in storage.*—The volume of capillary water taken from or added to the soil is the product of the mean difference of moisture content of the unsaturated soil, dry weight basis, the mean volume weight of the soil, the depth of the soil in feet, and the area in acres of the valley floor.[3]

7. *Water inflow.*—All water flowing into or over the volume of soil under consideration during the time period selected, both surface and subsurface streams, is considered as water inflow.

8. *Outflow.*—All water flowing out of the volume of soil considered during the time period selected, both surface and subsurface, is considered as water outflow. (See also details under "Symbols and Equations.")

9. *Stream-flow depletion.*—This term has previously been defined (see p. 326). Briefly, the expression "stream-flow depletion" means the inflow less the outflow, and usually in past studies, though not always, its application has been confined to surface streams. In those cases where stream-flow depletion is considered for a valley the "outflow" may be concentrated and measured at only one place, whereas the "inflow" usually occurs in a number of streams and must be measured at several places. If it is desired to determine "stream-flow depletion" on parts of valley areas, usually several inflowing and outflowing streams must be measured.

10a. *Consumptive use.*—The Valley consumptive use includes all transpiration and evaporation losses from lands on which there is growth of vegetation of any kind, whether agricultural crops or native vegetation, plus evaporation from bare land and from water surfaces. The water consumed by native vegetation, evaporated from bare and fallow land surfaces, and from water surfaces, is designated as "non-beneficial" consumptive use.

10b. *Basic consumptive use equation in words.*—As defined by the Bureau of Agricultural Engineering, the Valley consumptive use is equal to the amount of water that flows into the valley during a 12-month year plus the yearly precipitation on the valley floor or project area plus the water in ground storage at the beginning of the year minus the amount of water in ground storage at the end of the year minus the yearly outflow (all amounts are measured in acre-feet). Later computations show acre-feet per acre per year for irrigated areas and for total areas.

11. *Symbols.*—Quantities involved in the foregoing defi... are identified by the following symbols:

Storage at beginning of year (acre-feet):
- Gravitational water above any datum surface .... G_s
- Capillary water above datum surface .... C_s

Inflow per year (acre-feet):
- Surface streams, sum of I
- Sub-surface streams, sum of .... F_i

Precipitation on the valley floor per year (acre-feet) .... P

Storage at end of year (acre-feet):
- Gravitational water above datum .... G_e
- Capillary water above datum .... C_e

Outflow per year (acre-feet):
- Surface streams, sum of .... R
- Sub-surface streams, sum of .... F_o

Stream-flow depletion per year (acre-feet):
- Surface inflow less outflow .... $I-R$

Consumptive use per year, total for tract or valley (acre-feet):
- On cropped lands .... K_c
- On fallow lands .... K_f
- On native vegetation lands .... K_n
- Evaporation from water surfaces .... E_w
- Evaporation from bare land .... E_l
- By the entire project or valley, i. e. ($K_c+K_f+K_n+E_w+E_l$) .... K

Land and water surface areas (acres):
- Producing crops .... A_c
- Irrigated lands .... A_i
- Fallow lands .... A_f
- Native vegetation .... A_n
- Water surfaces, river plus irrigation and drain ditches .... A_w
- Bare land area .... A_l
- Total area of valley floor ($A_c+A_f+A_n+A_w+A_l$) .... A
- Area of each crop each year .... a
- Area of each kind of native vegetation each year .... n

Stream-flow depletion per year, unit amounts (acre-feet per acre):
- Flow depletion per acre irrigated .... $\frac{I-R}{A_i}$
- Flow depletion per acre of total tract or valley area .... $\frac{I-R}{A}$

Stream-flow depletion plus precipitation per year, unit amounts (acre-feet per acre):
- Flow depletion plus precipitation per acre irrigated .... $\frac{I+P-R}{A_i}$
- Flow depletion plus precipitation per acre of total tract or valley area .... $\frac{I+P-R}{A}$

Consumptive use per year, unit amounts for tract or valley (acre-feet per acre):
- Use by crops per acre irrigated .... K_c/A_i
- Use by native vegetation per acre .... K_n/A_n
- All uses per acre irrigated .... K/A_i
- All uses per acre of tract or valley .... K/A
- By each agricultural crop per acre c
- By each kind of native vegetation per acre v

12. *Basic Rational Equations in Mathematical Form.*—In harmony with the basic equation stated in words in article 10b follows that:

[2] The actual decrease in the volume of gravitational ground water in storage may be less than the volume thus computed for small changes in the average depth of the water table because of the influence of the capillary fringe zone. However, this difference is probably balanced in part at least by the fact that a lowering of the water table automatically causes a decrease in the equilibrium amount of capillary water in the root zone provided the water table is within a few feet of the land surface. Moreover, the facts that the magnitude of the specific yield used herein must be assumed, and that the average amount of annual change in the volume of ground water is a very small part of the annual consumptive use, justify the belief that the error from the source mentioned is negligible.

[3] The decrease or increase in the amount of water in capillary water storage during the plant-growing season may be a significant item in the annual consumptive use. For this reason mention is here made of capillary storage even though there are no data available for estimating the amount of change in capillary storage in the Bureau's studies of consumptive use for years prior to 1936.

$$(C_s) + I + F_i + P =$$
$$(C_e) + R + F_o + K_c + K_f + K_n + E_w + E_l \qquad (1)$$

…o doubt, clear that the annual valley consumptive use …ropped land may be estimated by summarizing the products of the annual use by each crop times the number of acres of land used to produce it. The consumptive use by native vegetation in the valley may be estimated in a similar way. It follows, therefore, that:

$$K_c = \Sigma(ca) = c_1a_1 + c_2a_2 + c_3a_3, \textit{ etc.} \qquad (2)$$

$$K_n = \Sigma(vn) = v_1n_1 + v_2n_2, \textit{ etc.} \qquad (3)$$

Equation 1 is general in character. However, under certain conditions, it must be observed that a strict application of this equation would necessitate an assumption, either implied or specifically stated.[4]

13. *Restrictions.*—(a) The quantities C_s and C_e of equation 1 are not available for studies of consumptive use in past years for either of the 3 major valleys of the Upper Rio Grande Basin. Moreover, the difference $(C_s - C_e)$, which may be positive or negative, is relatively small and may be neglected for present purposes.

(b) There are no measurements available for the quantities F_i, but the concensus of opinion seems to be, for the Mesilla Valley at least, that the quantity is small and may be neglected. Some engineers feel that the sub-surface inflow, F_i, probably exceeds the subsurface outflow, F_o, but all seem to be of the opinion that both quantities are relatively small.

The quantity F_o was measured by C. S. Slichter in August 1904 (74) and found to be about 0.13 second-foot, which certainly is negligible.

Applying these two restrictions, (a) and (b), and remembering t… $K = K_c + K_f + K_n + E_w + E_l$, it follows from equation 1 that:

$$K = (I + P) + (G_s - G_e) - R \qquad (4)$$

(c) A further restriction seemingly essential to a clear review and comparison of past studies in Upper Rio Grande Basin, is to neglect the quantities P and $(G_s - G_e)$ on the right-hand side of equation 4. The resulting quantity, that is, $(I - R)$, as mentioned hereinbefore, has frequently been designated "consumptive use." Actually the precipitation is "consumed" in part at least. Hence to designate $(I - R)$ as consumptive use may be misleading. Rather, "stream-flow depletion" alone is properly designated $(I - R)$.

Applications

In studies of past use of water, Method A (equation 4 in particular) has been applied to two major valleys in the Upper Rio Grande basin, that is: San Luis Valley, Colo.; Mesilla Valley, N. Mex. and Tex.

However, there are noteworthy differences in the amount and the reliability of available data, and therefore differences in the assumptions introduced for each valley. Consequently it is essential to indicate procedure and list assumptions for each valley separately.

Parts of San Luis Valley.—The past studies of San Luis Valley permit the application of equation 4 in whole or in part to certain tracts in the San Luis Valley, notably the Bowen-Carmel area of some 17,300 acres, studied by Tipton and Hart; the southwest area including the Conejos area or excluding it, and the Conejos area alone, investigated by Tipton; the Bureau of Agricultural Engineering area of some 375,000 acres in the southwest; and water districts nos. 20, 21, 22, 23, and 26, studied by Osgood and Black.

The past investigations in most of these parts of San Luis Valley …as include only measurements of inflow (I) and outfl… (R) and therefore constitute real stream-flow depletion studies. One of the investigations includes part of (P) and another includes part of (P) and also $(G_s - G_e)$. Details of each of the investigations on parts of San Luis Valley area are reported.

There are no available data for past years of the quantity $(G_s - G_e)$ for San Luis Valley as a whole.

The quantity R for the San Luis Valley as a whole is available.

Application to Mesilla Valley.—The quantity (I) for Mesilla Valley includes annual river inflow at Leasburg plus the arroyo inflow. The latter is small, relatively, and must be estimated because there are few, if any, reliable measurements. The quantity (P) is the product of the calendar year precipitation in feet and the area of the valley floor in acres. Records are available for only one rainfall station in the valley; namely, State College. Therefore, considering the Mesilla Valley as a whole, it is possible to make only approximations of the volume of yearly precipitation.

For the quantity (R) only the records at one station need be considered; namely, those obtained at Courchesne (El Paso).

The quantity $(G_s - G_e)$ is considered as a unit so that absolute evaluation of either (G_s) or (G_e) is unnecessary the difference only being needed. This is the product of the difference in the average depth of water table in January of 1 year to January of the following year, measured in feet, multiplied against the specific yield of the soil and the area of the valley floor.

For estimates of ground-water use it was assumed that the specific yield was 15 percent of the total soil volume. It should be observed that if, at the end of the year, the average depth to the water table is less than at the beginning, the quantity (G_e) is greater than (G_s) and therefore the quantity $(G_s - G_e)$ is negative.

Evapo-Transpiration Studies in 1936

Following a survey of the Upper Rio Grande Valley in April 1936 experiment stations were established in

[4] If, for instance, an appreciable part of a valley has a water table at a great depth below the root zone, say 50 feet or more, it would be impractical to measure C_s and C_e in all the soil above the water table. In such a case it must be assumed that deep percolation losses from the soil where the water table is at a great depth do not add to the capillary soil moisture in storage in the soil below the depth to which soil moisture observations are made to determine C_s and C_e. In other words, it must be assumed, under the conditions described, that deep percolation losses from the soil root zone will contribute to ground water supplies and be measured either as increase in such storage or as subsurface outflow. (See par. 2, p. 1379 A. S. C. E. 1760.) Equations 2 and 3 are general, containing no assumptions. However, the measurements of the quantities (c) and (v) are very difficult to make and …ore the use of equations 2 and 3 may necessitate certain assumptions.

the San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley. At a conference with representatives of Texas and New Mexico it was agreed that results obtained in Mesilla Valley would be applicable to El Paso Valley and other areas in Texas above Fort Quitman.

Soil-Moisture Studies

Field plots were selected in the Middle Rio Grande Valley and the Mesilla Valley for various agricultural crops to determine consumptive use of water by means of soil-moisture studies. When possible these plots were selected in areas where the soil was fairly uniform and the depth to ground water was such that it would not influence the soil moisture fluctuations within the root zone. Suitable locations for such studies were not found in San Luis Valley, primarily because of the coarse gravel subsoil and high water table.

Soil samples were taken by means of a standard soil tube before and after each irrigation, with some sampling between irrigations, in 6-inch sections for the first foot and thereafter in 1-foot sections in the major root zone.

Standard laboratory practices were used in determining the moisture content of the soil samples (4). The samples were weighed and dried in an electric oven at 110° C. and the dry weights were determined. The water content of a sample was expressed as percentage of the oven-dry weight of the soil. From the moisture percentage thus obtained, the amount of water in acre-inches per acre removed from each foot of soil was computed by using the formula $D=\frac{MVd}{100}$, where M represents the moisture percentage, V the apparent specific gravity (or volume weight) of the soil, d the depth of soil in inches, and D the equivalent depth of water in acre-inches per acre.

Some of the terms used in this study are defined as follows:

Apparent specific gravity (volume-weight).—The ratio of the weight of a unit volume of oven-dry soil of undisturbed structure to that of an equal volume of water under standard conditions.

Real specific gravity.—The ratio of the weight of a single soil particle to the weight of a quantity of water equal in volume to the particle of soil.

Moisture equivalent.—The amount of water retained by a soil in a standardized apparatus when the moisture-content is reduced by means of a constant centrifugal force (1,000 times gravity) until brought into a state of capillary equilibrium with the applied force. It is expressed as percent of dry weight.

Field-capacity.—The amount of water retained in the soil after excess mobile water has drained away and the rate of downward movement has materially decreased following an application of water from rain or irrigation.

Moisture percentage.—Percentage of moisture in the soil based on the weight of oven-dry material.

Porosity.—The property of a rock or earth of containing stices. It is quantitatively expressed as the percentage of aggregate volume of interstitial space to total volume.

Specific retention.—The amount of water retained against pull of gravity by rock or earth after being saturated and allow to completely drain to a remote body of mobile water by way of continuous capillary interstices. Specific retention is expressed ordinarily as percent by volume. To fulfill this definition in laboratory tests it is necessary to use a soil column of height considerably exceeding the height of the capillary fringe, to continue the experiment for extended periods of time, especially when working with fine-textured material, and to provide temperature control. Standardization of the limiting conditions is one of the serious problems of ground-water hydrology.

Specific yield.—The amount of water which a rock or earth will yield after being saturated and allowed to drain under the conditions specified for determining specific retention. It is expressed as percent by volume. The sum of specific retention and specific yield equals the porosity of the material drained.

Tank Experiments

The consumptive use of water by agricultural crops and by various types of moist-area native vegetation commonly found along stream beds, swamps and cienagas, was measured by means of tanks during the 1936 season at different stations throughout the Upper Rio Grande Basin. Standard Weather Bureau pans were installed at many of these stations since evaporation records are valuable in estimating evaporation losses from free-water surfaces and consumptive use of water by native vegetation growing in moist areas.

The general procedure was similar to that develop by the Bureau of Agricultural Engineering (3), (4, (48). Soil and natural vegetation were placed in the tanks as nearly as possible in conformity with their natural state.

Mariotte apparatus was used to supply and maintain a constant water table in the soil for some of the tanks. Its value lies in the ease with which periodic measurements of water used may be made, as it is automatic in operation. However, sufficient funds were not available to equip many of the tanks with Mariotte apparatus, so the consumptive use of water was determined by measuring the amount of water applied. Either this measurement must be supplemented by determination of soil moisture at different times, or the differences in soil moisture at the beginning and end of period under consideration must be eliminated. The direct determination of the soil moisture in the tanks is scarcely practicable on account of the objectionable disturbance of the soil in the tanks when the samples are taken. The practical way of meeting the difficulty is to conduct the experiments in such manner that the difference in soil moisture at the beginning and end of the period is as nearly as possible reduced to zero. Hence the following method was used:

(1) At the beginning of the month (or period) of record, a measured amount of water was added to tl

tank until the water table had stabilized at elevation close to the surface of the soil. (This elevation is used as the initial observation or "zero" point in determining the consumptive use of water.) Then a measured amount of water was withdrawn until the water table in the tank had stabilized at the elevation proposed to be maintained throughout the season.

(2) Thereafter, at frequent intervals throughout the period water in measured amounts was added, the amount added each time being that calculated as sufficient to cause the water table to stabilize at the desired level.

(3) At the end of the month (or period) and at the close of the season just before harvest, a measured amount of water was added until the water table had stabilized as nearly as practicable at the initial observation or "zero" point.

San Luis Valley

Various conditions relating to the geography, soils, and climate of San Luis Valley, some of which are mentioned in preceding sections of this report, may be described together as follows:

The Valley is located in the south central part of Colorado and extends several miles into New Mexico. (See fig. 75 and p. 298). The valley floor, which in former geologic periods was the bed of a large lake, extends about 100 miles north and south, and 50 miles [illegible] and west. The farming area lies from 5,700 to [illegible]0 feet above sea level (p. 298).

The principal streams are: Rio Grande and Conejos River, and Alamosa, Culebra, Trinchera, La Jara, Saguache, Cottonwood, Spanish, Willow, Crestone, Cotton, Rito Alto, San Luis, Costilla, La Garita, and Carnero Creeks. The water supply for agricultural use comes primarily from these streams. The main gravity supply is the Rio Grande and Conejos River and Alamosa Creek, but considerable water is obtained from tributaries and independent creeks and, in some areas, from artesian wells. Farmers cannot rely on precipitation, although in some seasons the run-off from rains contributes materially to the flow of the streams in summer. At Manassa precipitation has averaged only 6.81 inches annually, at Del Norte only 8.19 inches; in some years it is even less. (See table 17.) During dry seasons farmers in some sections have drilled wells and pumped for irrigation from their underground supply.

The climate is characterized by dry and cool summers limited rainfall, and high spring winds. (See pp. 315 and 316). Temperature and precipitation records of the United States Weather Bureau stations in the Valley in 1936 are shown in table 45.

The soils (p. 316) are mostly sandy and in certain sections contain some alkali. The subsoil is gravelly. Large areas are waterlogged, but the gravelly subsoil makes drainage easy.

1936 Studies

In May 1936, a preliminary survey was made in San Luis Valley to locate stations and areas suitable for conducting studies on consumptive use of water.

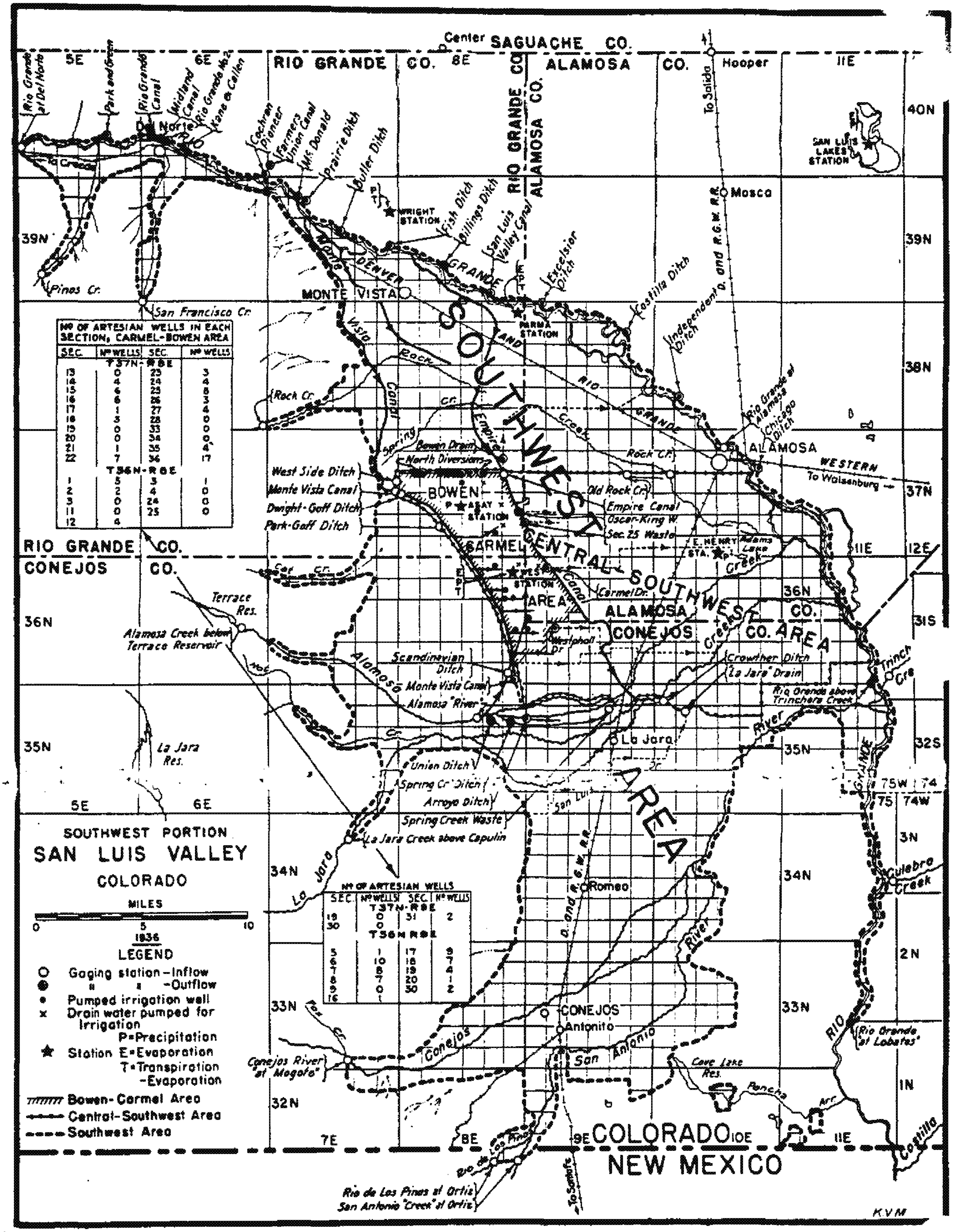
Experiment stations were established by the Bureau of Agricultural Engineering at Parma, West ranch, Wright ranch, and San Luis Lakes. Wheat and potato tanks were installed at the West and Wright stations, native vegetation tanks at Parma station and standard Weather Bureau pans at the San Luis Lakes, Parma and West stations. Details of these experiments are described in later pages. (Pl. 11).

Rain gages were installed by the Bureau at Parma, West, Asay, and East Henry in the southwest area, and at Wright ranch and San Luis Lakes in the closed area. The precipitation records for June to November 1936 are shown in table 46.

Three large tracts were selected for the determination of stream-flow depletion and consumptive use of water in San Luis Valley by the inflow-outflow method: (1) Bureau of Agricultural Engineering Southwest area consisting of some 400,000 acres; (2) Central Southwest

TABLE 45.—*Monthly temperatures and precipitation at specified United States Weather Bureau stations in San Luis Valley, 1936*

Month	Alamosa		Del Norte		Garnett		Manassa		Saguache		Valley
	Mean temperature °F.	Precipitation in inches	Mean temperature °F.	Precipitation in inches	Mean temperature °F.	Precipitation in inches	Mean temperature °F.	Precipitation in inches	Mean temperature °F.	Precipitation in inches	Mean precipitation in inches for 5 stations
January	20.2	0.08	22.9	T	19.0	0.11	21.9	0.18	20.3	0.22	0.12
February	25.2	.15	28.6	0.33	23.8	.11	28.9	.16	24.6	.06	.16
March	33.4	.13	36.4	.51	32.0	.14	35.0	.09	33.4	.18	.21
April	42.2	.28	44.0	.35	40.0	.13	43.4	.26	41.8	.33	.27
May	51.8	.16	52.6	.15	50.3	.06	52.2	.84	54.0	.50	.34
June	60.5	1.35	59.9	1.05	59.2	.68	60.8	.40	62.2	.68	.83
July	63.0	1.00	62.1	1.15	....	.91	63.0	.89	65.4	2.14	1.22
August	62.8	3.68	61.2	3.78	60.8	3.07	61.8	4.84	62.6	2.58	3.59
September	53.8	1.62	55.1	1.15	51.6	1.34	53.2	2.29	54.6	.78	1.43
October	42.0	.69	44.4	.35	39.0	.74	43.6	.45	44.5	.07	.46
November	30.8	0	33.5	.20	27.3	.06	....	.06	32.7	0	.06
December	23.2	.03	25.0	.17	19.9	T	24.8	T	23.4	.04	.05
Annual	....	9.17	....	9.19	....	7.35	....	10.46	....	7.54	8.74



№ OF ARTESIAN WELLS IN EACH SECTION, CARMEL-BOWEN AREA

SEC.	№ WELLS	SEC.	№ WELLS
T37N-R8E			
13	0	23	3
14	4	24	4
15	6	25	8
16	6	26	3
17	1	27	4
18	3	28	0
19	0	33	0
20	0	34	0
21	1	35	4
22	7	36	17
T36N-R8E			
1	5	3	1
2	2	4	0
3	0	24	0
11	0	25	0
12	4		

№ OF ARTESIAN WELLS

SEC.	№ WELLS	SEC.	№ WELLS
T37N-R8E			
19	0	31	2
30	0		
T36N R8E			
5	1	17	9
6	10	18	7
7	8	19	4
8	7	20	1
9	0	30	2
16	1		

FIGURE 78.– Intensive study area in southwest portion of San Luis Valley, Colo.

TABLE 46.—*Monthly ~ cipitation at Bureau of Agricultural Engineering stations in San Luis Valley, Colo., 1936*

Month	Precipitation in inches					
	Parma	Wright	West	Asay	East Henry	San Luis Lakes
June	1.07	0.79	0.36	0.47	0.43	1.48
July	1.16	1.80	.54	.69	1.28	2.18
August	3.06	2.62	4.13	3.77	3.51	4.26
September	1.26	.58	1.30	1.47	1.67	.64
October	.59	.14	.88	.73	1.23	.66
November	.14	....	.18	.21	.20	.07

area of about 114,000 acres; and (3) Bowen-Carmel area of approximately 20,000 acres. (See fig. 78.) The latter area is practically identical with the area used by Tipton and Hart in their 1930, 1931, and 1932 studies.

Bureau of Agricultural Engineering Southwest Area

The Southwest area of the San Luis Valley was chosen by the Bureau of Agricultural Engineering for studies of stream-flow depletion and consumptive use because of the availability of practically all inflow and outflow records of importance in such investigations. One study is based on previous stream-flow measurements made by the United States Geological Survey and the State engineer of Colorado for the 11-year period 1925 to 1935. A similar study, based on measurements by the same agencies in 1936 was made by the Bureau of Agricultural Engineering.

Description.—The Southwest area, which includes all the "live" area south of the Rio Grande, is shown in figure 78. Beginning at Del Norte the boundary is the Rio Grande down to the point where it intersects the south boundary of Trinchera estate; thence it extends northwesterly to the Conejos River; thence southwesterly along the east boundary of lands irrigated by Conejos River to a point in the extreme southwestern portion of the Valley where the highest lands are irrigated from Los Pinos Creek; thence northerly to the Conejos River and up the river to the highest irrigated lands; thence northeasterly and northerly along the western boundary of lands irrigated by Conejos River and thence westerly to include all lands irrigated by La Jara Creek and Cat Creek; thence northerly and westerly to include all lands irrigated by Alamosa Creek to the point of diversion of Terrace canal from Alamosa Creek; thence northerly along Terrace canal to its intersection with Monte Vista canal; thence up Monte Vista canal to its point of diversion from Rio Grande; together with the lands irrigated by water from Rock Creek, Pinos Creek, and San Francisco Creek.

Practically all the irrigated land in water districts 21 and 22 is included in the tract, and part of the land in water district 20.

Consumptive use of water.—Determinations of consumptive use of water and stream-flow depletion for the Southwest area were made by the Bureau of Agricultural Engineering for the years 1925 to 1936, inclusive, by the inflow-outflow method. The data for 1936 are the most accurate and thus are considered separately in the following discussion.

Acreage.—The Southwest area was mapped by the Bureau of Agricultural Engineering in 1936.[5] The gross area in round numbers is 400,000 acres and the irrigated area is 224,000 acres. Table 47 shows the land classification for 1936.

The 1932 surveys of irrigated land in San Luis Valley made by John H. Bliss have been used together with the annual area estimates of Colorado water commissioners as a basis for estimating the irrigated area each year from 1925 to 1934, inclusive. Bliss found 210,000 acres irrigated within the tract in 1932. In view of the fact that the water commissioners' reports show great variation in the irrigated area of water district no. 20, and the further fact that a substantial part of district no. 20 lands are not included in the southwest area, its irrigated areas are not used as a basis for estimating the area irrigated within the tract each year. For water districts nos. 21 and 22, in 1932, the water commissioners reported an irrigated area of 144,000 acres. In order to estimate the acreage irrigated each year in the southwest area from 1925–34, the ratio of 210,000 acres to 144,000 acres was multiplied by the sum of the yearly irrigated areas in water districts nos. 21 and 22. The irrigated areas for each year, thus determined, are shown in column 5 of table 48. The 1935 crop acreage reported by commissioners for districts nos. 21 and 22 is undoubtedly too high, hence the 1936 irrigated area is used in computing the stream-flow depletion per acre for 1935.

TABLE 47.—*Classification of land in Bureau of Agricultural Engineering southwest area, San Luis Valley, Colo. and N. Mex., 1936 (Pl. 11)*

Irrigated land		Native vegetation		Miscellaneous	
Type	Acres	Type	Acres	Type	Acres
Alfalfa, clover, etc.	51,700	Grass	21,800	Temporarily out of cropping.	6,630
Grass (hay)	58,300	Brush	106,000	Towns	4,000
Pasture	33,500	Trees and bosque.	17,600	Bare land, highways, etc.	15,740
Early crops	54,800			Pooled water surface	330
Late crops	19,400			Water surfaces (rivers, canals, etc.).	3,940
Miscellaneous	6,400				
Total	224,100		145,400		30,700

NOTE.—Total area of tract 400,200 acres, or in round numbers, 400,000 acres.

Inflow.—Inflow measurements to the southwest area were made at the stations and locations shown on figure 78 and in table 49. All inflow measurements for the six major streams, as noted, were made at stations equipped with automatic recorders. Five of the sta-

[5] This area has different boundaries and is somewhat smaller than the "southwest area" discussed by the engineer in charge, Rio Grande Joint Investigation (See fig. 78, Pl. 11, and p. 175, Part I.)

tions are classed as "good" and one as "fair", on the basis of the relative accuracy of the records they produced. Previous to 1936 inflow measurements were not made for Pinos, San Francisco, and Rock Creeks. Total diversions for irrigation as recorded by the water commissioners were taken as the inflow from these streams. The quantities thus determined are probably too small, because flood- and winter-flows were not used for irrigation; but since the total contribution from these creeks is relatively small, the estimates of inflow from this source may be considerably in error without materially affecting the accuracy of the results of the entire study. Gaging stations have been maintained for some time on San Antonio River and Alamosa, La Jara and Los Pinos Creeks, but the records for the winter months are incomplete. The data for the missing periods were estimated from the biennial reports of the State engineer of Colorado on the basis of the records for years when discharge measurements were available, nature of drainage basin, and type or characteristics of the year in relation to the mean year. The inflows from Trinchera Creek, 1925 to 1935, inclusive, were estimated by Dan Jones, special deputy State engineer of Colorado, on the basis of the average annual discharge of the creek below Smith Reservoir minus the average annual diversion for irrigation between the reservoir and the mouth of the creek. The annual contribution of Culebra Creek was considered negligible as practically all the water is utilized for either direct irrigation or storage purposes before it reaches the Rio Grande. (Pl. 11.)

Return Flow from North.—The amount of the average annual return flow to the Rio Grande below Del Norte was taken as 55,440 acre-feet. This estimate is based on the seepage investigation conducted by the State engineer's office during 1924 and the experience of Dan Jones, who is in charge of the distribution of the waters of the Rio Grande. The average annual return flow to the river from outside the southwest area or, in other words, from the north side of the river, was assumed to be one-half of the amount, or 27,720 acre-feet. The yearly return flow was then computed on the assumption that it has the same relation to the average return flow as the annual discharge at Del Norte has to 706,900 acre-feet, the mean annual discharge of the river for a 46-year period. The return flow from the north for each year from 1925 to 1936 was computed on the basis of this assumption.

Inflow from Artesian Wells.—The inflow from artesian wells was not included because prior to 1936 no records were available and in 1936 the records for only a portion of the area (central southwest) for the period May to December were available. (Pls. 5 and 11.)

Outflow.—In view of the fact that a considerable amount of the flow of the Rio Grande at Del Norte is diverted from the river to irrigate lands to the ... most of which are in the "closed" area, the divers... by 18 canals and ditches are considered as outflo... which, together with the outflow of the Rio Grande ... Labatos (State line station), constitutes the to... annual outflow. For the irrigation canals and ditches only the seasonal outflow (as obtained from the records of the water commissioners and from the State engineer's reports) are considered; whereas, both the monthly and the annual outflow of the Rio Grande near Lobatos are included. (Pl. 11.)

The outflow through the large Rio Grande, Farmers' Union, and San Luis Valley canals includes reservoir water. This is true also of the smaller Midland canal and Kane and Callen ditch. The reservoir water is, of course, measured also at points of inflow to the area and therefore is included in the total annual inflow.

Ground-Water Storage.—No account was taken of the changes in ground-water storage in either study as no records for the area were available prior to 1936 and then for only a portion of the area during part of the year. It is believed, however, that the net effect of changes in ground-water storage throughout the year was small because most of the area is drained and the tendency would be for the drains to lower the ground water to the level of the drains during the winter when no irrigation water is being applied. (Pl. 5.)

Precipitation.—The quantity P for the Southwest area for the years 1925 to 1935 was computed from ... Weather Bureau records of the Del Norte and Mana... stations and the total area of the tract as determined by the 1936 crop survey by the Bureau of Agricultural Engineering. This area in round numbers is 400,000 acres. For the 1936 study on this tract, the Weather Bureau monthly records for Del Norte, Manassa, and Alamosa for the entire year and the Bureau of Agricultural Engineering's records for the Parma, East Henry, West, and Asay stations for the period from June to November, inclusive (see tables 45 and 46), were used, together with the 1936 survey acreage of 400,000 acres in computing the contribution to the water supply by the precipitation.

Results for 1925 to 1935.—The results of the stream-flow depletion and consumptive use studies for the years 1925 to 1935, determined as explained above, are given in table 48. The amounts of the inflow to and outflow from the tract for each year are given in columns 2 and 3, and the acreages irrigated in column 5. The stream-flow depletion (inflow minus outflow) is given in column 4 and the stream-flow depletion per acre irrigated in column 6. The latter values have a range of from 2.60 acre-feet per acre in the wet year 1932 to 1.33 acre-feet per acre in the extremely dry year 1934. The average for the entire period is 1.92 acre-feet per acre. The last four columns in table 48 give the annual pr...

TABLE 48.—*Use of water in Bureau of Agricultural Engineering southwest area, San Luis Valley, Colo., for years 1925 to 1935* [1]

Year (1)	I, acre-feet (2)	R, acre-feet (3)	$I-R$, acre-feet (4)	A_i,[2] acres (5)	$\frac{I-R}{A_i}$, acre-feet per acre (6)	P,[3] acre-feet (7)	$I+P-R$, acre-feet (8)	$\frac{I+P-R}{A_i}$, acre-feet per acre (9)	$\frac{I+P-R}{A}$, acre-feet per acre (10)
1925	1, 174, 300	715, 200	459, 100	250, 000	1. 84	228, 000	687, 100	2. 75	1. 72
1926	1, 184, 100	804, 500	379, 600	239, 000	1. 59	186, 000	565, 600	2. 37	1. 41
1927	1, 642, 200	1, 107, 900	534, 300	237, 000	2. 25	259, 000	793, 300	3. 34	1. 98
1928	1, 087, 500	692, 800	394, 700	239, 000	1. 65	231, 000	625, 700	2. 62	1. 56
1929	1, 565, 600	1, 033, 500	532, 100	230, 000	2. 31	312, 000	844, 100	3. 67	2. 11
1930	1, 011, 600	616, 300	395, 300	212, 000	1. 86	194, 000	589, 300	2. 78	1. 47
1931	652, 600	329, 400	323, 200	196, 000	1. 65	269, 000	592, 200	3. 02	1. 48
1932	1, 637, 200	1, 092, 100	545, 100	210, 000	2. 60	191, 000	736, 100	3. 50	1. 84
1933	947, 400	562, 600	384, 800	191, 000	2. 01	297, 000	681, 800	3. 57	1. 70
1934	530, 200	276, 200	254, 000	191, 000	1. 33	165, 000	419, 000	2. 19	1. 05
1935	1, 291, 400	841, 700	449, 700	[4] 224, 000	2. 00	330, 000	779, 700	3. 48	1. 95
Average	1, 156, 700	733, 800	422, 900	219, 900	1. 92	242, 000	564, 900	3. 02	1. 66

[1] As indicated by Bureau of Agricultural Engineering estimates of inflow (I), outflow (R), stream-flow depletion ($I-R$), irrigated area (A_i), total area (A), stream-flow depletion per acre irrigated $\frac{I-R}{A_i}$ precipitation (P), consumptive use as measured by inflow plus precipitation minus outflow ($I+P-R$), consumptive use per irrigated acre $\left(\frac{I+P-R}{A_i}\right)$, and consumptive use per acre for entire area $\left(\frac{I+P-R}{A}\right)$.

[2] Estimated from Bliss survey of 1932 and Colorado water commissioners' figures for districts 21 and 22 for years 1925 to 1934, inclusive.

[3] The average of the annual precipitation at Del Norte station and Manassa station multiplied by 400,000, the acreage of the Southwest area (A).

[4] Bureau survey figure for 1936 was used as water commissioners' figures for 1935 apparently are too high.

TABLE 49.—*Use of water in Bureau of Agricultural Engineering Southwest area, San Luis Valley, Colorado and New Mexico, as determined from inflow, outflow, and precipitation records, 1936*

Item	January	February	March	April	May	June	July	August	September	October	November	December	Annual
	Acre-feet												
Inflow:													
Rio Grande at Del Norte	9, 320	9, 970	13, 880	67, 330	141, 200	89, 150	39, 550	37, 570	27, 100	15, 130	12, 390	9, 710	472, 300
Pinos Creek	[1] 400	[1] 400	[1] 450	5, 200	5, 930	2, 620	1, 000	1, 880	972	681	760	[1] 550	20, 843
San Francisco Creek	[1] 100	[1] 100	[1] 100	600	802	320	175	502	217	137	108	[1] 100	3, 321
Rock Creek at Monte Vista	[1] 150	[1] 200	[1] 200	1, 335	2, 230	758	457	1, 210	453	446	403	[1] 400	8, 242
Cat Creek				[1] 100	[1] 100								200
Alamosa Creek below Terrace Reservoir	2, 070	1, 860	1, 920	13, 180	24, 200	13, 630	6, 770	6, 990	4, 630	1, 890	1, 790	1, 840	80, 770
LaJara Creek above Capulin	[1] 150	[1] 200	[1] 250	[1] 500	1, 380	549	1, 960	691	523	650	421	[1] 400	7, 674
Conejos River at Mogote	2, 100	2, 540	3, 870	47, 630	87, 900	34, 300	8, 760	13, 310	9, 870	9, 440	7, 540	4, 130	231, 400
Los Pinos Creek at Ortiz	[1] 1, 200	[1] 1, 500	1, 891	36, 320	32, 430	8, 370	2, 270	2, 930	1, 960	3, 300	2, 960	[1] 2, 900	98, 031
San Antonio Creek at Ortiz	[1] 800	[1] 1, 000	1, 180	15, 180	4, 010	306	394	941	182	467	875	[1] 900	26, 235
Trinchera Creek at mouth	[1] 100	[1] 140	[1] 500	[1] 200	171	14	10	419	619	1, 180	2, 000	[1] 1, 000	6, 343
Culebra Creek at mouth					0	0	10	96	0	0	0		106
Return flow from north [2]	1, 570	1, 470	1, 580	1, 520	1, 570	1, 530	1, 570	1, 570	1, 530	1, 570	1, 520	1, 580	18, 580
Total	17. 960	19, 380	25, 821	189, 095	301, 983	151, 547	62, 926	68, 109	48, 056	34, 891	30, 767	23, 510	974, 045
Outflow:													
Park and Green Ditch				210	310	240	120	124	120	8	0		1, 132
Rio Grande Canal		615	6, 530	28, 190	50, 620	29, 460	13, 640	22, 470	18, 000	12, 780	272		182, 577
Midland Canal				405	1, 030	366	565	287	161	409	526		3, 749
Rio Grande no. 2 Canal				224	248	240	248	248	272	124	0		1, 604
Kane and Callen Ditch				380	588	451	473	444	348	0	0		2, 684
Farmers' Union Canal			0	6, 200	15, 970	16, 050	7, 380	34	37	39	4		45, 714
Cochran Pioneer Ditch			0	126	186	180	186	186	180	186	30		1, 260
McDonald Ditch			144	716	868	840	871	852	568	248	40		5, 147
Prairie Ditch				1, 480	5, 920	2, 500	424	240	176	100	17		10, 857
Hubbard Ditch			0	54	62	60	62	26	20	0	0		284
Butler Ditch			32	312	432	420	154	236	182	124	0		1, 892
Fish Ditch			0	200	284	210	217	80	26	0	0		1, 017
Billings Ditch			0	942	1, 830	684	474	219	67	51	18		4, 285
San Luis Valley Canal			793	3, 380	7, 700	3, 470	1, 320	461	1, 110	2, 560	992		21, 786
Excelsior Ditch			0	660	4, 200	3, 180	2, 360	638	628	157	187		12, 010
Costilla Ditch			0	2, 100	4, 830	1, 800	119	1, 320	1, 200	495	292		12, 156
Independent Ditch			0	264	660	660	20	0	0	0	0		1, 604
Chicago Ditch			0	0	802	1, 846	1, 798	668	0	0	0		5, 114
Rio Grande at Lobatos	15, 380	19, 800	16, 000	60, 420	78, 700	11, 040	1, 060	8, 970	7, 740	13, 890	24, 680	23, 270	280, 950
Total	15, 380	20, 415	23, 499	106, 263	175, 240	73, 697	31, 491	37, 503	30, 835	31, 171	27, 058	23, 270	595, 822
Stream-flow depletion ($I-R$)	2, 580	−1, 035	2, 322	82, 832	126, 743	77, 850	31, 435	30, 606	17, 221	3, 720	3, 709	240	378, 223
Precipitation (P) [3]	2, 800	7, 200	8, 000	10, 000	12, 800	24, 400	32, 000	127, 600	52, 400	23, 200	4, 400	2, 400	307, 200
Consumptive use ($I+P-R$)	5, 380	6, 165	10, 372	92, 832	139, 543	102, 250	63, 435	158, 206	69, 621	26, 920	8, 109	2, 640	685, 423
Stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$ [4]	0. 01	−0. 005	0. 01	0. 37	0. 56	0. 35	0. 14	0. 14	0. 08	0. 02	0. 02	0	1. 69
Consumptive use:													
Per irrigated acre $\left(\frac{I+P-R}{A_i}\right)$	0. 02	0. 03	0. 05	0. 41	0. 62	0. 46	0. 28	0. 71	0. 31	0. 12	0. 04	0. 01	3. 06
Per acre (entire area) $\left(\frac{I+P-R}{A}\right)$ [5]	0. 01	0. 02	0. 03	0. 23	0. 35	0. 25	0. 16	0. 39	0. 17	0. 07	0. 02	0. 01	1. 71

[1] Estimated by comparison with streams for which monthly records were available.

[2] Return flow computed as explained on page 352.

[3] Based on Del Norte, Manassa, and Alamosa precipitation records, except from June to November, inclusive, when records for Parma, West, Assy, and East Henry were included. Total area of tract used (400,000 acres).

[4] Irrigated area 224,000 acres, from 1936 crop survey.

[5] Entire area, 400,000 acres, from 1936 crop survey.

tation in acre-feet on the entire area (column 7), the consumptive use of the entire tract (column 8), the consumptive use per irrigated acre (column 9), and the consumptive use per acre of the entire tract (column 10). The average consumptive use per acre irrigated during the 11-year period is 3.02 acre-feet per acre and the average consumptive use per acre of the entire tract is 1.66 acre-feet. The range of the latter values is from 2.11 acre-feet per acre in 1929 to 1.05 acre-feet per acre in 1934, one of the dryest years on record. During this year the total supply of water available per acre was not sufficient to produce a normal growth in the crops or the native vegetation.

Results for 1936.—The results of the 1936 use-of-water study of the Bureau of Agricultural Engineering southwest area are reported in table 49. As shown in the table the annual stream-flow depletion in acre-feet per irrigated acre is 1.69, the annual consumptive use in acre-feet per irrigated acre is 3.06, and the annual consumptive use in acre-feet per acre of entire area is 1.71. The average values for these items as determined by the study of the same area by the Bureau for the 11-year period from 1925 to 1935 (table 48), are, respectively, 1.92, 3.02. and 1.66 acre-feet per acre.

Comparison With Tipton's Estimates.—For the purpose of comparing the results of the stream-flow depletion and consumptive use studies of the Bureau of Agricultural Engineering with those made previously, the data in tables 23 and 24, considered heretofore under the heading "Tipton", were combined in table 50. In reviewing the following discussion concerning table 50, it is essential to make reference to tables 23 and 24 which, for the years 1930 to 1934, were computed by the Bureau of Agricultural Engineering following the plan used by Tipton for the years 1921 to 1929.

The combined area, as shown, is nearly 191,000 acres. As shown in part A of table 50, the 9-year average stream-flow depletion from 1921 to 1929 is 2.24 acre-feet per irrigated acre. The minimum 1.15 acre-feet in 1924 is less than one-half of the maximum of 3.10 acre-feet in 1929. The average stream-flow depletion in acre-feet is 428,000 as compared to 422,900 for the period 1925 to 1935 shown in column 4 of table 48.

For the 5 years, 1930 to 1934, the inflow to and the outflow from the Tipton southwest area have been extended on the same plan followed by Tipton for the previous years and the results are summarized in part B of table 50, which shows (column 9) that the consumption was smaller for the 5-year period 1930 to 1934 than during the earlier 9-year period. This was caused in part by two very dry years, 1931 and 1934. The average for the 5-year period was only three-fourths of the earlier 9-year average. The true irrigated area for 1930 to 1934 would probably have e... the constant area used in the computations (th... 191,000 acres), because of the general trend tow... increase, but for the fact that during the very dry y... of 1931 and 1934 some lands normally irrigated were ... irrigated because of the inadequacy of the water supply.

TABLE 50.—*Water consumption in Tipton's Southwest area, San Luis Valley, Colo., for the years 1921 to 1934* [1]

Year	Inflow in 1,000 acre-feet			Outflow in 1,000 acre-feet			Consumption	
	Conejos	Southwest minus Conejos	Total	Conejos	Southwest minus Conejos	Total	Total in 1,000 acre-feet	Per acre in acre-feet
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
PART A [2]								
1921	365	934	1,299	158	713	871	428	2.24
1922	440	710	1,150	260	428	688	462	2.42
1923	523	636	1,159	306	400	706	453	2.38
1924	299	682	981	312	449	761	220	1.15
1925	318	441	759	99	232	331	428	2.24
1926	372	434	806	191	241	432	374	1.96
1927	492	770	1,262	251	481	732	530	2.78
1928	280	408	688	115	215	330	358	1.88
1929	450	568	1,018	207	219	426	592	3.10
Average	404	609	1,014	211	375	586	428	2.24
PART B [3]								
1930	315	322	637	137	231	368	269	1.41
1931	179	234	413	41	108	149	264	1.38
1932	540	570	1,110	312	268	580	530	2.78
1933	304	290	594	120	137	257	337	1.77
1934	142	205	347	32	94	126	221	1.16
Average	296	324	620	128	168	296	324	1 [illegible]

[1] "Water consumption" in this table is the equivalent of stream-flow deple... The irrigated area is assumed to be constant during the entire period 1921 to 1934, ... is equal to the sum of the areas used by Tipton, 75,000 acres and 115,890 acres, or 190,890 acres.

[2] Based on Tipton's 1930 report.

[3] Data for the years 1930 to 1934, inclusive, as noted in tables 23 and 24 have been computed by the Bureau of Agricultural Engineering on the basis of Colorado State engineer's water measurement records.

Precise comparisons of Tipton's 1930 estimates with those made herein for the Bureau of Agricultural Engineering Southwest area are not possible, but fairly close comparisons have been made and seem to be reliable. As just noted, the area for the Tipton estimates was considered constant; whereas, as shown in table 48, column 5, the Bureau estimates of area are different from year to year and the average exceeds the Tipton area by 28,900 acres.

The inflow and outflow measurements by Tipton did not cover exactly the same conditions as those used by the Bureau of Agricultural Engineering, the principal difference being that Tipton did not include the inflow from Pinos, San Francisco, Cat, Trinchera, and Culebra Creeks. The average annual contribution by these five streams for the period 1925 to 1935 was approximately 26,000 acre-feet.

The Rio Grande annual discharge at Del Norte plus seepage return along the river to Alamosa should equal the sum of the diversions to the south, plus diversions to the north, plus annual discharge of the Rio Gra...

at Alamosa (Tipton's station for measuring inflow). In the Bur . analysis the sum of the "diversions to the north ; considered outflow, which is equivalent to ting them negative inflow. In combining Tip- pilations (table 50) the La Jara drain is made ar as both outflow and inflow, and therefore nces. The Conejos at its mouth is included in Lobatos outflow. Also, the Rio Grande at Alamosa plus diversions to the south in Tipton's inflow balance the Bureau's showing of inflow of Rio Grande at Del Norte plus return seepage from the north and the diversion to the north considered as outflow.

It is therefore evident that the Bureau's stream-flow depletion should exceed the Tipton stream-flow depletion. For the comparable period 1925 to 1929 inclusive, the Bureau's stream-flow depletion ($I-R$) of 460,000 acre-feet exceeds the Tipton ($I-R$) of 456,000 acre-feet for the period by an average of 4,000 acre-feet.

Central Southwest Area

Stream-flow depletion and consumptive use studies were made by the Bureau of Agricultural Engineering on the central southwest area during 1936. This is a large tract of land for which it is possible to measure the principal factors influencing the use of water. The location of the area is shown in figure 78.

Description.—The central southwest area has for its northern boundary the east-west section line which goes through the southern part of Alamosa, and for its hern boundary Alamosa Creek and the lower end ne Empire canal. The Rio Grande is the eastern boundary and the Monte Vista canal the western boundary. There are minor deviations from these boundaries as may be observed by reference to figure 78, but in general the boundaries are as described.

The western portion of the area is mostly in cultivation, but the eastern portion is largely pasture land and native meadowland cut for hay. The area was mapped by the Bureau of Agricultural Engineering in 1936, and the crop classification as determined by the survey is as shown in table 51. The total area mapped was 113,995 acres and the total area irrigated was 61,120 acres, but for the purpose of the use-of-water computations the round numbers 114,000 and 61,000 were adopted.

TABLE 51.—*Classification of land in Central Southwest area, San Luis Valley, Colo., 1936*

Irrigated land		Native vegetation		Miscellaneous	
Type	Acres	Type	Acres	Type	Acres
Alfalfa, clover, etc.	18,140	Grass	8,640	Temporarily out of cropping.	1,730
Grass (hay)	19,280	Brush	40,180	Towns	12
Pasture	4,830	Trees and bosque.	422	Bare land, highways, etc.	1,120
Early crops	12,830			Pooled water surface	333
Late crops	5,360			Water surfaces (rivers, canals, etc.).	438
Miscellaneous	680				
Total	61,120		49,242		3,633

NOTE.—Total area of tract 113,995 acres, or in round numbers 114,000 acres.

Stream-flow.—The principal inflow to the area comes from the Rio Grande, the Empire canal, the Monte Vista canal, Rock Creek, La Jara Creek, Alamosa Creek, and the principal outflow from the Rio Grande where it leaves the area above the mouth of Trinchera Creek. Minor flows occur at various points. The locations are shown in figure 78 and the names are listed in table 52. The principal inflow and outflow stations were all equipped with recorders, and the measurements were made by the United States Geological Survey in cooperation with the Bureau of Agricultural Engineering. Where small flows occurred, staff gages were installed which were read daily. The flows were measured by current meter or Parshall measuring flume.

Complete records were obtained for the principal stations for the period May to December, inclusive, but some of the smaller flows had to be estimated for May because observations on these stations were not started until the last of the month. Observations on some of the stations were discontinued November 30. The flows for these stations also had to be estimated. Where partial records were available the flow for the entire month was estimated on the assumption that the flow for the previous part of the month was at the same rate as that for the period for which records were obtained. When no record was available the flow was estimated on the basis of the trend of the flow of streams for which the monthly discharges were known. The December records were estimated by assuming that the rate of flow on the last day of November continued throughout December. It is believed that this assumption is not far in error because the stream flow during the winter is quite uniform.

Seepage return from the east.—There is some seepage return to the Rio Grande from the east between the Alamosa and the mouth of Trinchera Creek, but no way was devised for determining its amount. It is believed that most of the seepage return to the river comes from the west because the water table is high throughout the area along the west side of the river. This return flow is measured as outflow in the river above the mouth of Trinchera Creek.

Artesian flow.—The artesian flow in the central southwest area was measured by the Ground Water Division of the Geological Survey. In the area between the Monte Vista canal and the Empire canal (Bowen-Carmel area) the flow of every well was measured or estimated. In the remaining area the wells on every other section were measured and the total artesian flow was taken as twice the amount measured. Each well was measured once during the

TABLE 52.—*Use of water in Central-southwest area, San Luis Valley, Colo., as determined from inflow, outflow, precipitation, and water-storage records, 1936*

Item	May	June	July	August	September	October	November	December	Perio…
	Acre-feet								
Inflow									
Rio Grande at Alamosa	5,000	2,870	2,630	3,260	1,470	1,660	10,860	12,160	39,910
Rock Creek	2,480	1,290	67	1,050	734	1,270	1,000	[1] 850-	8,731
Old Rock Creek	0	25	0	12	0	0	0	0	37
Empire Canal	11,700	8,590	130	2,540	1,700	989	290	0	25,939
West Side Ditch	[1] 110	52	19	38	7	1	0	0	227
Monte Vista Canal	7,800	4,390	946	2,400	1,550	538	98	0	17,722
Dwight Goff Ditch	[1] 100	36	19	1	1	0	0	0	157
Park Goff Ditch	[1] 160	56	4	34	75	0	0	0	329
Alamosa River	9,580	3,080	354	660	234	335	189	[1] 90	14,522
No. 6 Ditch	[1] 280	608	282	96	66	14	2	0	1,348
Spring Creek waste	[1] 770	282	15	58	64	154	87	0	1,430
La Jara Creek	2,670	1,550	337	1,438	1,349	2,327	2,206	[1] 1,860	13,737
Crowther Ditch	[1] 300	119	32	15	0	0	0	0	466
La Jara drain	[1] 560	470	187	406	515	609	585	[1] 550	3,882
Artesian wells	1,690	1,630	1,690	1,690	1,630	1,690	1,630	1,690	13,340
Total	43,200	25,038	6,712	13,698	9,395	9,587	16,947	17,200	141,777
Outflow:									
Bowen drain	340	281	36	118	121	253	251	[1] 300	1,700
North diversions	[1] 1,100	318	35	317	133	0	1	0	1,904
Union Ditch	[1] 1,220	6,72	187	124	151	81	18	0	2,453
Arroyo Ditch	924	378	156	78	12	0	0	0	1,548
Spring Creek Ditch	686	440	80	96	0	0	0	0	1,304
Chicago Ditch	802	1,846	1,798	668	0	0	0	0	5,114
Rio Grande above Trinchera Creek	12,530	3,670	313	4,750	4,330	6,870	15,480	14,870	62,813
Total	17,610	7,605	2,605	6,151	4,747	7,204	15,750	15,170	76,842
Stream-flow depletion $(I-R)$	25,590	17,433	4,107	7,547	4,648	2,383	1,197	2,030	64,985
Precipitation (P) [2]	4,790	6,500	8,890	36,370	15,620	7,300	1,140	110	80,720
Ground-water storage (G_s-G_e)	[3] −3,590	10,600	11,800	−5,640	3,250	−2,900	2,560	[3] 3,930	20,010
Consumptive use $[I+P-R+(G_s-G_e)]$	26,790	34,533	24,797	38,277	23,518	6,783	4,897	6,070	165,665
Stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$ [4]	0.42	0.29	0.06	0.12	0.08	0.04	0.02	0.03	1.06
Consumptive use:									
Per irrigated acre, $\left[\frac{I+P-R+(G_s-G_e)}{A_i}\right]$	0.44	0.57	0.41	0.63	0.38	0.11	0.08	0.10	2.72
Per acre (entire area), $\left[\frac{I+P-R+(G_s-G_e)}{A}\right]$ [5]	0.23	0.30	0.22	0.34	0.21	0.06	0.04	0.05	1.45

[1] Estimated on the basis of the flow of similar canals or streams for which records were available.
[2] Based on Weather Bureau precipitation records at Alamosa and Manassa from May to December combined with Bureau of Agricultural Engineering records at Par West, Asay, and East Henry stations from June to November. Total area of tract used, 114,000 acres.
[3] Estimated from partial month's record.
[4] Irrigated area, 61,000 acres, from 1936 crop survey.
[5] Entire area 114,000 acres, from 1936 crop survey.

year. Some of the wells are shut off during the winter or at least partly closed, for the purpose of conserving the artesian pressure. (Pl. 11.)

Ground-water storage.—Monthly readings were taken by the Geological Survey on the ground-water level in observation wells throughout the area during the period May to December. The readings were not all taken on the first of each month, and in order to make the readings comparable the readings for the first of each month were determined by interpolation. The observation wells in the Bowen-Carmel area were more closely spaced than in the remaining portion of the central southwest area, and in computing the changes in ground-water storage the weighted averages of the changes for the two portions of the area were used. The specific yield of the soil was taken as 15 percent of the volume. The product of the change in ground-water level in feet and the area in acres multiplied by 0.15, the assumed specific yield, gave the change in ground-water storage in acre-feet.

Precipitation.—The quantity P was obtained by multiplying the average monthly precipitation in feet by 114,000 acres, the entire area of the tract. The monthly precipitation was based on the Weather Bureau records at Alamosa and Manassa, and the Bureau of Agricultural Engineering records at Parma, West, Asay, and East Henry stations. The Weather Bureau records were available for the entire period May to December, inclusive, but the Bureau of Agricultural Engineering records covered only the period June to November, inclusive.

Results.—The results of the 1936 use-of-water study of the central southwest area are set forth in table 52, which is similar to table 49, except that it includes artesian inflow and change in ground-water storage, and that it is for the 8-month period from May to December, inclusive, instead of for the year. The table shows that for the 8-month period the stream-flow depletion is 1.06 acre-feet per acre, the consumptive use is 2.72 acre-feet per acre of irrigated area, and 1.45 acre-feet per acre of entire area.

Bowen-Carmel Area

The Bowen-Carmel area was chosen for an intensive use-of-water study during 1936 for the purpose of extending the results obtained by Tipton and Ha…

engineers for the State of Colorado, when making a similar study on approximately the same area during the years 1930, 1931 and 1932. The Bowen-Carmel area is wholly within the central southwest area and its boundaries are shown in figure 78 and Pl. 11.

Description.—The Bowen-Carmel area has for its northern and western boundaries the boundaries of the central southwest area, but for its eastern boundary it has the Empire canal, and for its southern boundary the approximate line of separation between the Carmel and Morgan drainage districts. In order to simplify the water measuring problem several small tracts were included which were outside of the boundaries of the area as just given.

A larger proportion of the Bowen-Carmel area is in cultivation than either the Southwest or Central Southwest areas. The principal crops are potatoes, alfalfa, grain, field peas, and sweetclover. The distribution of the crops by area, as determined by the 1936 crop survey is given in table 53. The total area of the tract was 19,988 acres and the total area irrigated in 1936 was 13,999 acres. In making the use-of-water computations, 20,000 acres was used for the total area and 14,000 acres for the irrigated area.

The Bowen-Carmel area is drained by an extensive system of open ditches and tile drains which keep the ground-water level within safe limits over most of the area. During periods of drought, water is pumped from the drains and applied to the land. Checks are sometimes placed in the drains to raise the ground-water level in the summer.

TABLE 53.—*Classification of land in Bowen-Carmel area, San Luis Valley, Colo., 1936 (Pl. 11)*

Irrigated land		Native vegetation		Miscellaneous	
Type	Acres	Type	Acres	Type	Acres
Alfalfa, clover, etc.	5,630	Grass	1,200	Temporarily out of cropping.	736
Grass (hay)	401	Brush	3,768	Bare land, highways, etc.	190
Pasture	202	Trees and bosque.	20	Water surfaces (canals and drains).	75
Early crops	4,840				
Late crops	2,930				
Miscellaneous	6				
Total	13,999		4,988		1,001

NOTE.—Total area of tract 19,988 acres, or in round numbers 20,000 acres.

There are some alkali areas but alkali is not as prevalent as in other portions of the Valley.

Stream-flow measurements and estimates.—The inflow and outflow measurements on the Bowen-Carmel area were started the last week in May and were continued through November. The list of the stations at which measurements were made is given in table 54. The locations of the stations are shown in figure 78. The principal inflow to the area is the Monte Vista canal and the principal outflows are the Bowen drain, the Carmel

TABLE 54.—*Use of water in Bowen-Carmel area, San Luis Valley, Colo., as determined from inflow, outflow, precipitation and ground-water storage records, 1936*

Item	May	June	July	August	September	October	November	December	Period
	Acre-feet								
Inflow:									
West Side Ditch	[1] 110	52	19	38	7	1	0	0	227
Monte Vista Canal	7,800	4,390	946	2,400	1,550	538	98	0	17,722
Dwight Goff Ditch	[1] 100	36	19	1	1	0	0	0	157
Park Goff Ditch	[1] 160	56	4	34	75	0	0	0	329
Monte Vista Canal backwater	[1] 12	16	0	4	12	0	2	0	46
Scandinavian Ditch	[1] 1,190	90	5	11	9	3	0	0	1,308
Artesian wells	140	186	140	140	136	140	136	140	1,108
Total	9,512	4,776	1,133	2,628	1,790	682	236	140	20,897
Outflow:									
Bowen drain	[1] 346	281	36	118	121	253	251	[2] 300	1,706
North diversions	[1] 1,100	318	35	317	133	0	1	0	1,904
Monte Vista Canal waste	[1] 416	183	0	176	286	186	41	0	1,237
Westphall drain	[1] 40	37	22	15	13	18	18	[2] 15	178
Carmel drain	[1] 960	441	130	364	438	580	522	[2] 500	3,935
Section 25 waste	[1] 35	0	0	0	0	0	0	0	35
Oscar King waste	0	0	0	0	0	0	0	0	0
Total	2,896	1,210	223	990	991	1,037	833	815	8,995
Stream-flow depletion $(I-R)$	6,616	3,566	910	1,638	799	−355	−597	−675	11,902
Precipitation (P) [3]	840	1,140	1,560	6,880	2,740	1,280	200	20	14,160
Ground-water storage (G_s-G_e)	−1,740	2,040	3,030	−570	540	−150	600	1,020	4,770
Consumptive use $[I+P-R+(G_s-G_e)]$	5,716	6,746	5,500	7,448	4,079	775	203	365	30,832
Stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$ [4]	0.47	0.25	0.06	0.12	0.06	−0.02	−0.04	−0.05	0.85
Consumptive use:									
Per irrigated acre $\left[\frac{I+P-R+(G_s-G_e)}{A_i}\right]$	.41	.48	.39	.53	.29	.06	.01	.03	2.20
Per acre (entire area) $\left[\frac{I+P-R+(G_s-G_e)}{A}\right]$ [5]	.28	.34	.28	.37	.20	.04	.01	.02	1.54

[1] Estimated on the basis of partial monthly records.
[2] Estimated on the basis of the previous month's record.
[3] Based on Weather Bureau precipitation records at Alamosa and Manassa from May to December combined with Bureau of Agricultural Engineering records at Parma, West, Asay, and East Henry stations from June to November. Total area of tract used, 20,000 acres.
[4] Irrigated area 14,000 acres, from 1936 crop survey.
Entire area, 20,000 acres, from 1936 crop survey.

drain, and the diversion to the north. The stations on these streams were equipped with recorders, except those on the diversions to the north. Staff gages were used on these diversions and the small inflows and outflows. These gages were read daily. All measurements of flows were made with a current meter, except several of the diversions to the north which were equipped with Parshall flumes.

The Monte Vista canal is built on a flat grade where it discharges into the Alamosa Creek, and when the stream is high the water sometimes backs up the canal into the area. A record of the flow was kept and is designated as Monte Vista canal backwater in table 54. The diversions to the north are diversions from the Monte Vista canal which cross the north boundary of the area and irrigate land outside it. The Scandinavian ditch diverts water from the Alamosa Creek and crosses the Monte Vista canal into the Bowen-Carmel area. The amount brought into the area is small because the right of the Scandinavian ditch to divert water is junior to most of the appropriations on the river, and consequently it is dry most of the season.

In view of the fact that the measurements of the inflow to and outflow from the Bowen-Carmel area were not started until the latter part of May and were not continued after the last of November, it was necessary to estimate the flow in May prior to the time the observations were started and in December after the observations were discontinued. These estimates were made in the same manner as those for the central southwest area.

Artesian flow.—A complete inventory of all the artesian wells in the Bowen-Carmel area was made by the Ground Water Division of the Geological Survey. The flow of each well was measured or estimated, and if the well was either wholly or partly closed during the winter the estimate of the flow was reduced accordingly. Although the flow of the wells during the winter months was less than in summer, the use-of-water study was made on the assumption that the artesian flow was at a uniform rate throughout the year. However, the monthly flow was made to conform to the number of days in the month. (Pl. 11.)

Ground-water storage.—Ground-water level records were kept by the Ground Water Division of the Geological Survey on 30 observation wells within the Area during the period from May 15 to December 15. The observations were taken twice monthly, and as near to the first and the fifteenth of the month as possible. The readings were transferred to the desired dates by interpolation. The changes in ground-water storage were computed on a monthly basis from the mean change in level of all the wells during the period. The specific yield of the soil in the Bowen-Carmel area was assumed to be 0.15—the same as for all the other areas on which use-of-water studies were made for the reason that sufficient specific yield determinations were not made to warrant using different values for each area. The monthly change in ground-water storage in acre-feet was obtained by multiplying the area of the tract by the change in ground-water level and by the specific yield.

Precipitation.—The contribution of the precipitation to the water supply of the Bowen-Carmel area was computed in the same manner as for the Central Southwest area, and was based on the precipitation records from the same station, but the acreage used was that of the Bowen-Carmel area.

Results.—The results of the 1936 study of the use of water on the Bowen-Carmel area for the period May to December, inclusive, are given in table 54. This table is similar to table 52 for the central southwest area. As shown in table 54, the stream-flow depletion for the period in acre-feet per irrigated acre is 0.85, the consumptive use in acre-feet per irrigated acre is 2.20, and the consumptive use in acre-feet per acre of entire area is 1.54.

Summary of Results of Large-Area Studies

The results of Bureau of Agricultural Engineering consumptive-use-of-water studies and the estimates of stream-flow depletion by different engineers are summarized briefly as follows:

Bureau of Agricultural Engineering results for ... — The results of the 1936 studies on the southwest, central southwest, and Bowen-Carmel areas are given in table 55.

TABLE 55.—*Summary of results of 1936 use-of-water studies by Bureau of Agricultural Engineering on Southwest area, Central Southwest area, and Bowen-Carmel area*

Name of area	Stream-flow depletion per irrigated acre in acre-feet	Consumptive use per irrigated acre, in acre-feet	Consumptive use per acre entire area, in acre-feet
Southwest (B. A. E.)	[1] 1.69	2.06	1.71
Central southwest	[2] 1.06	2.72	1.45
Bowen-Carmel	[2] .85	2.20	1.54

[1] For 12 months, January to December inclusive; does not include artesian flow or change in ground-water storage.
[2] For 8 months, May to December inclusive; includes artesian flow and change in ground-water storage.

Stream-flow depletion results.—For convenience in making comparisons, the results of stream-flow depletion per irrigated area in summary form for the period 1915 to 1936 on various areas in San Luis Valley by different engineers are presented in table 56.

The results of investigations on the Conejos Basin and the southwest area minus Conejos Basin appear in columns 2 and 3 of table 56. Column 4 is a combination of the results in columns 2 and 3, and the land represented is designated as Tipton's southwest ...

since the figures are based on Tipton studies. The land represented by the Bureau of Agricultural Engineering southwest area as shown in column 5 is substantially the same as in column 4, although in column 5 the average irrigated area exceeds the area of column 4 by 29,000 acres.

The data of columns 2 and 8 are nearly comparable. Yeo and Black, New Mexico engineers, designated the Conejos area as 76,000 acres, which is 1,000 acres greater than the irrigated area found by Tipton, a Colorado engineer; but the data agree quite closely.

As noted in the title of table 56, the amounts given represent stream-flow depletion per acre irrigated $\left(\frac{I-R}{A_i}\right)$. Probably there is greater variability in the different estimates of irrigated area (A_i) than in the stream-flow depletion ($I-R$).

The averages of columns 4, 5 and 7, based on 14, 12 and 14 years respectively, are all substantially the same; that is, approximately two acre-feet per irrigated acre. This seems noteworthy in view of the fact that these averages represent time periods and areas which are not strictly identical.

TABLE 56.—*Comparison of the results of stream-flow-depletion studies on different areas in San Luis Valley, Colo. (acre-feet per acre of irrigated area).*

Year (1)	Conejos Basin (2)	Southwest minus Conejos (3)	Southwest area (Tipton) (4)	Southwest area (B. A. E.) (5)	Bowen-Carmel area (6)	Water district no. 20 (7)	Water district no. 22 (8)	Entire San Luis Valley (9)
1915						1.98		2.20
1916						2.43		2.82
1917						1.98		2.27
1918						1.82		2.60
1919						[illegible].93		[illegible].05
1920						[illegible].39		[illegible]
1921	[illegible].73	1.31	2.24			1.68	2.74	1.89
1922	2.40	2.44	2.42			2.43	2.48	2.55
1923	2.89	2.04	2.38			1.99	2.99	2.40
1924	1.16	1.05	1.15			1.83	2.14	
1925	2.92	1.81	2.24	1.84		2.10	2.96	
1926	2.42	1.67	1.96	1.59		1.91	2.47	
1927	3.20	2.50	2.78	2.25		2.07	3.17	
1928	2.20	1.67	1.88	1.65		2.07	2.29	
1929	3.22	2.16	3.10	2.31				
1930	2.37	.80	1.41	1.86	1.13			
1931	1.84	1.09	1.88	1.65	1.25			
1932	3.04	2.61	2.78	2.60	1.88			
1933	2.45	1.32	1.77	2.01				
1934	1.47	.96	1.16	1.33				
1935				2.00				
1936				1.69	[1] 1.27			
Average	2.45	1.73	2.05	1.90	1.38	2.01	2.66	2.36

[1] Estimated from 8-month record.

NOTE.—Column 2. After Tipton for years 1921 to 1929, inclusive (see table 23), and for years 1930 to 1934 extended by Bureau of Agricultural Engineering. Area 75,000 acres.

Column 3. From same source as column 2 (see table 24). Area, 115,890 acres.

Column 4. From same source as column 2 (see table 50). Area, 190,890 acres.

Column 5. Bureau of Agricultural Engineering Southwest area. Area varies from 191,000 to 250,000 acres. (See tables 48 and 49.)

Column 6. After Tipton-Hart studies (see table 25) and Bureau of Agricultural Engineering 1936 study. Area, 14,000 acres (see table 54.)

Column 7. After Yeo and Black. Area, 235,000 acres. (78)

Column 8. After Yeo and Black. Area, 76,000 acres. (78)

Column 9. Bureau of Agricultural Engineering estimates. Area, 507,000 acres. (See table 28.)

Wheat and Potato Tank Experiments

In the latter part of May 1936 two experiment stations were established in San Luis Valley for the purpose of determining evapo-transpiration of wheat and potatoes grown in tanks; viz, the Wright station in the closed area and the West station in the live area.

Wright station.—This station was located in adjoining wheat and potato fields on the Lyman Wright farm several miles north of Monte Vista (section 12, R. 7 E., T. 39 N.) in the subirrigated section of the closed area. The soil consisted of a 10-inch layer of sandy loam underlain with a coarse gravelly subsoil which was typical of the subirrigated section of the Valley. (Pl. 11).

Four tanks were installed at the station, two in the wheat field and two in the potato field. These tanks were 4 feet in diameter and 3 feet deep, and were made of 18-gage galvanized metal. All tanks were tested for leaks before being filled with soil. Other equipment consisted of two ground-water observation wells and a standard 8-inch Weather Bureau rain gage.

Each 6-inch layer of soil was placed in a separate pile alongside the trench as it was being excavated for the tanks. A 2-inch layer of gravel was placed in the bottom of each tank, and two wire screen cylinders, 2 inches in diameter, were placed parallel and horizontal on the gravel and connected to two vertical wells 3 feet high and 2 inches in diameter.

FIGURE 79.—Potatoes growing in tank at Wright Station, San Luis Valley.

Another layer of gravel (6 inches) was added and then the 6-inch layers of soil were replaced in their respective order until the soil was within 2 inches of the top of the tanks.

The seed in the adjacent wheat field had been drilled on April 1, 1936, and plants were transplanted from the field to the two soil tanks on June 1 in such manner as to be representative of natural field conditions.

The potatoes in the field and in the soil tanks were planted June 1. Those in the tanks were planted in rows at 10-inch intervals, with four plants to each tank. The crops in fields completely surrounded the growth in the tanks so that the exposure was normal.

The Wright station was visited at least twice a week until October; thereafter only weekly. Records were kept of depth to water table and amount of water added to or subtracted from each tank, depth to water table in the field outside the tank, and precipitation.

The water table in each tank was maintained at approximately the depths recommended by farmers using subirrigation in the adjacent farms, by adding water twice a week through the observation wells. The water tables fluctuated between 20 and 30 inches below the ground surface. For most of the period they were kept at the 22-inch level for the wheat tanks and the 18-inch level for the potato tanks.

On the first of each month the water table in the tanks was brought to a definite "zero" point near the ground surface for the purpose of eliminating differences in soil moisture in monthly consumptive-use measurements. After the water table had stabilized, water was pumped out of tank until the water table had dropped to the desired level. All water added to or withdrawn from each tank was measured. (See p. 348.) The tanks were also calibrated by adding a given amount of water at one-hour intervals and measuring the rise in water table.

The wheat was harvested September 1 and the potatoes September 15. The tanks were then used to determine evaporation from bare soil with water tables maintained at depths of 16, 18, and 19 inches.

The monthly uses of water by wheat and potatoes in tanks are shown in table 57. Evaporation from bare soil is shown in table 58.

West station.—This station was located about 8 miles southwest of Alamosa (section 1, R8E, T36N) in the Bowen-Carmel area, which is part of the so-called live area of San Luis Valley. Surface irrigation is practised in this section. The flooding method is used for wheat and the furrow method for potatoes. The 1936 climatic and soil conditions were representative of the area. The soil is gravelly but has about 10 inches of fertile top soil. Water was supplied from a nearby irrigation ditch and an artesian well.

TABLE 57.—*Monthly consumptive use of water by* *and potatoes in tanks, Wright station, San Luis Valley, Colo.,*

Tank number	Crop	Consumptive use of water in acre-inches (inches)				
		June	July	August	September	Total
1	Wheat [1]	3.41	6.64	4.05		14.10
2	Do.[1]	3.67	6.70	3.64		14.01
3	Potatoes [2]	.70	7.93	5.66	[3] 1.44	15.73
4	Do.[2]	1.74	6.43	5.25	[3] 1.60	15.02

[1] Crop harvested Sept. 1.
[2] Crop harvested Sept. 15.
[3] Sept. 1 to Sept. 15.

TABLE 58.—*Evaporation from bare soil in tanks at Wright station, San Luis Valley, Colo., 1936*

Period	Evaporation from bare soil, in inches		
	Tank no. 1 (depth to water 18 inches)	Tank no. 2 (depth to water 16 inches)	Tank no. 4 (depth to water 19 inches)
Sept. 15 to Oct. 1	2.97	3.19	0.84
Oct. 1 to Oct. 12	.88	.88	.55
Sept. 15 to Oct. 12	3.95	4.07	1.39
Average rate per 30 days	4.39	4.52	1.53

The station was equipped with two double-type tanks with an annular space of 1¼ inches between the inner and outer shells. The inner tank, which held the soil, was approximately 23⅛ inches in diameter and 6 feet deep, with a removable bottom. The outer tank was a reservoir for water which passed into th l through the inner shell perforations (3) (4). A - ard Weather Bureau evaporation pan, an 8-inch rain gage, an anemometer and two ground-water observation wells were also installed at the station.

The soil tanks were filled by the same methods used at the Wright station. One tank was placed in a wheat field and the other in a potato field, and they were completely surrounded by the crops. The wheat, which had been planted in the field April 3, 1936, was transplanted in one tank on June 1. The plants were 8 inches high and the shock resulting from transplanting retarded their growth so that throughout the season they never were as large as the plants in the adjoining field. The other tank was planted to potatoes, with two plants to the tank, on June 1, 1936.

The station was visited at least twice a week and observations were made on precipitation, wind movement, evaporation, depths to ground-water in the tanks and in the fields. Sufficient water was added to the tanks to maintain their water levels at approximately the same elevations as the water table in the adjoining fields. These varied from 24 to 53 inches below surface in the potato tank and 20 to 54 inches in the wheat tank.

On the first of each month the water table in the tanks was brought to a definite zero point near the (p. 348) for the purpose of determining the m consumptive use of water. All water added to or withdrawn from each tank was measured. Both tanks were calibrated with water table at various depths.

The wheat was harvested on August 10 and the potatoes on October 1, and the crops were weighed. The tanks were then used until October 12 to determine evaporation from bare soil with the water table depths maintained at 18 inches in one tank and 30 inches in the other.

The monthly use of water for wheat and potato tanks is shown in table 59 and evaporation from bare soil in table 60. The weekly and monthly evaporation from water surface, wind movement and precipitation are given in table 61.

TABLE 59.—*Monthly consumptive use of water by wheat and potato tanks, west station, San Luis Valley, Colo., 1936*

Tank number	Crop	Consumptive use of water in acre-inches per acre (inches)				
		June	July	August	September	Total
1	Wheat[1]	3.38	6.19	[2]0.77		10.34
2	Potatoes[3]	.82	5.44	9.83	3.80	19.89

[1] Crop harvested Aug. 10.
[2] Aug. 1 to Aug. 10.
[3] Crop harvested Oct. 1.

TABLE 60.—*Evaporation from bare soil in tanks at west station, San Luis Valley, Colo., 1936*

Period	Evaporation from bare soil, in inches	
	Tank no. 1 (depth to water level 18 inches)	Tank no. 2 (depth to water level 30 inches)
Aug. 10 to Sept. 1	1.66	
Sept. 1 to Oct. 1	4.25	
Oct. 1 to Oct. 12	.91	1.28
Aug. 10 to Oct. 12	6.82	

TABLE 61.—*Weekly and monthly evaporation and meteorological data at West station, San Luis Valley, Colo., season of 1936*

Period	Evaporation in inches	Wind movement in—		Precipitation in inches
		Miles	Miles per hour	
Week ending—				
June 22	2.66			0.03
June 29	2.31			.23
Month, Ju[illegible]	[1]3.70			[1].35
Week ending—				
July 6	2.49	452.9	2.76	
July 13	2.24	620.7	3.68	.11
July 20	2.36	393.3	2.34	.01
July 27	2.13	300.7	1.78	.14
Month, July	9.47	1,882.5	3.09	.54
Week ending—				
Aug. 3	1.49	324.9	1.94	1.91
Aug. 10	.84	298.2	1.77	.58
Aug. 17	1.89	323.5	1.93	.16
Aug. 24	1.44	277.6	1.64	.89
Aug. 31	1.56	322.7	1.92	.87
Month, August	6.67	1,353.1	1.77	4.13
Week ending—				
Sept. 7	1.82	449.5	2.67	.02
Sept. 14	1.46	426.6	2.54	.10
Sept. 21	1.23	413.4	2.46	.08
Sept. 28	.55	645.4	3.84	1.10
Month, September	5.35	[2]1,008.4 [3]443.0	[2]2.42 [3]2.44	1.30
Week ending—				
Oct. 5	.91	([4])	([4])	T
Oct. 12	.88			.42
Month, October	[1]1.51			[1].42

[1] For 11 days.
[2] Sept. 1 to 18.
[3] Sept. 24 to Oct. 1.
[4] Instrument cup broken.

Tank Experiments—Native Vegetation and Evaporation

In order to obtain some measure of the quantity of water used by native plants growing in moist areas of San Luis Valley during 1936, an evapo-transpiration station was established at Parma and an evaporation station at San Luis Lakes. (Pl. 11.)

Parma station.—This station was located 6 miles east of Monte Vista (section 1, R8E, T38N) in a swamp of tules and native grasses just south of Rio Grande. A small plot in which to place the equipment was fenced with woven wire to protect the station from animals. The soil was heavy and somewhat impervious to the depth of 6 feet, and was mixed with vegetative matter. The Centennial canal, about 150 feet south of the station, appeared to supply water to the swamp by seepage. A good supply of water for the station was obtained from the canal and from a well driven on the site.

The general arrangement of the station is shown in figure 80. To simulate swamp conditions the tanks were entirely surrounded by similar growth. All the tanks were made of galvanized iron and were 2 feet in diameter and 3 feet deep. Other equipment consisted of a standard Weather Bureau evaporation pan, a standard 8-inch rain gage, a thermograph, and an anemometer.

Tank no. 1 contained transplanted tules (*Scirpus americanus* and *Typha latifolia*) which developed a growth comparable in vigor with the natural tule growth in the swamp surrounding the tule tank. Several times a week a measured amount of water was added to the tank until the soil surface was covered to a depth of approximately 2 inches.

Sections of native meadow (*Agrostis idahoensis* and *Calamovilfa longifolia*) sod 24 inches in diameter and 12 inches deep were transplanted into tanks nos. 2 and 3. The water table in tank no. 2 was kept at or above the ground surface by adding measured amounts of water several times a week. Tank no. 3 was equipped with a Mariotte supply bottle to maintain the ground water at 8 inches below the surface, but this depth was not always maintained because of rains which raised the water table.

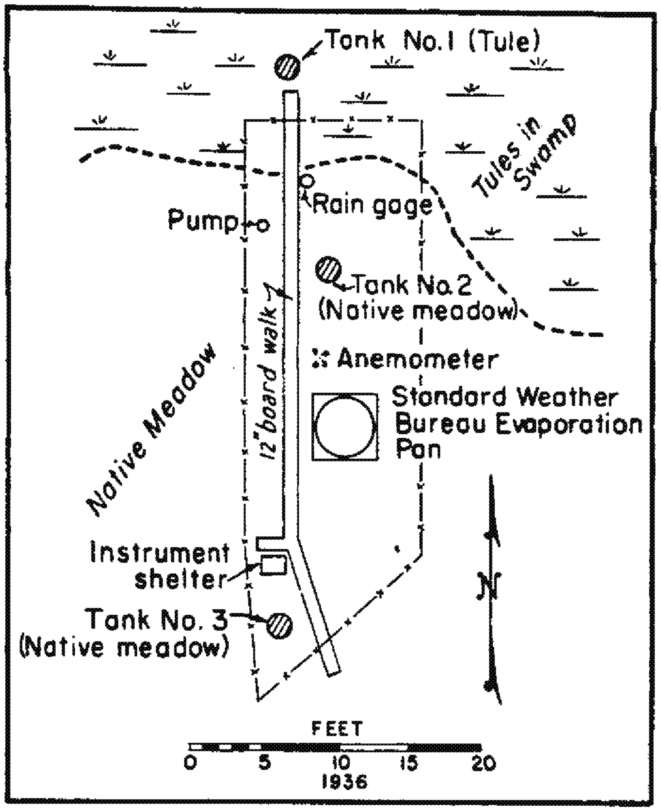


FIGURE 80.—Plan of Parma Station, San Luis Valley, Colo.

FIGURE 81.—Parma evaporation and transpiration station, San Luis Valley.

Water-use records in the tule and the two native meadow tanks were not begun simultaneously, hence comparisons of the total use of water by the different tanks prior to July may not be made. However, records from July to November, inclusive, are available for each of the three tanks. For this period the quantity of water used by tule growth in tank no. 1 was 27.32 inches of depth, with a monthly maximum of 11.60 inches in July and a minimum of 1.30 inches in November, when plant growth had ceased. Comparison of the October and November consumptive use with loss from the Weather Bureau pan for the same period indicates that all the water lost from the tule tank during this period was chargeable to evaporation rather than to use of water by plant growth. This is true also for each of the meadow tanks, as in each case the consumptive use by vegetation is less than the depth of water evaporated in the Weather Bureau pan. Thus the indications are that in San Luis Valley the growing season for native vegetation ends early in September and that transpiration by plants is not a factor in consumptive use beyond that time.

Comparison of tule tank no. 1 and native meadow tank no. 2 shows that each growth used nearly the same quantity of water during the July-November period. Tank no. 3, however, in which the water table was approximately 8 inches below the surface, con-

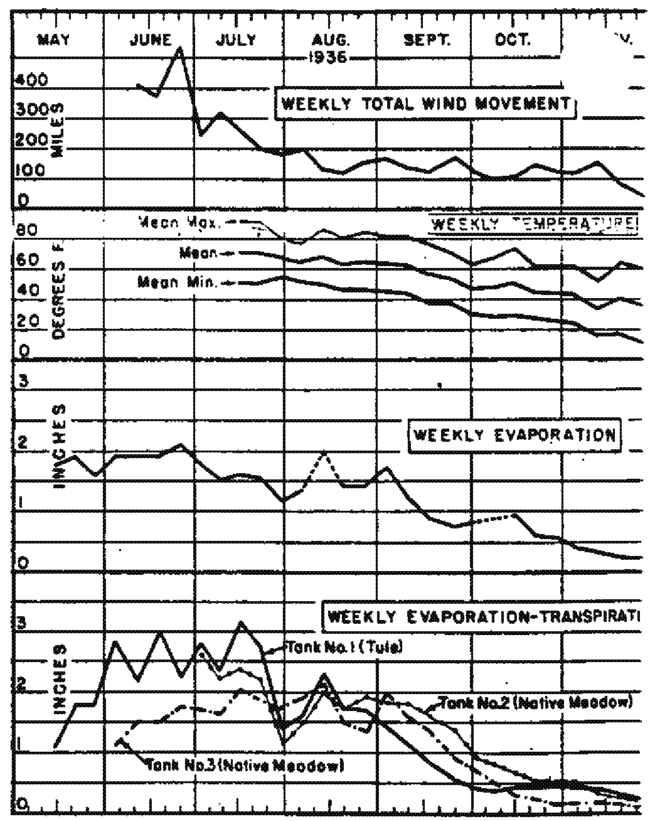


FIGURE 82.—Weekly use of water, evaporation, and wind movement at Parm Station, San Luis Valley, Colo.

sum[illegible] about four inches less than the tank with saturated soil.

A measure of consumptive use is available through comparison with evaporation from a free water surface. Thus, evaporation from the Weather Bureau pan at the Parma station for the July-November period amounted to 22.54 inches or if reduced to reservoir values through use of the accepted coefficient of 0.70, to 15.78 inches. Application of this value indicates that consumptive use by the tules was 173 percent of the evaporation; use by native meadow tank no. 2 was 178 percent; and meadow grass with a water table 8 inches below the surface was 152 percent.

Data obtained at the Parma station during 1936 are shown in tabulated form as follows: Table 62, Weekly consumptive use of water, evaporation and meteorological data, and table 63, Summary of monthly consumptive use of water, evaporation and meteorological data. The weekly variations are shown in figure 32.

San Luis Lakes evaporation station.—This station was located on a neck of land between two of the San Luis lakes in section 26, R. 11 E, T. 40 N., on the same site that the State of Colorado used in 1930, 1931, and 1932. An evaporation pan of the Weather Bureau type was fenced with woven wire for protection from rabbits and other animals. The site was free from windbreaks or other obstructions. The surrounding vegetation was rabbitbrush, saltgrass, and chico.

The equipment consisted of one standard Weather Bureau pan, one 8-inch rain gage, and one anemometer

TABLE 62.—*Weekly consumptive use of water, evaporation and meteorological data of Parma station, San Luis Valley, Colo., season of 1936*

Week ending—[1]	Consumptive use of water, in inches			Average depth to water table in inches, tank no. 3	Evaporation in inches (standard Weather Bureau pan)	Meteorological data					
	Tank no. 1—Tule in water	Tank no. 2—Native meadow	Tank no. 3—Native meadow			Temperature in degrees Fahrenheit [2]			Wind movement in total miles	Average wind movement, miles per hour	Precipitation in inches
						Mean maximum	Mean minimum	Mean			
May 18	1.02				1.70						
May 25	1.76				1.89						
June 1	1.76				1.47	71	34	53			
June 8	2.78		1.19	7.00	1.93	80	41	60			
June 15	2.14		1.51	9.00	1.93	86	45	66	402	2.39	0.20
June 22	2.87		1.51	10.25	1.93	82	46	64	374	2.23	.00
June 29	2.17		1.75	13.75	2.06	82	42	62	541	3.22	.75
July 6	2.75	2.56	1.66	8.50	1.66	78	43	60	242	1.44	.12
July 13	2.23	2.18	1.58	5.75	1.47	84	45	64	318	1.89	.27
July 20	3.09	2.34	2.04	10.75	1.59	89	51	70	246	1.46	.00
July 27	2.73	2.21	1.86	9.25	1.47	88	49	68	198	1.17	.28
Aug. 3	1.30	1.23	1.53	7.25	1.11	79	53	66	187	1.11	.47
Aug. 10	1.56	1.52	1.82	5.50	1.30	77	51	64	196	1.17	1.29
Aug. 17	2.31	2.06	2.14	8.00	[3] 1.96	87	48	68	122	.73	.49
Aug. 24	1.67	1.63	1.45	5.25	[3] 1.40	80	46	63	116	.69	.70
Aug. 31	1.63	1.88	1.28	11.25	1.39	82	47	64	154	.92	.00
Sept. 7	1.34	1.79	1.94	8.25	1.70	80	45	62	157	.93	.55
Sept. 14	1.10	1.71	1.58	7.25	1.15	80	43	62	131	.78	.06
Sept. 21	.78	1.59	1.29	8.25	.91	77	37	57	120	.71	.06
Sept. 28	.62	1.26	.83	7.25	.71	71	36	54	160	.95	1.15
Oct. 5	.49	.34	.74	[illegible]	.77	[illegible]	[illegible]	45	116	.59	.02
Oct. 12	[illegible]	.73	.48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.56	[illegible]
Oct. 19	[illegible]	.61	.32	[illegible]	[illegible]	72	[illegible]	[illegible]	105	.32	.09
Oct. 26	.42	.45	.21	5.75	.58	59	26	42	142	.85	.20
Nov. 2	.43	.49	.15	5.75	.54	60	24	42	117	.70	.15
Nov. 9	.41	.39	.26	7.50	.42	51	15	33	152	.90	.10
Nov. 16	.35	.25	.23	9.50	.38	63	16	40	96	.57	.00
Nov. 23	.27	.24	.37	7.90	.33	60	17	38	56	.33	.00
Nov. 30	.21	.18		11.00	[3] .30	58	10	34	24	.14	.04

[1] Data for weekly periods have been corrected if time interval varied more than 1 hour.
[2] Records from May 25 to June 13 were taken at Alamosa Weather Bureau station.
[3] Estimated.

TABLE 63.—*Summary of monthly consumptive use of water, evaporation and meteorological data of Parma staion, San Luis Valley, Colo., season of 1936*

Month	Consumptive use of water in inches			Average depth to water table in inches tank no. 3	Evaporation in inches (standard Weather Bureau pan)	Meteorological data					
	Tank no. 1—Tules in water	Tank no. 2—Native meadow	Tank no. 3—Native meadow			Temperature in degrees Fahrenheit [1]			Wind movement in total miles	Average wind movement, miles per hour	Precipitation in inches
						Mean maximum	Mean minimum	Mean			
May [2]	4.02				4.15						
June	11.45		6.51	10.00	8.26	80	42	61	1,286	1.79	1.07
July	11.60	9.55	8.27	8.50	6.52	89	50	70	1,029	1.38	.99
August	8.31	8.04	7.79	7.50	6.61	81	49	65	618	.83	3.06
September	4.10	7.79	5.80	7.75	4.70	77	40	59	616	.85	1.28
October	2.01	2.74	1.18	3.80	3.22	66	28	46	487	.65	.59
November	1.30	1.15	.95	8.90	1.49	58	15	36	352	.49	.14

[1] Records from May 25 to June 13 were taken at Alamosa Weather Bureau station.
[2] May 15 to 31.

with cups 20 inches above the ground level. Evaporation records were started on May 18, 1936.

Table 64 gives monthly evaporation from a standard Weather Bureau pan, and wind movement and precipitation from May to November 1936, at San Luis Lakes station.

TABLE 64.—*Monthly evaporation, wind movement and precipitation at San Luis Lakes station, San Luis Valley, Colo., season of 1936*

Month	Evaporation in inches (Weather Bureau pan)	Wind movement in total miles	Precipitation in inches
May [1]	4.89	....	....
June	10.84	2,076	1.48
July	9.33	2,464	2.18
August	7.76	2,045	4.26
September	5.60	2,199	.64
October	3.74	2,159	.66
November	1.56	1,727	.07

[1] May 18 to June 1.

Middle Rio Grande Valley

The area here considered as Middle Rio Grande Valley extends from Sandoval County, through Bernalillo and Valencia Counties to San Marcial in Socorro County, a total distance of about 150 miles. The average width is about 2 miles. The valley floor is divided into a number of units each of which may be considered a subarea of the valley proper.

Most of the land irrigated is supplied water by gravity from the Rio Grande through the system of the Middle Rio Grande Conservancy District. The district is comprised of four divisions, the Cochiti, the Albuquerque, the Belen, and the Socorro, named in order downstream. Each has its own diversion dam, main canal or canals, and distribution system. El Vado Dam and Reservoir may be considered as a fifth division. The dam is built across the Chama River in northern New Mexico about 17 miles west of Tierra Amarilla. The storage capacity of El Vado Reserv... abo 200,000 acre-feet. (See pp. 309 to 310.)

The climate of the Middle Rio Grande Vall... ...ri the average annual precipitation varying fr... ...oo 8 inches at Albuquerque to about 10 inches at Socor... nearly two-thirds of which occurs during the growi... season. (See tables 18 and 19.) Snowfall is light a... disappears rapidly. Mean temperature and precipi... tion records for 1936 at Albuquerque, Los Lunas, a... Socorro are shown in table 65.

The soils of the Valley consist principally of alluv... deposits and in most places are underlain by sand... gravel. Because of the water-borne method of depo... the valley soils are quite irregular. In places the su... soil contains muck, indicating former swamp are... (See table 20.)

A preliminary survey of the Valley was made... April 1936 for the purpose of locating places wi... favorable conditions for conducting consumptive-u... of-water studies. Sites were selected for tank expe... ments and soil-moisture studies. Experiment statio... were established for agricultural crops at Los Poblan... ranch 5 miles north of Albuquerque and at Phillips fa... 5 miles south of Albuquerque, and for native vegetati... at Isleta. Evaporation stations were installed at ... Vado Dam, Isleta and Socorro. Routine observatio... were conducted cooperatively with the Weather Bure... and the Middle Rio Grande Conservancy D... ...t El Vado, Middle Rio Grande Conservancy I... Isleta and the Geological Survey at Socorro. ... co... ference with representatives of New Mexico and Tex... an area on the east side of the Rio Grande betwe... Isleta and Belen was selected for an intensive stu... of stream-flow depletion and the consumptive use... water in cooperation with the Geological Survey. ... soil-moisture laboratory was established in the ci... engineering laboratory of the University of New Mexi... at Albuquerque.

TABLE 65.—*Mean temperature and precipitation records at Albuquerque, Los Lunas, and Socorro, 1936* [1]

Month	Albuquerque				Los Lunas				Socorro			
	Temperature in degrees Fahrenheit			Precipitation in inches	Temperature in degrees Fahrenheit			Precipitation in inches	Temperature in degrees Fahrenheit			Precipit... tion i... inches
	Mean maximum	Mean minimum	Mean		Mean maximum	Mean minimum	Mean		Mean maximum	Mean minimum	Mean	
January	46.2	19.1	32.6	0.55	45.5	17.1	31.3	0.60	51.8	22.5	37.2	0
February	54.3	25.6	39.9	.12	54.9	23.8	39.4	.17	61.6	28.7	45.2	
March	63.9	30.8	47.1	.11	62.4	28.4	45.4	.00	70.7	32.8	51.8	
April	72.5	38.4	55.4	.09	73.2	36.5	54.8	.05	79.3	41.3	60.3	
May	81.1	48.9	65.0	.27	80.8	45.8	63.3	.37	87.6	49.6	68.6	
June	91.7	56.9	74.3	.43	90.6	53.1	71.8	.17	98.2	56.5	77.4	
July	91.8	62.3	77.0	.67	92.1	60.5	76.3	1.53	96.6	61.4	79.0	1
August	91.8	61.4	76.4	.62	90.4	58.8	74.6	.42	95.9	60.0	78.0	
September	79.3	53.2	66.2	2.05	78.3	51.6	65.0	1.82	84.9	53.7	69.3	2
October	69.5	54.1	55.2	.17	69.0	37.8	53.4	.00	75.0	39.6	57.3	
November	58.5	25.4	42.0	T	59.1	22.1	40.6	.00	62.3	27.1	44.7	
December	49.6	20.7	35.2	.13	48.3	17.2	32.8	T	54.8	22.9	38.8	
Annual	70.8	41.4	56.1	5.21	70.4	37.8	54.1	5.13	76.6	41.3	59.0	7

[1] Records were obtained from Weather Bureau, Albuquerque, N. Mex., through the courtesy of Erle L. Hardy, meteorologist in charge.

...a-Belen Area

...he Isleta-Belen Area is in the north end of the Belen ...vision of Middle Rio Grande Conservancy District ...nd includes all the land under the canal system east of the Rio Grande between the Isleta diversion dam and the highway bridge crossing the river east of Belen. It is approximately 18 miles long and has maximum width of about 3 miles. Figure 83 shows the location of the area.

Water is diverted for irrigating this area through the Chical lateral (12.74 miles long), the Chical Acequia (3.16 miles long), the Cacique Acequia (3.06 miles long), and the Peralta main canal (16.54 miles long). The tract has a drainage system consisting of several interior drains and the upper Peralta riverside drain and the lower Peralta riverside drain. The latter two parallel the Rio Grande and extend along the entire west side of the area. Automatic water stage recorders and staff gages were installed and daily discharge records compiled by the surface water division of the Geological Survey for all the main canals and drains in the area. The Ground Water Division of the Survey installed about 135 observation wells in the area and kept monthly records of ground-water fluctuations.

Acreage.—The Bureau of Agricultural Engineering 1936 survey shows that there is 21,074 acres in the Isleta-Belen area of which 9,147 acres were irrigated. ...bout 1,200 acres is native vegetation growing along ...e river and thus has access to an unlimited supply of water. Table 67 shows the detailed land classification.

If the acreage between the gages on the interior drains and wasteways and the Rio Grande is excluded, the Isleta-Belen area is reduced to approximately 17,500 acres.

Inflow.—Surface water entering the area (I) through the Chical lateral, Chical Acequia, Cacique Acequia and the Peralta main canal was measured at Isleta diversion and is considered inflow. There may have been a small amount of arroyo inflow between Isleta and Belen after summer rainstorms; if so, it was negligible.

Outflow.—The "outflow" from the area was measured from Otero drain, San Fernandez drain, Tome drain and Public wasteway, which flow into the upper and lower Peralta Riverside drains, and from the lower Peralta main canal and La Constancia Acequia wasteway, which empty directly into the Rio Grande. An analysis of available data indicates that a considerable portion of the water flowing in the upper and lower Peralta Riverside drains is seepage from the river; thus the discharge measurements of these drains cannot be used as outflow (R) from the area unless a correction is applied.

Precipitation.—The number of acre-feet of precipi...on (P) contributed to the area is based on the monthly record at Albuquerque for April and May and the Isleta station record for June to December 1936, inclusive.

Ground-water storage.—The amount of change in ground-water storage ($G_s - G_e$) is estimated from measurements of ground-water fluctuations in some 135 observation wells in the area made by the Geological Survey. In December 1936 the average depth to water was about 0.5 foot lower than in April 1936. An assumed specific yield of 15 percent was used. The change in ground-water storage was small, averaging only 0.08 acre-foot per acre for the area.

Consumptive use of water.—The use of water in the Isleta-Belen area was estimated by both the inflow-outflow and the integration methods.

Inflow-Outflow Method.—Several analyses were made using all the canals entering the area at Isleta as "inflow" and all the canals, drains and wasteways flowing out of the area as "outflow", but no satisfactory solution was found because of the large amount of river water intercepted by drains, especially those along the river.

The most feasible method of determining the consumptive use of water in this area, with the data available, is to disregard the acreage below the gaging stations of the Otero, San Fernandez and Tome drains and the Peralta canal and La Constancia Acequia wasteway, and consider a smaller area of some 17,500 acres above these gaging stations, thus eliminating the necessity of including the uncertain outflow of the upper and lower Peralta riverside drains. Under this plan only the interior drains and wasteways are considered as outflow. However, a large portion of the section excluded supports a growth of water-loving vegetation which, if included, would probably increase the use of water in the entire area. Stream-flow depletion and consumptive use of water as determined by the above method for the period April 1936 to December 1936 are shown in table 66. The consumptive use was 4.46 acre-feet per acre of irrigated land and 2.28 acre-feet per acre for the 17,500 acres for the 9-month period. It is estimated that the annual or Valley consumptive use would be 2.7 acre-feet per acre, on the assumption that the use of water for January and February would be 0.1 acre-foot per acre per month and for March, 0.2 acre-foot.

The gross diversion or inflow to the area at Isleta, for the period, was 89,386 acre-feet or 9.8 acre-feet per acre of irrigated land and 4.3 acre-feet per acre for gross acreage of 21,000.

Integration Method.[6]—The areas of different types of land in the Isleta-Belen area have been grouped and are

[6] The sum of the products obtained by multiplying the area of land in each classification by the unit consumptive use for each gives the consumptive use of the area. The process is designated the integration method.

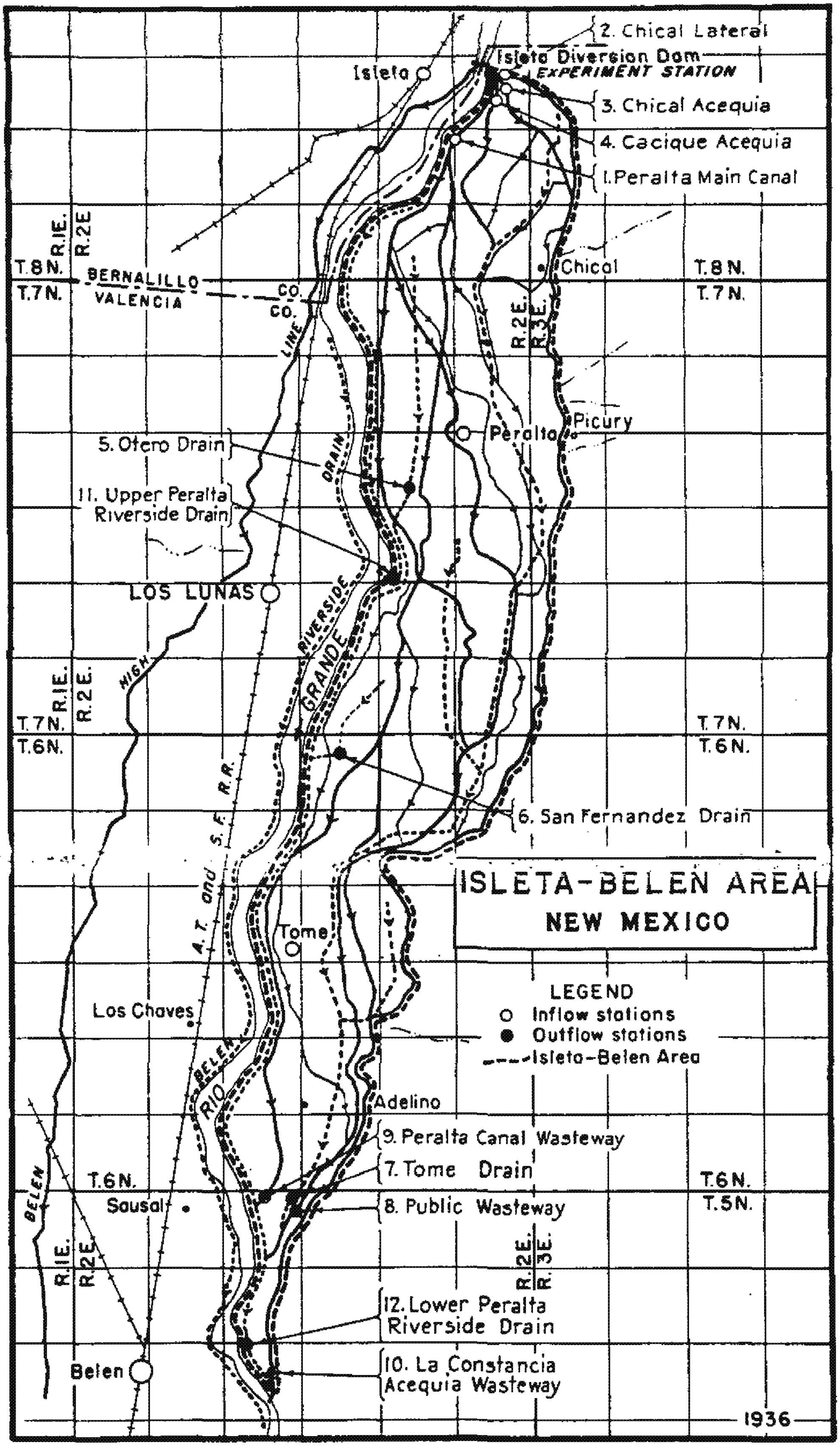


FIGURE 83.—Isleta-Belen intensive study area, Middle Valley, N. Mex.

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TABLE 66.—*Use of water in Isleta-Belen area in Midd!: Rio Grande Valley, N. Mex., as determined by inflow, outflow, and precipitation records, April to December 1936, inclusive*

Item	April	May	June	July	August	September	October	November	December	Total	
	Acre-feet										
Inflow:											
1. Peralta main Canal	9,160	10,910	9,440	8,120	9,060	9,080	7,080	6,870	0		
2. Chical lateral	2,640	2,880	1,810	1,240	1,990	1,510	587	1,270	0		
3. Chical Acequia	378	508	356	315	370	221	54	147	0		
4. Cacique Acequia	388	614	724	419	593	430	39	183	0		
Total	12,566	14,912	12,330	10,094	12,013	11,241	7,760	8,470	0	89,386	
Outflow:											
5. Otero drain	176	207	222	215	190	209	211	222	277		
6. San Fernandez drain	154	187	157	143	111	132	124	124	132		
7. Tome drain	1,720	2,350	2,200	2,030	2,150	2,100	1,610	1,720	1,680		
8. Public wasteway	[1] 1,820	2,270	1,540	1,460	2,090	2,970	1,740	1,230	34		
9. Peralta canal wasteway	[1] 2,200	[1] 4,980	2,280	1,370	1,390	3,470	4,160	1,570	24		
10. La Constancia Acequia wasteway	[1] 530	[1] 577	426	164	176	377	191	119	0		
Total	6,600	10,571	6,825	5,382	6,107	9,258	8,336	4,985	2,147	60,211	
Inflow minus outflow	5,966	4,341	5,505	4,712	5,906	1,983	−576	3,485	−2,147	29,175	
Precipitation	131	394	555	2,310	990	4,540	420	0	190	9,530	
Consumptive use	6,097	4,735	6,060	7,022	6,896	6,523	−156	3,485	−1,957	38,705	
Stream-flow depletion:											
Per irrigated acre (9,000 acres)	0.66	0.48	0.61	0.52	0.66	0.22	−0.06	0.39	−0.24	[2] 3.24	[3] 3.39
Consumptive use:											
Per irrigated acre (9,000 acres)	.68	.53	.67	.78	.77	.72	−.01	.39	−.22	[2] 4.31	4.46
Per acre (17,500 acres)	.35	.27	.35	.40	.39	.37	−.02	.20	−.11	[2] 2.20	[3] 2.28

[1] Estimated.
[2] Excluding change in ground-water storage.
[3] Including change in ground-water storage.

shown in table 67. Estimated consumptive use for various types is shown in table 67. The units upon which these estimates are based were selected arbitrarily. The entire area of the tract (21,074 acres) is used in the computations. Estimates of Valley consumptive use range from 53,287 to 61,655 acre-feet for ` 21,074 acres. The unit consumptive use ranges n 2.53 acre-feet per acre to 2.93 with an average of ..73 acre-feet per acre. This average is close to that obtained by application of the inflow-outflow method (2.7 acre-feet per acre).

Consumptive use in the Middle Valley.—With the iata available for Middle-Rio Grande Valley, the integration method offers the best present means of estimating consumptive use of water. Hence the average consumptive use in the Middle Rio Grande Conservancy District was determined by this method. The acreage mapped by the Bureau of Agricultural Engineering in 1936 and the estimated unit consumptive use for various crops based on the Bureau's 1936 studies were used in the computations. The acreages of land in the different classifications, the estimated unit consumptive use, and the computed normal Valley consumptive use for the Cochiti, Albuquerque, Belen, and Socorro divisions are shown in tables 68 to 71.

TABLE 67.—*Consumptive use of water in Isleta-Belen area in Middle Rio Grande Valley, N. Mex., as estimated by integration method, using different units*

Crop	1936 area	Consumptive use [1]					
	(a)	(c)	(ca)	(c)	(ca)	(c)	(ca)
	Acres	Acre-feet per acre	Acre-feet	Acre-feet per acre	Acre-feet	Acre-feet per acre	Acre-feet
Irrigated land:							
Alfalfa	3,088	4.0	12,352	4.5	13,896	3.5	10,808
Grass (hay) and pasture	1,299	3.0	3,897	3.0	3,897	2.5	3,248
Miscellaneous crops	4,760	2.0	9,520	1.5	7,140	2.0	9,520
Native vegetation:							
Grass	5,186	3.0	15,558	2.5	12,965	2.0	10,372
Brush	1,600	3.5	5,600	3.5	5,600	3.0	4,800
Weeds	1,572	3.0	4,716	3.0	4,716	2.5	3,930
Bosque	1,194	5.0	5,970	4.5	5,373	5.5	6,567
Miscellaneous:							
Temporarily out of cropping	477	2.0	954	2.0	954	2.0	954
Villages	42	2.0	84	2.0	84	2.0	84
Water surface: Pooled, canal, and drains	348	4.3	1,496	4.3	1,496	4.3	1,496
Bare land, roads, etc.	1,508	1.0	1,508	1.0	1,508	1.0	1,508
Total entire area	21,074	2.93	61,655	2.74	57,629	2.53	53,287

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

TABLE 68.—*Consumptive use of water in Cochiti Division, Middle Rio Grande Conservancy District, New Mexico, as estimated by integration method*

Type of land	1936 area	Consumptive use [1]	
	(a)	(c)	(ca)
	Acres	Acre-feet per acre	Acre-feet
Irrigated land:			
Alfalfa	698	4.0	2,792
Native hay and pasture	1,474	2.5	3,685
Miscellaneous crops	3,036	2.0	6,072
Entire area	5,208	2.41	12,549
Temporarily out of cropping	169	2.0	338
Towns and villages	401	2.0	802
Native vegetation:			
Grass	2,628	2.5	6,570
Brush	4,417	3.0	13,251
Trees—Bosque	4,187	5.0	20,935
Entire area	11,232	3.63	40,756
Water surfaces: pooled, river and canal	1,528	4.3	6,570
Bare land	901	1	901
Total (entire area)	19,439	3.19	61,910

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

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The total Valley consumptive use for 187,682 acres in the district was 582,858 acre-feet, and the average unit consumptive use 3.11 acre-feet per acre.

These figures may or may not represent normal use, for should the recently constructed storage, irrigation, and drainage works have their intended effects in altering the present agriculture of the Middle Valley, or should economic conditions reshape it, the water requirements might be much changed.

TABLE 69.—*Consumptive use of water in Albuquerque Division, Middle Rio Grande Conservancy District, New Mexico, as estimated by integration method*

Type of land	1936 area (a) Acres	Consumptive use[1] (c) Acre-feet per acre	(ca) Acre-feet
Irrigated land:			
Alfalfa	7,221	4.0	28,884
Native hay and pasture	3,055	2.5	7,638
Miscellaneous crops	12,543	2.0	25,086
Entire area	22,819	2.70	61,608
Temporarily out of cropping	913	2.0	1,826
Towns and villages	4,241	2.0	8,482
Native vegetation:			
Grass	10,487	2.5	26,218
Brush	4,968	3.0	14,904
Trees—Bosque	8,040	5.0	40,200
Entire area	23,495	3.46	81,322
Water surfaces: pooled, river and canal	5,738	4.3	24,673
Bare land	921	1.0	921
Total (entire area)	58,127	3.08	178,832

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

TABLE 70.—*Consumptive use of water in Belen Division, Middle Rio Grande Conservancy District, New Mexico, as estimated by integration method*

Type of land	1936 area (a) Acres	Consumptive use[1] (c) Acre-feet per acre	(ca) Acre-feet
Irrigated land:			
Alfalfa	7,883	4.0	31,532
Native hay and pasture	2,464	2.5	6,160
Miscellaneous crops	12,748	2.0	25,496
Entire area	23,895	2.73	65,188
Temporarily out of cropping	1,165	2.0	2,330
Towns and villages	530	2.0	1,060
Native vegetation:			
Grass	26,540	2.5	66,350
Brush	7,149	3.0	21,447
Trees—Bosque	7,105	5.0	35,525
Entire area	40,794	3.02	123,322
Water surfaces: Pooled, river and canal	6,779	4.3	29,150
Bare land	3,881	1.0	3,881
Total (entire area)	77,044	2.92	224,931

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

TABLE 71.—*Consumptive use of water in Socorro Division, M[illegible] Rio Grande Conservancy District, New Mexico, as estima[illegible] by integration method*

Type of land	1936 area (a) Acres	Consumptive [illegible] (c) Acre-feet per acre	(ca) Acre-feet
Irrigated land:			
Alfalfa	1,632	4.0	6,528
Native hay and pasture	772	2.5	1,930
Miscellaneous crops	4,833	2.0	9,666
Entire area	7,237	2.50	18,124
Temporarily out of cropping	733	2.0	1,466
Towns and villages	993	2.0	1,986
Native vegetation:			
Grass	4,313	2.5	10,782
Brush	3,105	3.0	9,315
Trees—Bosque	7,462	5.2	38,802
Entire area	14,880	3.96	58,899
Water surfaces: Pooled, river and canal	7,850	4.5	35,325
Bare land	1,379	1.0	1,379
Total (entire area)	33,072	3.54	117,179

[1] ca = the product of unit consumptive use in acre-feet per acre (c) by area in acres (a).

Soil Moisture Studies—Agricultural Crops

Suitable sites for soil moisture studies in the Middle Rio Grande Valley are very limited as the water table in most sections is relatively high. Plots were selected in a deciduous orchard, an alfalfa field and a vineyard on the farm of J. L. Phillips, approximately 5 mil[illegible] south of Albuquerque, after careful consideration [illegible] been given to the following factors: (a) Absence o[illegible] high water table; (b) willingness of farmer to cooperate; (c) uniformity of soil; (d) general condition of crop; (e) conditions affecting water delivery, especially facilities for measurement.

The experimental plots were on Anthony silty clay loam soil underlain, at about 3 feet, by approximately 12 inches of pinkish-gray silty clay. A dense clay layer was encountered between 7 and 10 feet below the surface. The top soil was moderately friable and easily cultivated.

The water for the farm is obtained by pumping with a vertical centrifugal pump with a 6-inch discharge, driven by a 15-horsepower electric motor, from a well 85 feet deep. The water level is normally at 33 feet. The discharge is approximately 540 gallons per minute.

The amount of water applied and the frequency of irrigation was determined by the owner. The water was measured over a 2-foot rectangular weir. During the irrigation season some precipitation occurred. This ranged up to 1.55 inches in single storms and totaled about 5.11 inches.

Soil samples were taken on each plot to a depth of 10 feet before and after irrigation, with some additional sampling between irrigations, to determine the so[illegible] moisture fluctuations and the rate of moisture ext[illegible] y the crops at various depths. All soil samples taken with the Veihmeyer improved soil tube at ...itely established points in the plots. This sampling was done at 6-inch intervals in the first foot and at 1-foot intervals thereafter, to the final depth of 10 feet.

Standard methods were used in weighing and drying the soil samples and in the computation of the moisture percentages. From the moisture percentages thus obtained the amounts of water used by the crops (in acre-inches per acre from each foot of soil) were computed by using the previously discussed formula $D=\frac{MVd}{100}$. (See p. 348.) The total use was then reduced to equivalent uses for 30 days.

The apparent specific gravity (volume-weight) and field capacity of the soil in the various plots are shown in table 72.

Orchard.—The orchard (3.5 acres) was planted in 1929. The ground has a slope of 1 foot in 100 feet. The orchard contains apples, peaches, plums, and quinces, the trees being spaced 24 feet apart in each direction. The trees began to shed their leaves Oct. 20, 1936. Soil samples were taken around a plum tree. The six holes were placed on two lines at right angles to each other. Holes no. 1 and no. 6 were 12 feet from the tree; no. 2 and no. 5, 9 feet; and no. 3 and no. 4, feet.

The results of the soil moisture studies are summarized in tables 73 and 74. Table 73 shows the average moisture content at each sampling, with the dates and quantities of irrigation water applied. In table 74, the moisture percentages have been reduced

Table 72.—*Results of apparent specific gravity and field capacity determination of Anthony silty clay loam soil, Phillips ranch near Albuquerque, N. Mex., 1936*

Depth of soil	Orchard		Alfalfa		Vineyard	
	Apparent specific gravity	Field capacity (percent)	Apparent specific gravity	Field capacity (percent)	Apparent specific gravity	Field capacity (percent)
First 6 inches	1.35	9.3	1.27	15.1	1.35	11.7
Second 6 inches	1.49	11.0	1.33	23.7	1.40	18.1
Second foot	1.36	19.6	1.20	22.9	1.32	12.7
Third foot	1.27	14.1	1.20	23.1	1.32	9.4
Fourth foot	1.22	17.4	1.33	22.1	1.41	6.0
Fifth foot	1.27	11.3	1.23	17.8	1.38	5.4
Sixth foot	1.35	5.3	1.14	22.7	1.35	7.3
Seventh foot	1.43	4.4	1.16	24.2	1.28	13.2
Eighth foot	1.42	4.4	1.17	15.8	1.21	17.4
Ninth foot	1.42	5.6	1.23	12.4	1.21	16.6
Average	1.33	10.2	1.23	20.0	1.31	11.8

to acre-inches of water per acre taken by the growing crop from each foot in depth of soil. Soil moisture determinations were made on approximately 540 samples in the orchard.

The soil moisture percentages used for the first 3 feet on May 8 are the values for field capacity. The moisture percentages used for October 10 for the fifth, sixth, seventh, eighth, and ninth foot are equal to those for September 9, since it was found that a heavy rain penetrated the soil only 4 feet.

Vineyard.—The vineyard (6.9 acres) was also planted in 1929. The slope is 1.4 feet in 100 feet. The vines (Alicante) are 8 feet apart. Picking of the grapes on a large scale started October 14, 1936. Samples were taken 4 feet north and south of each of three vines which were 92 feet apart. Soil moisture determinations were made on about 510 samples. Table 75 shows the average moisture content at each sampling. Table 76

Table 73.—*Results of soil sampling and irrigation data, Phillips mixed orchard near Albuquerque, N. Mex., season of 1936*

Date of sampling	Average moisture content of the soil, percent											Dates of irrigation	Depth of irrigation water applied, inches
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Tenth foot		
May 8	9.3	11.0	19.6	14.1	20.0	7.7	6.7	5.9	5.8	6.6	14.9		
May 23	4.4	6.4	15.7	12.6	17.4	9.8	4.5	4.0	3.9	5.5	15.5	May 16	3.16
June 2	9.3	11.0	19.6	14.1	17.4	11.3	5.3	4.4	4.4	5.6	13.0		
July 7	5.5	6.2	12.1	8.9	12.2	8.4	4.5	3.9	5.6	8.3	17.7	July 9	3.73
July 28	8.8	11.0	17.1	10.2	13.1	9.8	5.3	4.1	5.1	7.5		July 21	3.82
Aug. 7	7.1	9.4	15.8	9.0	9.7	6.3	6.6	5.4	6.1	6.4			
Aug. 14	5.6	8.9	14.2	7.9	9.3	6.2	6.3	5.1	6.0	5.7		Aug. 31	4.18
Sept. 9	8.1	12.8	21.6	12.2	17.1	7.8	4.8	4.2	4.7	4.5			
Oct. 6	12.4	16.1	26.1	12.5	16.8	7.8	4.8	4.2	4.7	4.5			

Table 74.—*Quantities of water used in intervals between irrigations in Phillips mixed orchard near Albuquerque, N. Mex., season of 1936*

Interval	Soil moisture loss, acre-inches per acre												
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Rain in inches	Total loss	Calculated loss in 30 days
May 8 to May 23	0.40	0.41	0.56	0.23	0.38	−0.32	0.28	0.33	0.32	0.19	0.18	2.96	5.92
June 2 to July 8	.31	.43	1.13	.79	.76	.44	.13	.09	−.21	−.46	1.41	4.82	4.14
July 28 to Aug. 14	.26	.19	.44	.35	.55	.55	−.16	−.17	−.15	.31	.40	2.57	4.54
Sept. 9 to Oct. 6	−.35	−.30	−.68	−.05	.04	0	0	0	0	0	2.99	1.65	1.84

shows the calculated loss in acre-inches per acre for the periods considered and per 30 days.

Alfalfa.—The alfalfa, which has in this region a growing season from about April 15 to about October 10, was planted in the spring of 1933. The stand in 1936 was fair. Samples were taken at three holes on the center line of the field (1.37 acres) 110 feet apart. This field has a slope of 1 foot per 100 feet. All the soil moistures and the dates of sampling are shown in table 77, together with the amounts of irrigation water applied. The calculated uses of water in acre-inches per acre per 30 days are shown in table 78.

Soil Moisture in Native Vegetative Areas

In the summer of 1936 soil samples were taken typical areas of high water table in the Albuquer Belen, and Socorro divisions of the Middle Rio Grande Conservancy District near some of the observation wells of the Geological Survey. The primary purpose of this investigation was to determine the soil characteristics and the amount of water available in the soil above the water table for use of native vegetation.

The samples were taken with a standard soil tube, in 6-inch and 1-foot sections. The depth to ground water, soil type, and vegetative cover were observed when the soil samples were taken.

TABLE 75.—*Results of soil sampling and irrigation data, Phillips vineyard, near Albuquerque, N. Mex., season of 1936*

Dates of sampling	Average moisture content of the soil, percent											Dates of irrigation	Depth of irrigation water applied (inches)
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Tenth foot		
May 9	16.2	24.0	18.2	13.5	8.3	5.8	7.8	13.7	15.8	18.7	17.6		
June 10	11.2	15.6	13.8	12.8	8.3	6.3	7.9	13.0	19.2	20.7	16.9	June 10	3.48
June 18	11.2	17.4	13.0	11.4	8.1	9.3	8.4	12.9	16.0	21.5	18.5		
July 7	6.5	11.2	9.9	10.4	7.5	7.4	9.3	11.9	18.1	18.3	14.4	July 24	3.05
July 28	11.7	18.1	12.7	9.4	6.0	5.4	7.3	13.2	17.4	16.6			
Aug. 6	8.3	19.9	11.4	9.8	6.4	5.8	8.6	14.1	17.3	18.7			
Aug. 13	6.9	10.9	10.5	9.1	5.9	4.7	8.1	13.6	16.6	19.3		Aug. 18	5.30
Sept. 2	9.2	13.7	10.9	9.4	5.6	5.4	7.9	13.7	16.0	17.7			
Sept. 24	12.2	11.4	10.6	10.4	6.2	4.8	6.2	8.1	14.3	22.4			

TABLE 76.—*Quantities of water used in intervals between irrigations in Phillips vineyard, near Albuquerque, N. Mex., season 1936*

Interval	Soil moisture loss, acre-inches per acre												
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Rain in inches	Total loss	Calculated loss in 30 days
May 9 to June 10	0.41	0.71	0.70	0.11	0.00	−0.08	−0.02	0.11	−0.49	−0.29	0.68	1.84	1.73
June 18 to July 7	.38	.52	.49	.16	.10	.31	−.15	.15	−.30	.46	.61	2.73	4.32
July 28 to Aug. 13	.39	.30	.35	−.35	[illegible] .32	.12	−.13	−.06	.12	−.39	.10	[illegible]	[illegible]
Sept. 2 to Sept. 24	−.24	.19	.35	−.16	−.10	.10	.28	.36	.25	−.59	[illegible]	[illegible]	[illegible]

TABLE 77.—*Results of soil sampling and irrigation data, Phillips alfalfa field, near Albuquerque, N. Mex., season of 1936*

Dates of sampling	Average moisture content of the soil, percent											Dates of irrigation	Depth of irrigation water applied (inches)
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Tenth foot		
June 19	12.7	17.3	23.3	21.1	15.3	12.1	20.2	19.4	12.3	11.4	12.1	June 13	6.00
July 7	15.1	23.7	22.9	23.1	22.1	17.8	22.7	24.2	15.8	12.4	10.7	June 30	6.72
Aug. 6	15.1	19.1	20.1	21.2	16.7	13.8	22.7	23.6	15.2	12.0		July 27	6.54
Aug. 13	11.8	10.7	17.1	19.3	12.4	12.1	27.3	23.3	15.2	13.0			
Sept. 9 [1]	15.1	23.7	22.9	23.1	22.1	17.8	22.7	24.2	15.8	12.4		Sept. 1	9.42
Oct. 6	18.3	18.7	25.7	19.9	10.2	12.0	24.2	19.5	14.1	12.2			

[1] Soil samples lost. Moisture estimated to be at field capacity as determined July 7.

TABLE 78.—*Quantities of water used in intervals between irrigations in Phillips alfalfa field, near Albuquerque, N. Mex., season of 1936*

Interval	Soil moisture loss, acre-inches per acre												
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Seventh foot	Eighth foot	Ninth foot	Rain in inches	Total loss	Calculated loss in 30 days
Aug. 6 to Aug. 13	0.25	0.67	0.43	0.25	0.69	0.27	−0.63	0.04	0.0	−0.15	0.18	2.00	8.57
Sept. 9 to Oct. 6	−.24	.40	−.40	.46	1.90	.93	−.21	.65	.24	.03	2.99	6.75	7

The percent of moisture in the soil at the time of sampling, the saturation percentage, the apparent specific gravity (volume-weight), the real specific gravity and the porosity were determined in the laboratory. In addition, moisture-equivalent determinations were made of the samples taken in Socorro division. Tables 79 to 81 give some of the results in each division.

TABLE 79.—*Results of some of the soil moisture studies, Albuquerque division, Middle Rio Grande Valley, N. Mex., July 1936*

HOLE NO. 5

Depth of sample (feet)	Field moisture content (percent)	Saturation (percent)	Apparent specific gravity	Real specific gravity	Porosity (percent)	Ratio field moisture to saturation
0.0 to 0.5	3.6	28.7	1.43	2.60	40.9	12.5
0.5 to 1.0	6.7	30.4	1.74	2.63	52.9	22.0
1.0 to 2.0	22.1	37.7	1.39	2.62	52.4	58.7
2.0 to 3.0	18.2	27.3	1.20	2.64	32.7	67.0
3.0 to 4.0	26.5	26.5	1.42	2.62	37.4	100.0
4.0 to 5.0	33.6	42.2	1.22	2.48	51.6	79.6

HOLE NO. 6

Depth of sample (feet)	Field moisture content (percent)	Saturation (percent)	Apparent specific gravity	Real specific gravity	Porosity (percent)	Ratio field moisture to saturation
0.0 to 0.5	18.7	37.2	1.08	2.53	49.2	50.3
0.5 to 1.0	10.4	26.4	1.89	2.59	50.4	39.4
1.0 to 2.0	8.5	21.9	1.53	2.63	33.7	38.8
2.0 to 3.0	12.5	20.0		2.66		62.6

HOLE NO. E2-6

Depth of sample (feet)	Field moisture content (percent)	Saturation (percent)	Apparent specific gravity	Real specific gravity	Porosity (percent)	Ratio field moisture to saturation
0.0 to 0.5	24.7	62.2		2.44		39.7
0.5 to 1.0	20.0	39.9	1.25	2.57	50.1	50.1
1.0 to 2.0	19.0	31.3	1.35	2.64	42.4	60.7
2.0 to 3.0	13.9	27.4	1.03	2.64	28.2	50.8
3.0 to 4.0	23.8	23.8	1.75	26.7	41.5	100.0

NOTE.—Hole no. 5, depth to water table, 5.2 feet; vegetation, salt grass. Hole no. 6, depth to water table, 3.0 feet; vegetation, salt grass. Hole no. E2-6, depth to water table, 4.4 feet; vegetation, weeds.

TABLE 80.—*Results of some of the soil moisture studies, Belen division, Middle Rio Grande Valley, N. Mex., July 1936*

HOLE NO. 1W-53

Depth of sample (feet)	Field moisture content (percent)	Saturation (percent)	Apparent specific gravity	Real specific gravity	Porosity (percent)	Ratio field moisture to saturation
0.0 to 0.5	6.7	32.4	1.41	2.58	45.8	20.7
0.5 to 1.0	5.3	37.3	1.35	2.58	50.2	14.2
1.0 to 2.0	7.1	36.5	1.41	2.60	51.5	19.4
2.0 to 3.0	31.5	49.6	.97		48.0	63.5
3.0 to 4.0	23.9	23.9		2.65		100.0

HOLE NO. 4W-53

Depth of sample (feet)	Field moisture content (percent)	Saturation (percent)	Apparent specific gravity	Real specific gravity	Porosity (percent)	Ratio field moisture to saturation
0.0 to 0.5	12.6	48.5	1.37	2.56	66.7	26.0
0.5 to 1.0	16.5	46.9	1.39	2.56	65.3	35.2
1.0 to 2.0	15.3	35.7	1.44	2.58	51.4	42.8
2.0 to 3.0	17.1	45.1	1.26		56.8	38.0
3.0 to 4.0	38.1	59.8	1.16	2.51	69.3	63.7
4.0 to 5.0	28.0	38.0	1.19		45.3	
5.0 to 6.0	26.9	26.9		2.63		100.0

HOLE NO. 4E-453

Depth of sample (feet)	Field moisture content (percent)	Saturation (percent)	Apparent specific gravity	Real specific gravity	Porosity (percent)	Ratio field moisture to saturation
0.0 to 0.5	16.9	43.5	1.22	2.61	53.1	38.9
0.5 to 1.0	19.2	45.0	1.55	2.61	60.7	42.7
1.0 to 2.0	18.2	29.9	1.66	2.60	49.5	60.8
2.0 to 3.0	32.7	41.5	1.24		51.5	78.8
3.0 to 4.0	34.2	34.2		2.55		100.0

NOTE.—Hole no. 1 W-53, depth to water table, 4.8 feet; vegetation, bosque and salt grass. Hole no. 4W-53, depth to water table, 5.8 feet; vegetation, salt grass. Hole 4E-453, depth to water table, 33 feet; vegetation, salt grass.

TABLE 81.—*Results of some of the soil moisture studies in Socorro division, Middle Rio Grande Valley, N. Mex., 1936*

Depth of sample, feet	Hole no. 1				Hole no. 2			
	Field moisture content (percent)	Apparent specific gravity	Moisture equivalent (percent)[1]	Porosity, (percent)	Field moisture content (percent)	Apparent specific gravity	Moisture equivalent (percent)	Porosity (percent)
0.0 to 0.5	14.0	1.06	18.13	59.6	31.0	1.44	13.96	44.9
0.5 to 1.0	5.5	1.06	5.04		21.9	1.44	10.97	
1.0 to 1.5	4.3	1.33	2.20	49.8	41.0	1.07	31.29	57.5
1.5 to 2.0	5.2	1.33	1.44		48.8	1.07	38.40	
2.0 to 2.5	4.1	1.66	1.40	37.6	47.9	1.14	35.00	54.0
2.5 to 3.0	5.8	1.66	1.34		52.2	1.14	37.22	
3.0 to 3.5	18.7	1.38	2.89	48.1	66.9		43.52	
3.5 to 4.0	16.1	1.38	1.94		79.3		43.69	
4.0 to 4.5	18.9	1.70	1.84	38.8				
4.5 to 5.0	24.4	1.70	2.54					
5.0 to 5.5	24.7	1.57	2.47	41.2				
5.5 to 6.0	26.5	1.57	2.48					

[1] Moisture equivalent determinations below the first foot are of questionable value because of sandy nature of soil.

Alfalfa Tank Experiments

A station for the study of the consumptive use of water by alfalfa grown in tanks was established on June 8, 1936, in a 10-acre alfalfa field of the Los Poblanos Ranch, approximately 5 miles north of Albuquerque. The alfalfa was planted in the spring of 1935.

The climatic conditions at the station are representative of the Middle Rio Grande Valley. Depths to the water table in the surrounding fields ranged from 4½ feet to 5½ feet. The soil is Gila loam. Characteristics of the soil in the field near the tanks are shown in table 82.

TABLE 82.—*Field capacity, apparent specific gravity, and pore space of Gila loam soil at Los Poblanos ranch, near Albuquerque, Middle Rio Grande Valley, N. Mex., 1936*

Depth in feet	Type of soil	Field capacity (percent)	Apparent specific gravity	Porosity (percent)
0.0 to 0.5	Silty clay loam	30.4	1.38	48.0
0.5 to 1.0	do	21.1	1.37	48.5
1.0 to 2.0	Fine sandy loam	11.6	1.36	48.8
2.0 to 3.0	Loam	20.5	1.26	52.5
3.0 to 4.0	do	32.0	1.26	52.5
4.0 to 5.0	Fine sandy loam	24.0	1.24	53.3
5.0 to 6.0	Sandy loam	23.7	1.36	48.8
6.0 to 7.0	Fine sand	21.4	1.60	39.8
7.0 to 8.0	do	23.7	1.66	37.5
Average		23.2	1.39	47.7

Installation of equipment.—A standard 8-inch rain gage and two soil tanks, each connected to a Mariotte apparatus were installed at the station. The soil tanks were the double type with an annular space between the inner and outer shells (3), (4). The inner tank, 23 11/16 inches in diameter by 6 feet deep, was suspended in the outer tank (diameter 25¼ inches) by means of a heavy angle-iron rim around the top. The bottom of the inner tank was removable and bolted in place by long rods, to the supporting top rim. The inner tank held the soil, the outer being a reservoir for water which passed into the soil through the bottom plate and the inner shell perforations.

Since it was deemed desirable to have the same soil structure and growth of alfalfa in the tanks as in the surrounding field, each tank was filled by forcing the bottomless inner shell into the ground, so cutting a core of soil of the same diameter as that of the tank to a 6-foot depth. The earth around the tank shell was excavated as the filling of the tank proceeded.

A tripod was erected by means of which the 6-foot tank could be hoisted above ground. It was also used in driving the inner tank into the soil. A heavy timber was placed across the top of the tank, and a weight hoisted by means of a block and tackle attached to the tripod, was allowed to fall on the timber, thereby forcing the tank down. Friction of soil against the outside of the tank was relieved by excavating around the tank, this excavation generally being kept a few inches ahead of the cutting edge of the tank.

When the inner tank shell was filled, the soil column was cut off by walking the shell after having connected it, by means of a strong cable, to a block and tackle fastened on the tripod. As soon as sufficient clearance was obtained, the bottom plate of the inner tank was pushed across the bottom edge and bolted to the angle-iron rim at the top of the tank. This method was found more satisfactory than jacking the bottom plate across the bottom edge of the tank as had been done in some installations in the past (4). The inner tank was then hoisted above ground by means of the chain block. The outer shell was next set in place in the excavation, and the inner shell, with its soil content, was lowered into the outer, where it hung suspended from the heavy iron rim around the top. The tanks were designated as the north tank and the south tank.

The soil columns in both tanks were then completely saturated. After 36 hours the water was pumped from the annular space. Twelve hours later the wa… vel had stabilized at a depth of 58 inches beneat… the ground surface in the north tank and at 60 inche… e south tank. The alfalfa in the tank was affect… y little by this procedure.

Operation of tanks.—The 5-gallon Mariotte supply bottles with which the tanks were equipped stood in an inverted position in wooden boxes about 3 feet above the ground so that their shadows would not fall on the tanks. Water was conducted through a rubber hose and through a ½-inch pipe into the annular space between the inner and outer shells of each tank. The lower end of the pipe was placed so as to maintain the water level at 4½ feet below the ground surface. When water was withdrawn by the plants from the soil column, the water level in the annular space would drop and air would enter the pipe and the bottle. The resulting unbalanced air pressure would force water out of the bottle until the end of the pipe was again submerged and equilibrium established.

On the evenings of the fifteenth and last days of each month the soil columns were completely saturated. About 80 percent of the water was applied as subirrigation by filling the annular space, and 20 percent by flooding the soil surface. The water was pumped down to the desired level the following morning. While it is more desirable to subirrigate only, so as to expel all the air in the soil, flooding was used to s… ate the soil quickly in order, so far as possible, to e… te evapotranspirational losses during observations. All the water added or withdrawn was measured (see p. 348).

Results.—Table 83 shows the consumptive use of water, the temperatures at Albuquerque, and the precipitation, arranged by periods.

Over the entire period from June 26 to October 31 the average consumptive use of the two tanks was 30.3… inches, which is equivalent to 1.67 inches per 7-day

TABLE 83.—*Weekly and monthly consumptive use of water for alfalfa tanks with water table at an average depth of 4½ feet, Los Poblano Ranch, near Albuquerque, N. Mex., June 26 to Oct. 31, 1936*

Period	Number of days	Consumptive use in acre-inches per acre (inches)									Precipitation, inches	Mean temperature, °F.[1]			Dates of irrigation
		North tank			South tank			Average							
		For period	Per week	Per 30 days	For period	Per week	Per 30 days	For period	Per week	Per 30 days		Mean maximum	Mean minimum	Mean	
June 26 to July 15	19	7.56	2.79	11.94	5.29	1.95	8.35	6.24	2.29	9.87	0.56	91.9	61.3	76.6	{June : {July
July 15 to Aug. 1	17	5.05	2.08	8.91	4.44	1.83	7.84	4.75	1.96	8.38	.42	92.8	63.9	78.4	Aug.
Aug. 1 to Aug. 15	14	5.55	2.77	11.89	6.40	3.20	13.72	5.98	2.98	12.80	.24	92.1	61.4	76.7	Aug.
Aug. 15 to Sept. 1	17	3.76	1.55	6.64	4.70	1.94	8.29	4.23	1.75	7.47	.34	90.7	61.4	76.0	Aug. :
Sept. 1 to Sept. 16	15	2.94	1.37	5.88	2.61	1.22	5.22	2.78	1.30	5.55	.41	85.8	57.4	71.6	Sept.
Sept. 16 to Oct. 1	15	2.30	1.07	4.60	2.46	1.15	4.92	2.38	1.11	4.76	2.49	72.8	48.9	60.9	Sept. :
Oct. 1 to Oct. 17	16	3.60	1.57	6.74	2.95	1.29	5.53	3.28	1.43	6.14		74.1	42.4	58.3	Oct.
Oct. 17 to Oct. 31	14	.39	.20	.84	1.03	.52	2.21	.71	.36	1.53	.16	64.6	39.5	52.1	Oct. :

[1] At Albuquerque.

NOTE.—Alfalfa cut on June 27, July 14, Aug. 22, and Oct. 15.

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per[...]nd to 7.17 inches per 30-day period. If the [...]l use of water is extended back to April 15, the [beg]inning of the growing season of alfalfa, the use com[put]ed on the basis of mean temperatures would be 44.5 inches.

The alfalfa in the field was cut four times with two irrigations for each cutting. In each irrigation approximately 6.1 acre-inches per acre of water was applied, which gave a seasonal application of approximately 49 acre-inches per acre.

The alfalfa in the tanks was cut on June 27, August 22, and October 15. One crop was lost on July 14, being destroyed by livestock. Each crop was weighed green and oven-dry. The weights are given in table 84.

The amount of water required to produce 1 pound of dry alfalfa was computed for the crops harvested on August 22 and October 15. The water necessary to produce these crops was reduced from acre-inches to pounds and corrected for evaporation losses in the top 6 inches of soil. The water requirements for the four crops (two from each tank) were averaged and found to be 1,140 pounds of water per pound of dry alfalfa.

TABLE 84.—*Yield of alfalfa grown in tanks, Los Poblanos Ranch, near Albuquerque, N. Mex.*

Date	Weight of crop in grams			
	North tank		South tank	
	Green	Oven-dry	Green	Oven-dry
1936				
June 27	164.0	36.0	329.0	71.0
July 14 [1]				
Aug. 22	162.5	44.0	281.0	77.0
Oct. 15	225.0	52.0	231.0	55.0

[1] Lost.

Native Vegetation and Evaporation Experiments

Water-loving vegetation and the presence of a high ground water throughout much of the area of natural growth in the Middle Valley result in the consumption of large quantities of water. Salt grass, willows, tules, and cottonwoods are the principal users on account of their greater acreage. E. B. Debler and C. C. Elder recognized this fact when they established a tank experiment station at Los Griegos (p. 340). To extend these previous investigations the Bureau of Agricultural Engineering established an evapo-transpiration and evaporation station at Isleta and evaporation stations at El Vado Dam and Socorro.

Isleta station.[7]—The Isleta station was instituted by the Bureau of Agricultural Engineering at Isleta (about 13 miles south of Albuquerque) during May 1936. It was located on the east side of Rio Grande adjacent to the Isleta diversion dam of the Middle Rio Grande Conservancy District, in a low, moist area containing a variety of water-loving plants including sedges, tules (cattails), salt grass, and willows. Data on tank installation at the Isleta station are given in table 85, and a sketch of the station is shown in figure 84. Here as elsewhere with similar work, Mariotte apparatus was used to supply water to vegetation tanks as well as keep the water surface in the tank at a constant level (4). The method of using the apparatus is indicated in figure 85.

Each of the vegetation tanks was placed in a surrounding of natural growth of the same species (that is, in its natural environment), so that consumptive use of water would presumably be the same as for similar growth outside the tank. In previous investigations it has been found that all tank vegetation must be protected from the elements by surrounding growth of the same species.[8]

Since a considerable area in the Middle Rio Grande Valley is occupied by swamp growth, a study of con-

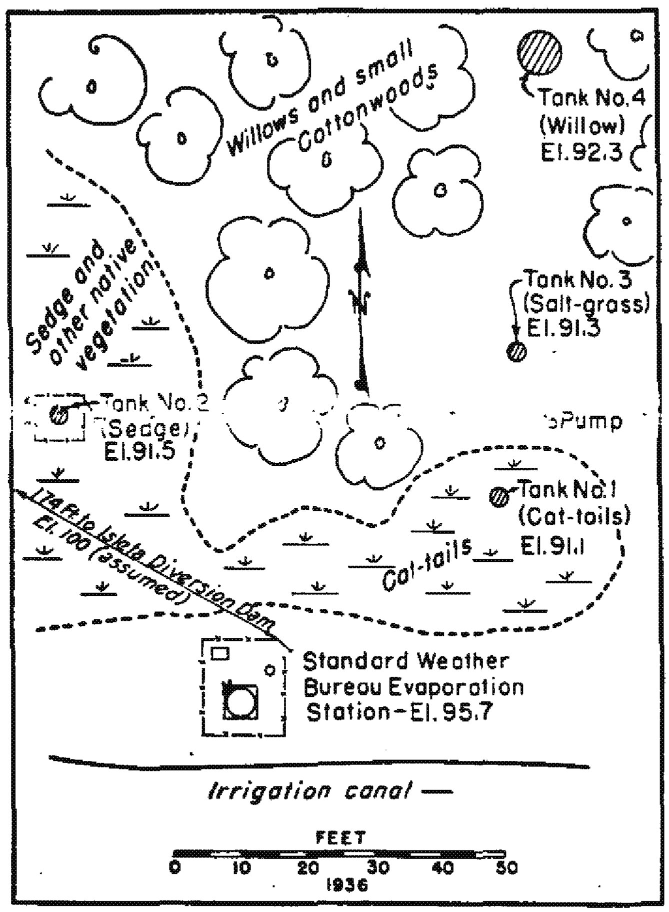

FIGURE 84.—Plan of Isleta Station, N. Mex. 1936.

[7] Discussion of Isleta station results was prepared principally by A. A. Young, [Associ]ate irrigation engineer, Bureau of Agricultural Engineering.

[8] Tules, for instance, growing in isolated tanks use immense quantities of water daily during the growing season—frequently an acre-inch per acre per day for weeks at a time. In fact, there is a record in the Santa Ana Valley, Calif., of a maximum consumptive use of 3.6 inches of depth in a single 24-hour period by tules in an isolated tank. Obviously, such water use by plant growth is abnormal, otherwise tule swamps would recede and streams dry up at the source (3), (4).

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TABLE 85.—*Installation data on tanks used at Isleta station, Middle Rio Grande Valley, N. Mex., 1936*

Tank number	Diameter of tank (inches)	Purpose of tank	Period of test		Name of content of tank		1
			Beginning	Ending	Common	Botanical [1]	
1	24 1/16	Use of water	May 1936	November 1936	Cattail	Typha latifolia	(2)
2	24 1/16	do	do	do	Sedge	Carex and eleochoris	(2)
3	24 1/16	do	June 1936	do	Salt grass and drop grass	Distichlis copicata and sporobolis airoides	8
4	72 3/16	do	do	do	Willow	Salix argophylla	11
5	48	Evaporation [3]	May 1936	do	(4)	(4)	

[1] Classification by Dr. Willis H. Bell, professor of biology, University of New Mexico.
[2] At surface.
[3] Standard Weather Bureau pan.
[4] Free-water surface.

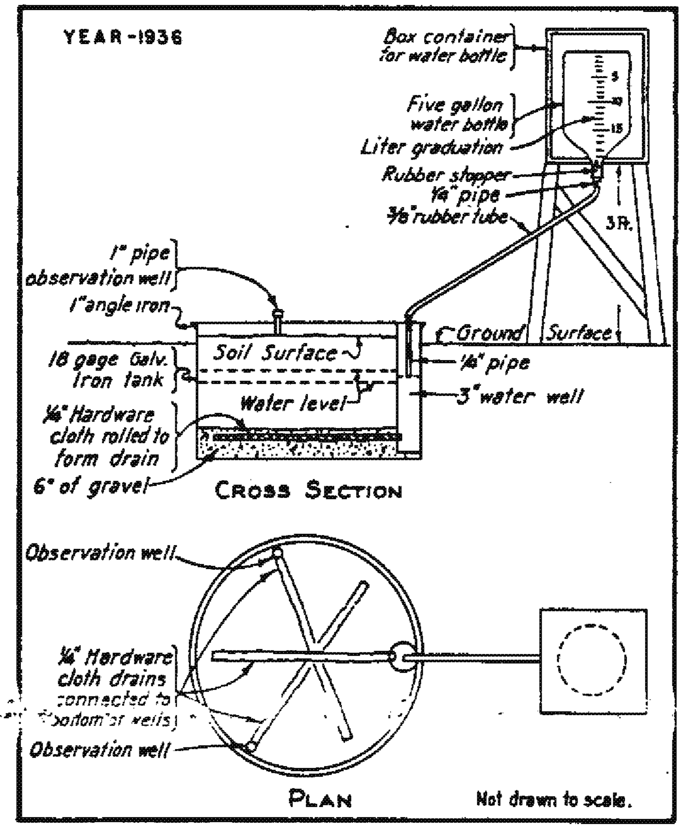

FIGURE 85.—Sketch of water supply layout at Isleta Station.

sumptive use of water by cattails growing in water was made at the Isleta station. This growth was transplanted into a tank placed in a swamp area where it could be protected from sun and wind by surrounding growth of the same species. Reference to figure 84 shows the relation of the various tanks to surrounding natural vegetation. Tables 86 and 87 summarize weekly and monthly use of water by cattails, sedges, salt grass, and willows, with pertinent meteorological data.

Comparison of consumptive use by cattails at Isleta (in 1936) with water use by cattails (tules) at Los Griegos (in 1928) discloses a greater loss at Isleta. Consumptive use by cattails during June to September, inclusive, 1936, at Isleta was 60.33 acre-inches per acre as compared with 42.16 acre-inches per acre for tules at Los Griegos for the same months in 1928. (See table 40.)

Consumptive use by sedge growing in water likewise determined, and apparently there are no other data on use of water by such vegetation in the Rio Grande Valley. Consumptive use during the 6-month period June to November, inclusive, 1936, amounted to 50.06 acre-inches per acre, identifying this growth as a water-loving species.

Consumptive use of water by salt grass at Isleta during the months June to November, inclusive, 1936,

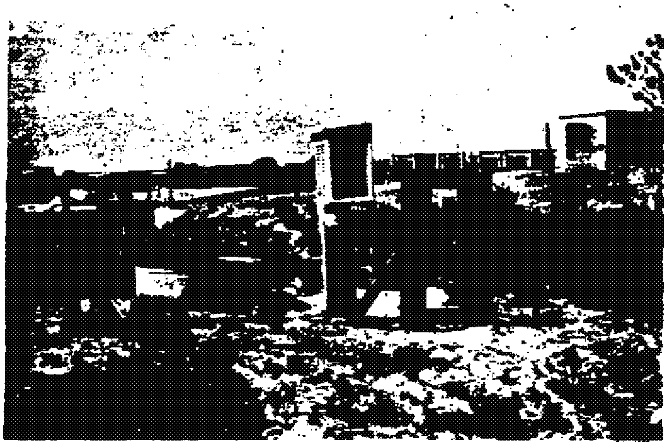

FIGURE 86.—Evaporation station at Isleta, Middle Rio Grande Valley, N. Mex.

FIGURE 87.—Willows growing in tank at Isleta Station, Middle Rio Grande V N. Mex.

does n·· compare favorably with consumptive use by simil· vegetation at Los Griegos for the same months . The salt grass tank at Isleta used 23.47 acre-s with an average depth to water of 7.7 inches, whereas at Los Griegos the total use was 34.56 acre-inches with depth of 5.0 inches. In a comparison of contributing factors, the difference in depth to water does not account for the increased consumptive use; the average hourly wind movement was approximately the same at both places, while mean temperature at Isleta was 7 percent higher than that at Los Griegos. A comparison of evaporation at the two stations shows Isleta to have the smaller amount by about 4 percent. Hence the differences in consumptive use are attributable to factors other than meteorological. The stations were alike in that they were located in native vegetation with high ground water, but differed in size of soil tanks and surroundings. At Los Griegos the salt grass tank was nominally 4 feet in diameter; at Isleta, 2 feet. At Los Griegos there was flat, open country without obstruction to wind movement, whereas at Isleta willows and brush grew in the vicinity of the soil tanks. How-

TABLE 86.—*Weekly consumptive use of water, evaporation, and meteorological data of Isleta station, Middle Rio Grande Valley, N. Mex. season of 1936*

Week ending—	Consumptive use of water in inches				Average depth to water table (inches)		Meteorological data							
	Tank no. 1	Tank no. 2[1]	Tank no. 3	Tank no. 4	Tank no. 3	Tank no. 4	Evaporation, inches (Weather Bureau pan)	Temperature (°F.)[2]			Precipitation (inches)	Wind movement		Average relative humidity at Albuquerque (percent)
	Cattails in water	Sedge in water	Salt grass	Willow	Salt grass	Willow		Mean maximum	Mean minimum	Mean		Total miles	Average miles per hour	
June 1	2.54	1.90					2.31	82	52	67	0.72			45
June 8	3.56	2.00	1.24	1.26	10.8	11.4	2.81	87	50	69	0			24
June 15	3.32	1.91	1.34	.70	7.3	14.6	[2]2.44	91	57	74	.18			48
June 22	4.15	2.20	1.32	.96	8.9	15.0	[2]2.77	95	53	74	0			30
June 29	3.79	2.25	1.19	.82	11.3	12.4	2.44	92	63	78	.20			42
July 6	3.57	2.40	1.23	.86	11.6	13.2	2.88	96	61	78	0	368	2.19	30
July 13	3.84	2.30	1.39	[3]1.08	4.3	5.9	2.34	89	61	75	1.52	423	2.52	60
July 20	3.60	2.69	1.41	[3]1.06	7.5	8.3	2.31	93	64	78	.06	370	2.20	40
July 27	4.18	3.22	1.43	.89	10.5	11.3	2.22	93	62	78	0	324	1.93	35
Aug. 3	3.82	2.16	1.34	1.03	10.8	11.0	2.10	89	64	76	.07	366	2.18	53
Aug. 10	3.83	3.78	1.26	.96	12.3	13.6	2.03	95	61	78	0	281	1.67	44
Aug. 17	4.34	4.34	1.47	1.13	11.2	12.8	2.34	97	61	79	.03	311	1.85	32
[illegible]	3.09	1.94	1.09	1.06	4.7	12.5	1.81	89	60	74	.53	275	1.[illegible]4	47
[illegible]	3.75	4.64	1.12	1.09	9.4	13.7	2.06	90	62	76	.05	417	2.48	45
[illegible]	3.51	2.07	1.12	1.08	11.5	7.3	1.81	90	58	74	.02	343	2.04	44
[illegible]	3.30	1.77	[3].93	[3]1.09	4.4	12.1	1.63	85	59	72	1.24	146	.87	53
Se[illegible] 21	2.53	1.75	[3].85	[3]1.00	.9	12.1	1.50	86	56	70	.40	281	1.67	54
Sept. 28	1.89	1.71	[3].91	[3].83	5.1	2.9	1.60	75	55	65	1.45	451	2.68	61
Oct. 5	1.47	1.21	[3].38	[3].89	−1.1	3.8	1.06	73	40	56	0	256	1.52	54
Oct. 12	1.28	1.22	[3].41	.67	.5	14.3	1.16	79	41	60	0	337	2.00	47
Oct. 19	1.20	1.07	.40	.82	9.9	11.0	1.09	80	44	62	0	294	1.75	41
Oct. 26	.75	.78	.37	.67	11.2	9.0	.87	64	42	53	.29	588	3.50	66
Nov. 2	.72	.80	.30	.46	12.6	13.0	.68	67	39	53	0	524	3.12	55
Nov. 9	.31	.33	.22	.26			.78	54	24	39	0	519	3.09	
Nov. 16	.49	.45	.20	.35			.74	54	24	[illegible]	0	384	[illegible]	
Nov. 23	.58	.54	.14	.22			.94	60	30	45	0	710	4.23	
Nov. 30	.51	.38	.14	.17			.24	55	23	39	0	789	4.76	
Dec. 1	.07	.07	.02	.03								51	2.12	

[1] Results doubtful from Aug. 3 to Aug. 31, as tank was tampered with.
[2] Weather Bureau records at Albuquerque from May 19 to June 15 and Nov. 2 to Dec. 1.
[3] Estimated use, based on period of observation and evaporation records.

TABLE 87.—*Summary of monthly consumptive use of water, evaporation, and meteorological data of Isleta station, Middle Rio Grande Valley, N. Mex., season of 1936*

Month	Consumptive use of water in inches				Average depth to water table (inches)		Meteorological data							
	Tank no. 1	Tank no. 2	Tank no. 3	Tank no. 4	Tank no. 3	Tank no. 4	Evaporation, inches (Weather Bureau pan)	Temperature °F.[1]			Precipitation, inches	Wind movement		Average relative humidity at Albuquerque (percent)
	Cattails in water	Sedge in water	Salt grass	Willow	Salt grass	Willow		Mean maximum	Mean minimum	Mean		Total miles	Average miles per hour	
June	13.58	8.98	5.46	3.77	9.6	13.4	11.07	91	56	74	0.38			36
July	16.98	11.45	6.07	4.24	8.5	9.7	10.06	92	62	77	1.58	1,644	2.21	42
August	18.52	[2]15.57	5.59	4.80	9.7	12.7	9.05	92	61	76	.68	1,423	1.91	44
September	11.25	7.39	[3]3.81	4.18	5.5	8.6	6.62	82	55	68	3.11	1,280	1.78	54
October	4.82	4.54	1.75	2.92	5.1	9.5	4.60	73	42	58	.29	1,789	2.34	49
November	2.52	2.13	.79	1.34			2.95	59	25	42	[4]T	3,124	4.34	
Total	67.67	50.06	23.47	21.25			44.34				6.04			
Average					7.7	10.8		82	50	66			2.52	45

·ther Bureau records at Albuquerque from May 19 to June 15 and from Nov. to Dec. 1.
·k tampered with, results doubtful.
·mated use, based on period of observations and evaporation records.
·ace.

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ever, the evaporation pan and anemometer were located on adjacent ground 4.4 feet higher than the wet land in which the soil tanks were placed. Undoubtedly brush growing immediately west of the salt grass tank cast shade on the tank during late afternoons. Thus, the 1936 results show a minimum use of water rather than an average use.

A test was also made of the quantity of water consumed by a clump of willows (6 to 8 feet high) growing in a tank 6 feet in diameter, the tank being set in a thicket of the same species. The water table in the willow tank fluctuated slightly throughout the season with an average depth for the 5 months of record of 10.8 inches, which was close to the ground-water levels outside the tank. Two of the smaller plants died from the shock of transplanting but the large plant flourished. The total consumptive use during the period June to November, inclusive, 1936, was 21.25 acre-inches per acre, which was less than 50 percent of the evaporation from a Weather Bureau pan. While the results indicate the use of water by scattered willow plants they are not representative of the denser growths along the river. The latter usually grow to heights of from 7 to 10 feet and to at least twice the thickness. Thus maximum use of water by willows growing along the Rio Grande will probably be double the amount shown by the Isleta tank, or approximately 42 inches (3.5 acre-feet per acre) for the 6-month period.

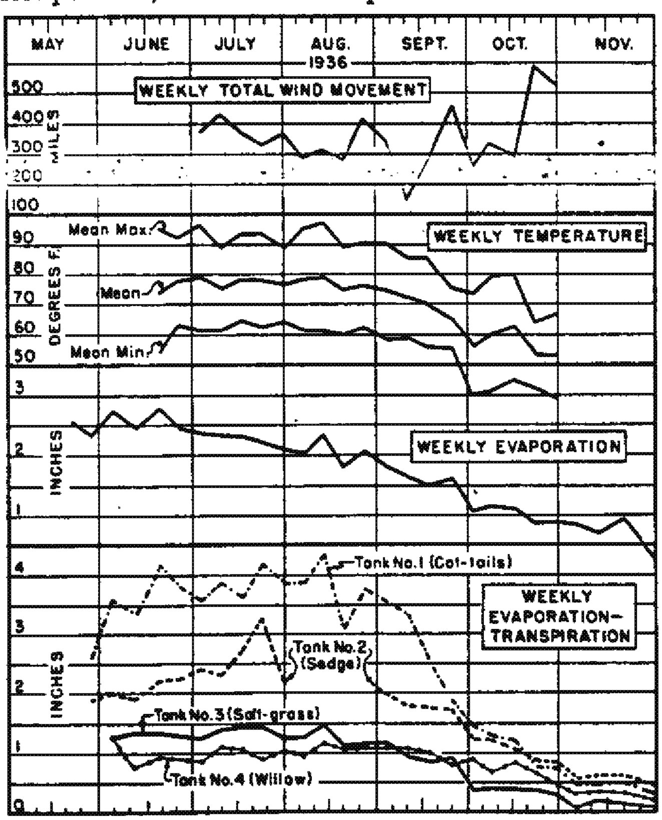

FIGURE 88.—Weekly use of water, evaporation, and wind movement at Isleta Station, N. Mex.

Summarizing vegetative use of water at Isleta ... the 6 months of record during the summer of 1936: Cattails used 67.67 acre-inches per acre, sedge 50.06 acre-i... salt grass 23.47 acre-inches, and willows 21.25 ... inches per acre. Evaporation from a Weather Bureau pan amounted to 44.34 inches. Compared with evaporation from a free water surface, cattails and sedge are extravagant users of water, while salt grass and willows are more economical—a conclusion supported by similar investigations elsewhere. The weekly variations in use of water, evaporation, temperature, and wind movement are illustrated in figure 1888.

El Vado Dam evaporation station.—In June 1936 this station was installed by the Bureau of Agricultural Engineering in cooperation with the Weather Bureau and Middle Rio Grande Conservancy District. The station is located on the high ground adjacent to El Vado Dam, in line with and at approximately the same elevation as the crest produced to the east.

This is a class A station, equipped as follows:

(*a*) Standard Weather Bureau evaporation pan (diameter 4 feet).
(*b*) Hook gage, Hoff type, reading to hundredths of an inch.
(*c*) Thermometers, maximum and minimum.
(*d*) Anemometer, Weather Bureau type (4-cup).
(*e*) Standard rain gage (8-inch).
(*f*) Instrument shelter, cotton region type.

Daily observations were made at 6 a. m., of e... ration, wind movement, maximum and minimu... peratures, and general weather conditions represe...g daylight hours.

Table 88 shows weekly and monthly evaporation and meteorological data at El Vado Dam station.

Socorro evaporation station.—This station was located in an open space in the Middle Rio Grande Conservancy District yard at Socorro. Early in June 1936 the Bureau of Agricultural Engineering established this station on a small plot furnished by the Conservancy District in cooperation with the Division of Ground Water, Geological Survey. Following is a list of equipment installed:

(*a*) Standard Weather Bureau evaporation pan (diameter 4 feet).
(*b*) Hook gage, reading to hundredths of an inch.
(*c*) Standard rain gage (8-inch).

Observations were made twice daily—once at 8 a. m. and once at 5 p. m.—by Walter E. Herkenhoff of the Division of Ground Water, Geological Survey. These observations consisted of measuring the water level in evaporation pan and recording hook gage readings and measuring and recording the amount of rainfall, if any. Also, a general statement of weather conditions for the day was recorded.

The evaporation pan was filled when necess... that the water level was kept between 2 and 3 ...

TABLE 88.—*Weekly and monthly evaporation and meteorological data at El Vado Dam evaporation station,*[1] *season of 1936*

Period	Evaporation (inches)	Temperature (° F.)			Rain (inches)	Snow (inches)
		Mean maximum	Mean minimum	Mean		
Week ending—						
June 22	[2] 2.62	90	42	66	0.02	....
June 29	2.00	90	49	70	.13	....
Month of June	[2] 9.93	....	....	....	....	....
Week ending—						
July 6	2.30	88	41	65	0	....
July 13	2.09	84	45	65	1.64	....
July 20	1.99	88	46	67	.06	....
July 27	1.99	89	47	68	.56	....
Month of July	8.90	87	45	66	2.26	....
Week ending—						
Aug. 3	1.81	85	49	67	.38	....
Aug. 10	1.43	83	48	65	.48	....
Aug. 17	2.07	90	46	68	.15	....
Aug. 24	1.54	83	44	64	1.24	....
Aug. 31	1.96	84	45	65	.78	....
Month of August	7.89	85	47	66	3.00	....
Week ending—						
Sept. 7	1.61	77	41	59	.11	....
Sept. 14	1.18	80	41	60	.18	....
Sept. 21	1.41	76	36	56	2.44	....
Sept. 28	1.58	69	35	52	1.55	....
Month of September	6.18	75	34	56	4.18	0.25
Week ending—						
Oct. 5	1.20	59	26	42	.22	....
Oct. 12	.95	65	24	44	.25	....
Oct. 19	1.19	71	26	48	0	....
Oct. 26	.42	57	28	42	.71	....
Month of October	3.64	63	27	45	1.48	.50
Week ending—						
Nov. 2	[2] .52	55	29	42	.82	....

[1] …ducted by Bureau of Agricultural Engineering in cooperation with Weather … and Middle Rio Grande Conservancy District. Standard Weather Bureau …

[2] …imated.

from the top of the pan. The pan was emptied and cleaned as often as necessary to keep the water clear. Hook gage readings were taken before and after each filling or cleaning.

Table 89 shows weekly and monthly evaporation and meteorological data at the Socorro station.

TABLE 89.—*Weekly and monthly evaporation and meteorological data at Socorro evaporation station,*[1] *season of 1936*

Period	Evaporation (inches)	Temperature (°F.)			Precipitation (inches)
		Mean maximum	Mean Minimum	Mean	
Week ending—					
June 8	2.93	92.9	49.6	71.3	0
June 15	2.82	99.6	55.0	77.3	.18
June 22	2.89	100.6	58.4	79.5	0
June 29	2.80	99.6	59.9	79.8	.53
Month, June	12.17	98.2	56.5	77.4	.71
Week ending—					
July 6	2.54	98.6	60.1	79.4	.04
July 13	2.69	94.4	61.6	78.0	1.35
July 20	2.09	97.0	61.3	79.2	.43
July 27	2.31	98.4	61.9	80.2	.02
Month, July	10.60	96.7	61.4	68.1	1.84
Week ending—					
Aug. 3	2.26	95.3	64.4	79.9	0
Aug. 10	2.30	97.1	60.6	78.9	0
Aug. 17	2.44	101.1	57.3	79.2	0
Aug. 24	2.09	94.1	61.3	77.7	.14
Aug. 31	1.69	92.1	59.1	75.6	.07
Month, August	9.27	95.9	60.0	78.0	.21
Week ending—					
Sept. 7	1.84	93	57	75	0
Sept. 14	1.67	90	57	74	.59
Sept. 21	1.45	85	56	70	.06
Sept. 28	1.06	76	49	62	1.64
Month, September	6.19	85	54	70	2.29
Week ending—					
Oct. 5	1.14	77	42	60	0
Oct. 12	1.17	77	37	57	.01
Oct. 19	1.27	82	42	62	0
Oct. 26	.70	65	39	52	.08
Month, October	4.64	75	40	58	.09
Week ending—					
Nov. 2	1.00	69	37	53	0
Nov. 9	.89	....	....	....	0
Nov. 16	.83	....	....	....	0
Nov. 23	.85	....	....	....	0
Nov. 30	.43	....	....	....	.03
Month, November	3.35	....	....	....	.03
Week ending—					
Dec. 7	.49	....	....	....	.17
Dec. 14	.71	....	....	....	0

[1] Conducted by Bureau of Agricultural Engineering in cooperation with United States Geological Survey. Standard Weather Bureau pan.

Lower Valley

The Lower Valley consists of a series of valleys extending from Elephant Butte Reservoir to Fort Quitman. (See p. 298 and fig. 75 and pls. 18–22, incl.)

Water is supplied by the Rio Grande project, built and operated by the Bureau of Reclamation. The project comprises the Elephant Butte Reservoir and dam, several diversion dams, distributing canals and laterals, and an extensive system of open drains to remove excess ground water and reduce alkali damage. The United States is required to furnish 60,000 acre-feet annually to Mexico in compliance with the terms of a treaty between the United States and Mexico signed May 21, 1906.

The climate of the section is characteristically arid, … cool nights, but high temperatures during the day. … 21 shows that the average length of growing season for the Valley ranges from 200 days to 241 days. The mean relative humidity is low. There are very few cloudy days and but little rainfall. These factors contribute to a high evaporation rate.

The average annual rainfall is only 8 to 10 inches per year, about two-thirds coming during the growing season. However, only a portion of this rainfall becomes available for crop use, since much of it occurs in light showers and is lost (consumed) by evaporation before it penetrates to the root zone.

Long time records for temperatures and precipitation have been shown heretofore. (See p. 321.) Table 90 gives the mean temperatures and precipitation for 1936 at El Paso, State College, and Elephant Butte Dam.

The soils of the Valley are alluvial deposit and are extremely variable in texture. (See p. 321.)

Early in April 1936 a preliminary survey was made, and at a conference with representatives of New Mexico and Texas it was agreed that consumptive-use-of-water

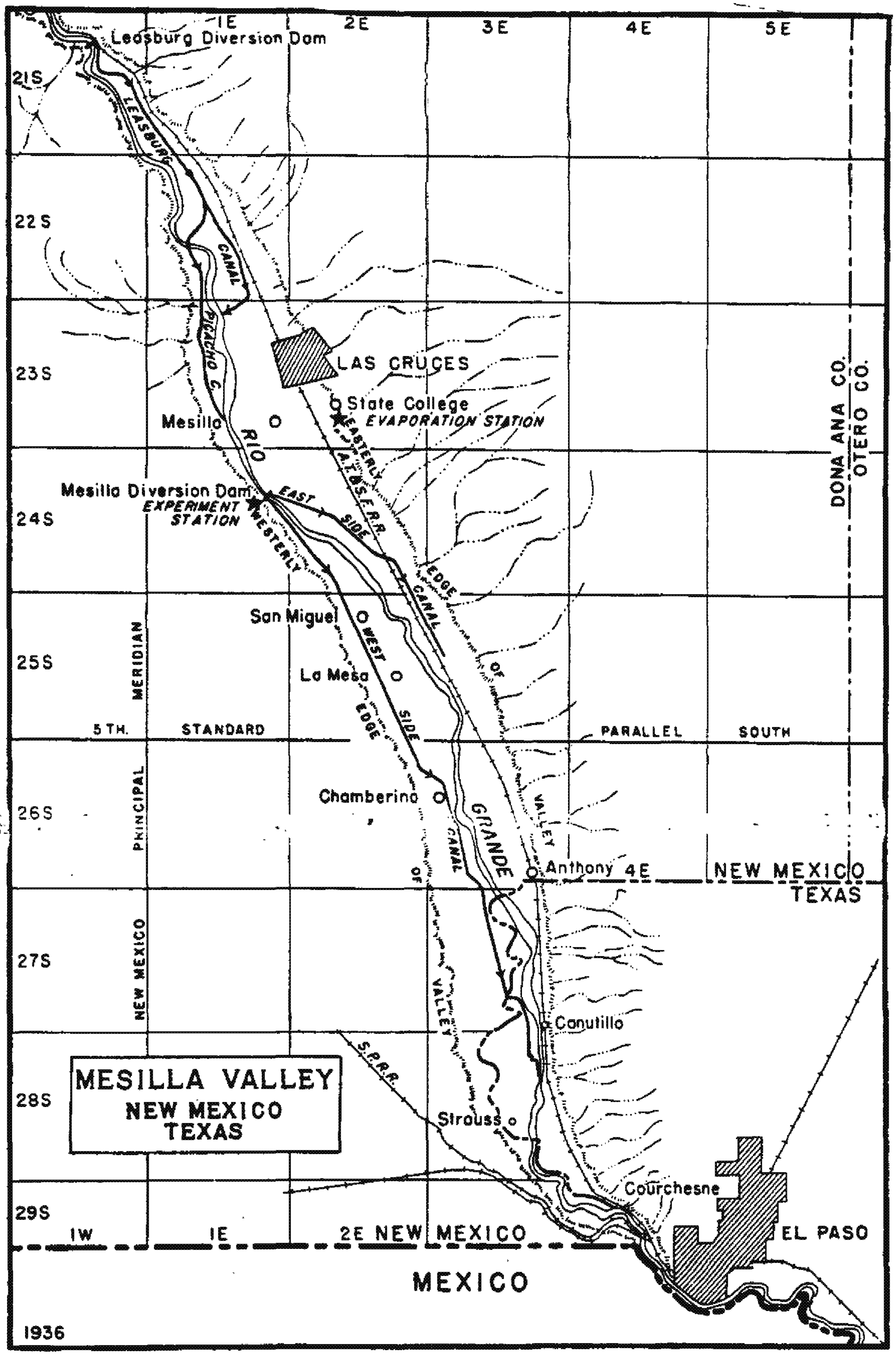

FIGURE 89.—Mesilla Valley intensive study area.

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TABLE 90.—*Monthly temperatures and precipitation, United States Weather Bureau stations at El Paso, State College, and Elephant Butte Dam, 1936*

Month	El Paso				State College				Elephant Butte Dam			
	Temperature (°F.)			Precipitation (inches)	Temperature (°F.)			Precipitation (inches)	Temperature (°F.)			Precipitation (inches)
	Mean maximum	Mean minimum	Mean		Mean maximum	Mean minimum	Mean		Mean maximum	Mean minimum	Mean	
January	57.4	33.6	45.5	0.57	54.7	24.9	39.8	0.98	54.1	28.2	41.2	0.49
February	62.7	39.8	51.2	.06	60.7	31.5	46.1	.29	61.2	34.1	47.6	.12
March	70.0	45.9	58.0	T	69.2	35.3	52.2	.13	68.8	39.9	54.4	0
April	78.8	52.7	65.8	.11	77.6	42.9	50.2	.07	76.0	47.9	62.0	.05
May	86.5	61.8	74.2	.56	85.5	54.3	69.9	.70	83.7	56.9	70.3	.94
June	95.4	69.5	82.4	.34	94.9	59.3	77.1	.14	93.4	64.8	79.1	.29
July	94.1	71.2	82.6	.68	92.7	65.9	79.3	1.53	91.3	67.0	79.2	1.54
August	91.9	69.6	80.8	1.94	91.2	63.2	77.2	1.35	86.6	66.8	76.7	1.09
September	84.4	63.0	73.7	3.52	82.3	58.0	70.2	2.12	79.8	59.7	69.8	1.59
October	75.2	51.5	63.4	.32	74.5	42.6	58.6	.40	71.6	48.4	60.0	.26
November	61.4	39.8	50.6	1.32	61.2	32.2	46.7	1.02	58.3	35.8	47.0	.55
December	57.9	35.7	46.8	.51	56.9	27.9	42.4	.77	56.2	30.2	43.2	.01
Annual	76.3	52.8	64.6	9.93	75.1	44.8	60.0	9.50	73.4	48.3	60.9	6.93

studies would be concentrated in the Mesilla Valley since this Valley was representative of the entire Lower Valley and the time available for the studies was limited.

Experiment stations were established at State College and Mesilla Dam by the Bureau of Agricultural Engineering in cooperation with the agricultural experiment station of the New Mexico College of Agriculture and Mechanic Arts. Soil moisture and tank studies on use of water by alfalfa and cotton were made at State College, and experiments on evaporation and trans-ation by native vegetation growing in wet areas at silla Dam. Details of these experiments are de-cribed in later pages.

Rain gages were installed by the Bureau in cooperation with the Bureau of Reclamation at Leasburg Dam, Mesilla Dam, La Union, and Berino. The precipitation records for May to December 1936 are shown in table 91.

TABLE 91.—*Precipitation recorded at Leasburg Dam, Mesilla Dam, La Union, and Berino, in Mesilla Valley, N. Mex., 1936*

Month	Precipitation in inches			
	Leasburg Dam	Mesilla Dam	La Union	Berino
May	----------	0.07	----------	----------
June	0.35	.41	----------	----------
July	.68	1.09	1.07	1.39
August	.78	.84	2.03	2.25
September	2.17	1.72	2.56	2.60
October	.41	.35	.31	.15
November	1.21	.91	1.27	.85
December	.41	----------	.67	----------

Mesilla Valley extends as a fairly flat, long, narrow strip along the Rio Grande from Leasburg diversion dam in New Mexico to a few miles above El Paso, Tex. Its total length is about 55 miles. The maximum width of the Valley is about 5 miles, the average being in the neighborhood of 2½ miles. Figure 89 shows the location of the Valley.

s noted hereinbefore, Mesilla Valley experience in sumptive-use estimates has been used by engineers as a basis for estimating consumptive use in Middle Valley. The following estimates of past consumptive use in Mesilla Valley, for the years 1919 to 1935, inclusive, have been made by the Bureau of Agricultural Engineering.[9]

Consumptive Use in Mesilla Valley Prior to 1936

The methods outlined hereinbefore have been used in estimating the past consumptive use of water in Mesilla Valley. (See p. 345.) The sources of information for the estimates are stated in the following paragraphs relative to each of the methods used.

Inflow-outflow method.[10]—Conditions in Mesilla Valley are especially favorable for estimating consumptive use of water by the inflow-outflow method. The Bureau of Reclamation records, experiments of the Bureau of Agricultural Engineering and New Mexico Agricultural Experiment Station on use of water by agricultural crops, and the United States and Mexico Boundary Commission water measurement records all contribute to the reliability of consumptive-use estimates. Moreover, the Valley is a basin from which the subsurface outflow was long since found to be negligible. Tributary surface inflow is certainly less than in Middle Valley and in San Luis Valley. There is less certainty relating to subsurface tributary inflow, but this is considered relatively small. From 1919 to 1935 the irrigated area in Mesilla Valley ranged from 47,314 acres to 77,061 acres, and the total Valley area was reported by the Bureau of Reclamation as about 109,000 acres.[11]

[9] Prof. Albert S. Curry, collaborator, has assisted liberally in the interpretation of New Mexico Agricultural Experiment Station data, and in constructive criticism of the other studies. Dean W. Bloodgood, associate irrigation engineer, Bureau of Agricultural Engineering, whose writings on Mesilla Valley irrigation and drainage problems have been helpful, has also given valuable suggestions.

[10] The data used for the inflow-outflow method were supplied largely by L. R. Fiock, superintendent, and W. F. Resch, hydrographer, Rio Grande project, from files of the Bureau of Reclamation, El Paso office.

[11] Results were compiled before the tabulations of areas mapped by the Bureau of Agricultural Engineering and stream-flow measurements for 1936 were available.

Inflow.—The inflow measurements of the Rio Grande at Leasburg into Mesilla Valley have been made each year from 1919 to 1935, inclusive. Results of these measurements were supplied by the Bureau of Reclamation office at El Paso. (Pl. 20.)

Records of arroyo inflow between Leasburg Dam and El Paso are estimates. However, in view of the fact that the annual water contribution from the arroyos is relatively very small (averaging probably not more than one percent of the annual consumptive use of the Valley), it is believed that the estimates are accurate enough to be considered here. The quantity (I) used in the computations is the sum of the river inflow at Leasburg and the arroyo inflow. (See p. 347.)

Precipitation.—The number of acre-feet of precipitation (P) contributed to the Valley water supply is based on precipitation measurements at State College, and on the Valley area (as reported by the Bureau of Reclamation), of 109,000 acres.

Outflow.—The outflow measurements have been made at El Paso (Courchesne) during all the years included in this study. They are considered reliable and probably the most accurate of all the measurements here dealt with. (Pl. 20.)

Ground-water Storage.—The amounts of changes in ground-water storage (G_s-G_e) are estimated from data supplied by the Bureau of Reclamation, the Bureau of Agricultural Engineering, and by the State Agricultural College. The Bureau of Reclamation records include the years 1925 to 1935, during which time depths to ground water were observed in 55 to 88 wells.

The Bureau of Reclamation wells are probably more nearly representative of the Valley as a whole than the State College wells, which were at first confined to 33 across the center of the Valley. However, the State College [12] well-depth records cover the years 1918 to 1934, and have been used as a basis for extending the Bureau of Reclamation records from 1924 back to 1918. The average depths for January of each year 1925 to 1934 are plotted on figure 90, by which the estimated

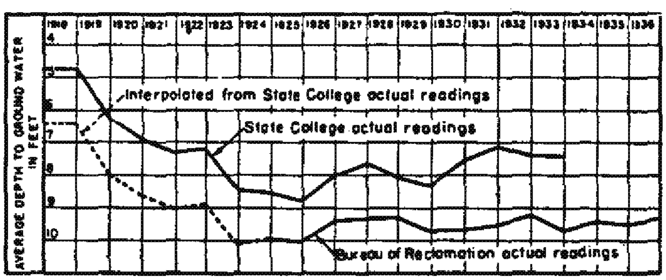

FIGURE 90.—Average depths to ground water in Mesilla Valley during January of each year, 1918 to 1936, based on measurements by the Bureau of Agricultural Engineering, the New Mexico Agricultural Experiment Station, and the Bureau of Reclamation.

[12] Cooperative records by Bureau of Agricultural Engineering and New Mexico Agricultural Experiment Station from 1918 to 1931.

depths of the Bureau of Reclamation wells are exte...ded from 1924 back to 1918. The average differe... depth of water in the two sets of wells, for th... 1925 to 1934, has been added to the average depths of the State College wells for each year, 1918 to 1924, to get the probable average depths of water in the Bureau of Reclamation wells.

For estimates of difference in ground-water storage it was assumed that the specific yield was 15 percent of the total volume of soil (see p. 347).

Results by Inflow-outflow Method.—The Valley consumptive use (K) determined by use of equation 4 for the 17-year period, 1919–35, is given in column 6 of table 92. The irrigated area (A_i) is shown in column 7. It will be noted that the average for K for the 17-year period is 297,756 acre-feet, and the average K/A_i is 4.52 acre-feet per acre of irrigated land. This quantity includes all the precipitation (P) which, for the Valley area (A) of 109,000 acres, amounts to 1.18 acre-feet per acre of irrigated land per year, and therefore is not comparable with the estimates of other engineers for the quantity $\left(\frac{I-R}{A_i}\right)$ hereinbefore reviewed.

TABLE 92.—*Consumptive use of water in Mesilla Valley, N. Mex. and Tex., for 17-year period 1919 to 1935, based on inflow-outflow method* [1]

Year	I Acre-feet	P Acre-feet	R Acre-feet	(G_s-G_e) Acre-feet	K Acre-feet	A_i Acres	$\frac{K}{A_i}$ Acre-feet per acre	...re-feet per acre
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1919	372, 131	73, 248	311, 327	−25, 343	159, 095	47, 314	3. 48	[illegible]
1920	602, 713	74, 338	509, 778	+10, 955	178, 228	48, 327	3. 69	1. 64
1921	997, 629	69, 433	870, 416	+6, 050	202, 694	51, 407	3. 94	1. 86
1922	999, 724	50, 794	780, 029	−1, 962	268, 527	48, 620	5. 52	2. 46
1923	924, 197	94, 067	[2] 664, 589	+20, 111	373, 786	53, 812	6. 95	3. 43
1924	992, 423	43, 927	[2] 799, 071	−3, 434	233, 845	61, 966	3. 77	2. 15
1925	857, 382	70, 850	633, 622	+1, 962	296, 572	67, 357	4. 40	2. 72
1926	823, 012	130, 473	556, 941	−11, 608	384, 936	76, 244	5. 05	3. 53
1927	880, 190	86, 001	610, 563	−1, 798	344, 830	73, 314	4. 70	3. 16
1928	915, 332	85, 020	623, 637	−327	376, 388	76, 057	4. 95	3. 45
1929	768, 935	83, 603	552, 742	+6, 703	306, 490	76, 772	3. 99	2. 81
1930	790, 538	62, 566	532, 000	−164	320, 940	76, 373	4. 20	2. 94
1931	740, 700	120, 000	518, 000	−2, 770	330, 930	76, 722	4. 43	3. 12
1932	816, 028	80, 224	567, 240	−5, 559	323, 453	76, 709	4. 22	2. 97
1933	824, 000	42, 728	609, 180	+8, 175	265, 723	77, 061	3. 45	2. 44
1934	768, 230	41, 856	508, 480	−4, 905	296, 701	68, 605	4. 32	2. 72
1935	632, 900	114, 995	459, 910	+1, 635	289, 710	62, 175	4. 66	2. 66
Average	835, 656	77, 890	618, 637	+2, 847	297, 756	65, 814	4. 52	2. 73

[1] As determined by Bureau of Agricultural Engineering from equation 4 showing inflow (I), outflow (R), precipitation (P) and difference in ground-water storage (G_s-G_e) in acre-feet; irrigated area (A_i) and entire Valley area (A) in acres; Valley consumptive use in acre-feet per irrigated acre $\left(\frac{K}{A_i}\right)$; and Valley consumptive use in acre-feet per acre for entire area $\left(\frac{K}{A}\right)$. A = 109,000 acres, as reported by Bureau of Reclamation, was used in computing (P) from State College precipitation records.

[2] The quantities in column 4 for each of the 17 years were taken from Bureau of Reclamation records and, for most of the years, they are in harmony with the results published by the Geological Survey in Water Supply Papers. However, for the calendar year 1923 the Water Supply Papers 568 and 588 show outflow at El Paso (Courchesne) of 728,700 acre-feet. If the Geological Survey results were used the total consumptive use would be decreased from 373,786 to 309,675 acre-feet, thus making an average of 5.74 acre-feet consumptive use per irrigated acre $\left(\frac{K}{A_i}\right)$ and 2.84 acre-feet consumptive use per acre of total Valley surface $\left(\frac{K}{A}\right)$. These are respectively 27 and 4 percent higher than the 17-year average and are much closer to th... than the quantities based on Bureau of Reclamation records. There i... crepancy for the year 1924. Water Supply Papers 588 and 608 show an o... 810,200 acre-feet as against 799,071 from the Bureau of Reclamation records.

The quantity (K) of column 6, table 92, consists of eam-flow depletion ($I-R$), plus precipitation (P), plus aft on ground water ($G_s - G_e$). Comparisons of the verages show that the stream-flow depletion constitutes 73 percent of the consumptive use; precipitation, 26 percent; and draft on ground water 1 percent. In terms of acre-feet per acre of irrigated land the averages for the 17-year period are as follows:

Stream-flow depletion $(I-R)/A_i$ equals	3.30
Precipitation P/A_i equals	1.18
Draft on ground water $(G_s-G_e)/A_i$ equals	0.04
	4.52

The stream-flow depletion of 3.30 acre-feet per acre of irrigated land is comparable with most of the estimates heretofore made by engineers and designated "consumptive use."

Stream-flow depletion is the most important item of the consumptive use. Irrigators are directly concerned with the net depletion of streams because of the use of water in irrigation. Moreover, it constitutes the largest of the three items included in consumptive use, being nearly three-fourths of it as an average for a 17-year period in Mesilla Valley. Precipitation on the valley floor tends to decrease the stream-flow depletion, but since precipitation cannot be controlled, the stream-flow depletion and its relation to irrigation areas and irrigation practices are of major practical importance.

The precipitation item (P/A_i) of 1.18 acre-feet per re of irrigated land may be misleading because of the fact that it includes precipitation on the entire valley floor, only six-tenths of which, as an average, was used on cropped land. The consensus of opinion of uthorities in Mesilla Valley seems to be that much of the precipiation which falls on the cropped lands of the valley is of but little, if any, direct benefit to crops.

In order to present amounts that are more nearly comparable with the estmates of engineers previously reported, table 93 was prepared. The quantity ($K-P$), column 2, is stream-flow depletion plus difference in ground-water storage, as may be seen readily by subtracting the quantity (P) from both sides of equation (4). Then

$$(K-P) = (I-R) + (G_s - G_e).$$

For convenience, the quantity at the left of the equality sign in the foregoing equation is written on columns 2 and 4 of table 93, instead of its longer equivalent on the right.

Column 4 shows the average of the quantity $\left(\frac{K-P}{A_i}\right)$ for the 17-year period to be 3.36 acre-feet per irrigated acre. The average of 3.36 is almost identical with Hosea's 1929 Mesilla Valley 5-year estimate for the m-flow depletion per acre irrigated $\left(\frac{I-R}{A_i}\right)$ for the years 1924 to 1928, namely, 3.42,[13] and with Debler's (1932) 4-year estimate of 3.40 acre-feet per irrigated acre for the years 1926 to 1929.

TABLE 93.—*Stream-flow depletion in Mesilla Valley, N. Mex. and Tex., for 17-year period 1919 to 1935, based on inflow-outflow method* [1]

Year	$K-P$ Acre-feet	A_i Acres	$\frac{K-P}{A_i}$ Acre-feet per acre	Proportion of average,[2] percent	$I-R$ Acre-feet	$\frac{I-R}{A_i}$ Acre-feet per acre
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1919	185,847	47,314	3.93	117.0	160,504	3.40
1920	103,890	48,327	2.15	64.0	92,935	1.92
1921	133,261	51,407	2.59	[illegible]	127,211	2.48
1922	217,733	48,620	4.48	[illegible]	219,695	4.52
1923 [3]	279,719	53,812	5.20	154.8	259,606	4.83
1924 [3]	189,918	61,966	3.06	91.1	193,352	3.12
1925	225,722	67,357	3.35	99.7	223,760	3.32
1926	254,463	76,244	3.34	99.4	266,071	3.49
1927	258,829	73,314	3.53	105.1	260,627	3.55
1928	291,368	76,057	3.83	114.0	291,695	3.84
1929	222,896	76,772	2.90	86.3	216,193	2.82
1930	258,374	76,373	3.38	100.6	258,538	3.39
1931	219,921	76,722	2.87	85.4	222,700	2.87
1932	243,229	76,709	3.17	94.4	248,788	3.24
1933	222,995	77,061	2.89	86.0	214,820	2.79
1934	254,845	68,605	3.71	110.4	259,750	3.79
1935	174,715	62,175	2.81	83.6	173,080	2.79
Average	219,866	65,814	3.36	100.0	217,019	3.30

[1] As determined by Bureau of Agricultural Engineering (see table 92) showing in column 2 stream-flow depletion plus difference in ground-water storage ($K-P$) in acre-feet, and in column 4 in acre-feet per irrigated acre $\left(\frac{K-P}{A_i}\right)$; together with percentage of each year's results of 17-year average in column 5 and stream-flow depletion ($I-R$) in acre-feet, and in acre-feet per acre of irrigated land $\left(\frac{I-R}{A_i}\right)$.

[2] Percent represented by corresponding yearly figures in column 4 relative to the average of column 4.

[3] Results based on Bureau of Reclamation records. See footnote 2, table 92.

The percentage of the quantity $\left(\frac{K-P}{A_i}\right)$ for each year, referred to the 17-year average, is given in column 5. Briefly summarized, the column 5 data show that during 6 years out of the 17, or 35 percent of the time, the consumptive use less precipitation was within 10 percent of the average for the period. During 13 years, or 76 percent of the time, the departure from the average did not exceed 20 percent, plus or minus; and during 14 of the 17 years the departure did not exceed 30 percent of the 17-year average. In 1 year, 1923, the consumptive use less precipitation exceeded the average by 55 percent.

Column 6 of table 93 shows the stream-flow depletion each year in acre-feet, and the average for the 17-year period. The average (217,019) plus the average change in ground water shown in column 5 of table 92 (2,847), is equal to the average consumptive use less precipitation shown in column 2 of table 93; namely, 219,866 acre-feet. The stream-flow depletion in acre-feet per acre of irrigated land, shown in column 7, indicates an average of 3.30 for the 17-year period. This average is only 0.06 acre-foot per acre less than the average of consumptive use less rainfall, shown in Column 4. The average stream-flow depletion $\left(\frac{I-R}{A}\right)$ for the 17-

[13] Hosea designates the quantity 3.42 "consumptive use."

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year period based on the entire valley area of 109,000 acres is 1.99 acre-feet per acre.

Consumptive use by integration method B.—The sum of the products of the areas of each crop (or group of crops) in acres, times the consumptive use for each crop, gives the consumptive use on all cropped land by method B, designated in this report as the integration method.

Land Area Classification.—The areas of land used for different groups of crops in Mesilla Valley are given in table 94. The detailed Bureau of Reclamation crop surveys of agricultural lands are classified by New Mexico State College authorities in eight groups: alfalfa, cotton, forage crops, fruits, grains, pasture, vegetables, and miscellaneous. Column 2 of the table shows that there has been a decrease in the area devoted to alfalfa since 1923. The cotton area has increased greatly. Column 10 of the table shows the total cropped area each year.

Table 95 shows the classification of Mesilla Valley land areas into cropped area (A_c), native vegetation (A_n), water surface (A_w), bare land (A_l) and fallow land (A_f). Column 2 shows the growth in cropped area. There are no long-time records of Mesilla Valley areas in native vegetation. Column 3 of table 95 shows the native vegetation areas from 1919 to 1935 as determined by subtracting from the area of the Valley floor, 109,000 acres, the sum of the cropped acreage (A_c), the water surface acreage (A_w), the bare land surface area (A_l), and the fallow area (A_f). The general trend in area of native vegetation from 1919 to 1933 was downward, and the increase from 1933 to 1935 is apparently attributable to an assumed reversion of fallow land to native vegetation. It is estimated that about one-third of the native vegetation area was trees and two-thirds brush and grass.

Experiments on Use of Water.—As noted on page 344 considerable experimental work has been done by the New Mexico Agricultural Experiment Station in cooperation with the Bureau of Agricultural Engineering, with a view to finding the irrigation requirements and the consumptive use of alfalfa, cotton, grains, and some vegetables. Results of this experimental work have been accumulated for many years, and many have been published, but not all. Both published and unpublished data have been analyzed.

It is believed that the consumptive use for cotton, which has recently been given most experimental study, may be determined for like conditions with a fair degree of accuracy on the basis of the experimental data. A study of the relation of the yield of cotton to the consumptive use of water for the years 1928 to 1933 seems to warrant the conclusion that cotton yields increased fairly well with increase in consumptive

TABLE 94.—*Mesilla Valley crop areas, in acres, from Bureau o[f] Reclamation records used in estimating consumptive [use] b[y] method B, by years, 1919–35*

Year	Alfalfa	Cotton	Forage	Fruits	Grains	Pasture	Vegetable	Miscellaneous	Tota[l]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1919	19,100	24	2,616	700	15,156	3,845	2,839	0	44,2
1920	16,795	6,682	1,534	768	13,422	3,270	3,390	0	45,8
1921	18,923	519	3,192	478	16,218	5,573	1,431	0	46,3
1922	20,270	2,731	1,934	708	11,617	3,682	4,033	284	45,2
1923	20,659	14,452	4,453	984	4,634	4,478	219	0	49,8
1924	15,344	29,049	2,555	547	2,183	3,549	2,545	0	55,7
1925	13,068	41,488	1,529	801	2,330	1,703	2,581	0	63,5
1926	13,663	43,860	910	701	3,418	902	3,768	2,502	69,7
1927	14,974	43,430	1,227	439	6,455	1,310	3,426	0	71,2
1928	10,422	57,220	925	198	2,326	1,331	2,740	0	75,1
1929	10,667	58,815	1,048	650	1,444	1,012	2,439	0	76,0
1930	12,927	53,619	1,584	348	3,377	787	3,103	0	75,74
1931	14,715	47,106	1,760	549	7,493	867	2,826	0	75,3
1932	14,783	42,271	3,505	389	7,818	1,966	4,212	0	74,9
1933	12,807	42,643	4,284	311	6,075	1,695	3,532	4,485	75,8
1934	12,767	35,356	4,626	686	6,305	1,565	3,129	413	64,84
1935	11,492	33,185	4,505	496	4,497	719	3,073	700	58,6
Average	14,904	32,497	2,482	574	6,751	2,250	2,899	493	62,8

TABLE 95.—*Mesilla Valley land classification in acres, used i[n] estimating consumptive use by method B, by years, 1919–35*

Year	Crops	Native vegetation	Water	Bare	Fallow	Total
	A_c	A_n	A_w	A_l	A_f	A
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1910	44,280	50,490	7,000	4,196	3,034	109,0
1920	45,561	49,477	7,000	4,196	2,466	109,0
1921	46,334	46,397	7,000	4,196	5,073	109,0
1922	45,259	49,184	7,000	4,196	3,361	[illegible]
1923	49,879	46,969	4,004	4,196	3,93	[illegible]
1924	55,772	38,832	4,004	4,196	6,1	[illegible]
1925	63,500	33,344	4,004	4,196	3,85	[illegible]
1926	69,724	24,556	4,004	4,196	6,520	[illegible]
1927	71,261	27,486	4,004	4,196	2,053	109,0
1928	75,162	24,743	4,004	4,196	895	109,0
1929	76,075	24,028	4,004	4,196	697	109,0
1930	75,745	24,427	4,004	4,196	628	109,0
1931	75,316	24,078	4,004	4,196	1,406	109,0
1932	74,936	24,091	4,004	4,196	1,773	109,0
1933	[illegible]5,332	[illegible]3,739	4,004	4,196	[illegible]229	109,0
1934	[illegible]4,347	[illegible]2,977	4,004	4,196	[illegible]2,376	109,0
1935	58,667	27,875	4,004	4,196	[illegible]4,258	109,0

use up to 2 acre-feet per acre, and that beyond a us[e] of 3 acre-feet per acre, the increase in yield was so sma[ll] as to be negligible. On the basis of these data a[n] estimated unit consumptive use of 2.5 is probabl[y] near the truth. It is believed that the error of th[e] average consumptive use is not more than 10 percent.

Estimates of the consumptive use of alfalfa are subjec[t] to a larger error. An analysis of the relation of alfalf[a] yield to the amount of irrigation water used, based o[n] many years of experimental work in Mesilla Valley a[s] reported by the New Mexico Agricultural Experimen[t] Station and Bureau of Agricultural Engineering (7) seems to indicate that alfalfa yield was not increase[d] much, if at all, with increase in amounts of irrigatio[n] water beyond 4 acre-feet per acre. All the data pub[-] lished about the more recent work on the consumptiv[e] use of alfalfa, as summarized by Prof. A. S. Curry would seem to give no basis for concluding th[at yie]ld was increased with increase in consumptive us[e] ...

5 acre-feet (60 acre-inches) per acre. The chances are probably equal that the consumptive use of alfalfa may vary at least plus or minus 20 percent from the average consumptive use based on the experimental work for conditions.

There are but few experimental data in New Mexico to form the basis of estimating the unit consumptive use of crops other than alfalfa, cotton, fruits, pasture and vegetables.

Estimates of Valley Consumptive Use.—The crop areas shown in table 94, which are based on Bureau of Reclamation records, are reproduced in table 96 with minor modifications to correct for duplications of some crops. It is important to note that the sum of the 17-year average areas for alfalfa and cotton (47,401 acres) is over 75 percent of the average cropped area of 62,850 acres, and that cotton alone represents more than 50 percent of the cropped area on the average. During the 5-year period 1928 to 1932 more than two-thirds of the cropped area was in cotton.

The unit consumptive use for alfalfa, cotton, and each of the other six groups of crops as used herein, is shown in line 3 of table 96. The experimental data described above have been used as a basis for the unit use estimates. The estimates for forage, fruits, pasture and miscellaneous crops, shown in columns 5, 6, 8, and 10 respectively of table 96, are based on experimental work in other States as well as New Mexico. They may, therefore, be less reliable than the estimates for alfalfa, cotton and grains.

Based on a net annual use, by alfalfa, of 4 acre-feet per acre and by cotton of 2.5 (the amounts used in table 96) these two crops (as an average for the 17-year period) used nearly 82 percent, or more than four-fifths of the consumptive use by all crops. It is, therefore, evident that the selection of unit consumptive use values for these two crops is of major importance. Cotton alone used an average of more than 81,000 acre-feet, which is 47 percent of the total amount used by all crops.

An error of 15 percent in the consumptive use by cotton would make an error of 7 percent in the use by all crops; whereas, an error of 100 percent in the unit value for pasture or vegetables would make an error of only 4 percent in the use by all crops. The use by miscellaneous crops is negligible.

Column 11 of table 96 shows the amounts of water consumed on cropped land. The average for the 17-year period is approximately 173,000 acre-feet; in round numbers the maximum is 205,000, and the minimum is 126,000. The maximum is 18 percent higher than the average, and the minimum is 27 percent lower.

TABLE 96.—*Amounts of water in acre-feet consumed by Mesilla Valley crops as estimated by multiplying assumed unit consumptive use by the acreage of each crop each year from 1919 to 1935, inclusive, by integration method B*

Year	Item	Crop and unit use (c)								Total crop use (K_s)
		Alfalfa	Cotton	Forage	Fruits	Grains	Pasture	Vegetables	Miscellaneous	
		4.0	2.5	3.0	2.0	1.5	3.0	2.0	2.00	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1919	(a)	19,100	24	2,616	700	15,156	3,845	2,839	0	
	(ca)	76,400	60	7,848	1,400	22,790	11,535	5,678	0	125,711
1920	(a)	16,795	6,682	1,534	768	13,422	3,270	3,390	0	
	(ca)	67,180	16,705	4,602	1,536	20,200	9,810	6,780	0	126,813
1921	(a)	18,923	519	3,192	478	16,219	5,573	1,431	0	
	(ca)	75,692	1,298	9,576	956	24,300	16,719	2,862	0	131,403
1922	(a)	20,270	2,731	1,934	708	11,617	3,682	4,033	284	
	(ca)	81,080	6,827	5,802	1,416	17,400	11,046	8,066	568	132,205
1923	(a)	20,659	14,452	4,453	984	4,634	4,478	219	0	
	(ca)	82,636	36,130	13,359	1,968	6,950	13,434	438	0	154,915
1924	(a)	15,344	29,049	2,555	547	2,183	3,549	2,545	0	
	(ca)	61,376	72,623	7,665	1,094	3,274	10,647	5,090	0	161,769
1925	(a)	13,068	41,488	1,529	801	2,330	1,703	2,581	0	
	(ca)	52,272	103,720	4,587	1,602	3,495	5,109	5,162	0	175,947
1926	(a)	13,663	43,860	910	701	3,418	902	3,768	2,502	
	(ca)	54,652	109,650	2,730	1,402	5,127	2,706	7,536	5,004	188,807
1927	(a)	14,974	43,430	1,227	439	6,455	1,310	3,426	0	
	(ca)	59,896	108,600	3,681	878	9,682	3,930	6,852	0	193,519
1928	(a)	10,422	57,220	925	198	2,326	1,331	2,740	0	
	(ca)	41,688	143,000	2,775	396	3,489	3,993	5,480	0	200,821
1929	(a)	10,667	58,815	1,048	650	1,444	1,012	2,439	0	
	(ca)	42,668	146,800	3,144	1,300	2,166	3,036	4,878	0	203,992
1930	(a)	12,927	53,619	1,584	348	3,377	787	3,103	0	
	(ca)	51,708	134,000	4,752	696	5,065	2,361	6,206	0	204,788
1931	(a)	14,715	47,106	1,760	549	7,493	869	2,826	0	
	(ca)	58,860	117,500	5,280	1,098	11,239	2,607	5,652	0	202,236
1932	(a)	14,783	42,271	3,505	389	7,818	1,966	4,212	0	
	(ca)	59,132	105,700	10,515	778	11,727	5,898	8,424	0	202,174
1933	(a)	12,807	42,643	4,284	311	6,075	1,695	3,532	4,485	
	(ca)	51,228	106,500	12,852	622	9,112	5,085	7,064	8,970	201,433
1934	(a)	12,767	35,356	4,626	686	6,305	1,565	3,129	413	
	(ca)	51,068	88,400	13,878	1,372	9,457	4,695	6,258	826	175,954
1935	(a)	11,492	33,185	4,505	496	4,497	719	3,073	700	
	(ca)	45,968	83,000	13,515	992	6,746	2,157	6,146	1,400	159,924
Average area	(a)	14,904	32,497	2,482	574	6,751	2,250	2,899	493	
Average use	(ca)	59,617	81,243	7,446	1,147	10,130	6,750	5,798	989	173,082

NOTE.—ca=the product of unit consumptive use (c) in acre-feet per acre by area (a) in acres=consumptive use in acre-feet.

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Because there can be no precise selection of unit consumptive use amounts applicable to a large valley such as the Mesilla Valley, two additional sets of assumed values have been selected and crop consumptive use determined each year for the 10-year period ending 1933, as shown in tables 97 and 98. The assumed unit consumptive use for alfalfa in table 97 is 3 acre-feet per acre, and in table 98 it is 5 feet, thus being three-fourths and five-fourths of the amount assumed in table 96. For cotton, the amount in table 97 is 2.0 acre-feet per acre, and in table 98 it is 3 feet, being four-fifths and six-fifths, respectively, of the amount used in table 96. Differences for other crops are of minor importance and can be compared [illegible] the tables.

In order to make the results of the analysis in 97 and 98 strictly comparable with those of tab[illegible], the same 10-year period must be used. The average crop consumptive use for the Valley lands on the basis of the 10-year period 1924–33 and the unit consumptive use values in table 96 is 193,548 acre-feet. This is 25 percent higher than the average of 154,740 in table 97 and 17 percent lower than the average of 233,090 in table 98.

It is probable that the inflow-outflow method is more reliable for Mesilla Valley than the integration method.

TABLE 97.—*Amounts of water in acre-feet consumed by Mesilla Valley crops for the 10-year period 1924–33, based on low estimates of unit consumptive use as shown in columns 3 to 10, inclusive, by integration method B*

Year	Item	Crop and unit use (c)								Total crop use (K_c)
		Alfalfa 3.0	Cotton 2.0	Forage 3.0	Fruits 1.5	Grains 1.5	Pasture 2.5	Vegetables 1.5	Miscellaneous 2.0	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1924	(a)	15,344	29,049	2,555	547	2,183	3,549	2,545	0	
	(ca)	46,032	58,098	7,665	820	3,274	8,860	3,818	0	128,567
1925	(a)	13,068	41,488	1,529	801	2,330	1,703	2,581	0	
	(ca)	39,204	82,976	4,587	1,201	3,495	4,257	3,871	0	139,591
1926	(a)	13,663	43,860	910	701	3,418	902	3,768	2,502	
	(ca)	40,989	87,720	2,730	1,051	5,127	2,250	5,652	5,004	150,523
1927	(a)	14,974	43,430	1,227	439	6,455	1,310	3,426	0	
	(ca)	44,922	86,860	3,681	658	9,682	3,280	5,139	0	154,222
1928	(a)	10,422	57,220	925	198	2,326	1,331	2,740	0	
	(ca)	31,266	114,440	2,775	297	3,489	3,330	4,110	0	159,707
1929	(a)	10,667	58,815	1,048	650	1,444	1,012	2,439	0	
	(ca)	32,001	117,630	3,144	975	2,166	2,530	3,658	0	[illegible]4
1930	(a)	12,927	53,619	1,584	348	3,377	787	3,103	0	
	(ca)	38,781	107,238	4,752	522	5,065	1,967	4,655	0	
1931	(a)	14,715	47,106	1,760	549	7,493	869	2,826	0	
	(ca)	44,145	94,212	5,280	823	11,239	2,175	4,239	0	[illegible]13
1932	(a)	14,783	42,271	3,505	389	7,818	1,966	4,212	0	
	(ca)	44,349	84,542	10,515	583	11,727	4,915	6,318		162,949
1933	(a)	12,807	42,643	4,284	311	6,075	1,695	3,532	4,485	
	(ca)	38,421	85,286	12,852	466	9,112	4,240	5,298	8,970	164,645
Average area	(a)	13,337	45,950	1,933	493	4,292	1,512	3,117	699	
Average use	(ca)	40,011	91,900	7,798	740	6,438	3,780	4,676	1,398	154,740

NOTE.—ca = the product of unit consumptive use (c) in acre-feet per acre by area (a) in acres = consumptive use in acre-feet.

TABLE 98.—*Amounts of water in acre-feet consumed by Mesilla Valley crops for the 10-year period 1924–33, based on high estimates of unit consumptive use as shown in columns 3 to 10, inclusive, by integration method B*

Year	Item	Crop and unit use (c)								Total crop use (K_c)
		Alfalfa 5.0	Cotton 3.0	Forage 3.5	Fruits 2.0	Grains 2.0	Pasture 3.0	Vegetables 2.0	Miscellaneous 2.0	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1924	(a)	15,344	29,049	2,555	547	2,183	3,549	2,545	0	
	(ca)	76,720	87,147	8,942	1,094	4,366	10,647	5,090	0	194,006
1925	(a)	13,068	41,488	1,529	801	2,330	1,703	2,581	0	
	(ca)	65,340	124,464	5,352	1,602	4,660	5,109	5,162	0	211,689
1926	(a)	13,663	43,860	910	701	3,418	902	3,768	2,502	
	(ca)	68,315	131,580	3,185	1,402	6,836	2,706	7,536	5,004	226,564
1927	(a)	14,974	43,430	1,227	439	6,455	1,310	3,426	0	
	(ca)	74,870	130,290	4,294	878	12,910	3,930	6,852	0	234,024
1928	(a)	10,422	57,220	925	198	2,582	1,331	2,740	0	
	(ca)	52,110	171,660	3,237	396	5,164	3,993	5,480	0	242,040
1929	(a)	10,667	58,815	1,048	650	1,444	1,012	2,439	0	
	(ca)	53,335	176,445	3,668	1,300	2,888	3,036	4,878	0	245,550
1930	(a)	12,927	53,619	1,584	348	3,377	787	3,103	0	
	(ca)	64,635	160,857	5,544	696	6,754	2,361	6,206	0	247,053
1931	(a)	14,715	47,106	1,760	549	7,493	869	2,826	0	
	(ca)	73,575	141,318	6,160	1,098	14,986	2,607	5,652	0	245,396
1932	(a)	14,783	42,271	3,505	389	7,818	1,966	4,212	0	
	(ca)	73,915	126,813	12,267	778	15,636	5,898	8,424	0	243,731
1933	(a)	12,807	42,643	4,284	311	6,075	1,695	3,532	4,485	
	(ca)	64,035	127,929	14,994	622	12,150	5,085	7,064	8,970	240,849
Average area	(a)	13,337	45,950	1,933	493	4,318	1,512	3,117	699	
Average use	(ca)	66,685	137,850	6,765	987	8,635	4,537	6,234	1,389	

NOTE.—ca = the product of unit consumptive use (c) in acre-feet per acre by area (a) in acres = consumptive use in acre-feet.

If this be true, the unit amounts for consumptive use given in tables 96 and 98 are closer to the true amounts for the Valley as a whole than those of table 97. This means that the estimates of 3 acre-feet per acre for alfalfa and 2 acre-feet per acre for cotton are too low; whereas, unit consumptive values for alfalfa from 4 to 5 acre-feet per acre and for cotton of 2.5 to 3.0 acre-feet per acre give results for the Valley consumptive use closer to those obtained by the inflow-outflow method.

Combined Consumptive Uses.—In table 99 the results of the integration method for agricultural crops, taken from table 96, are combined with estimated evaporation losses from fallow lands, use by native vegetation, and evaporation losses from bare lands and from water surfaces. The term "fallow" is applied to the land which is classed by the Bureau of Reclamation as irrigated but not cropped. The area is relatively small, and it is assumed that this land sustains an evaporation loss of 1 acre-foot per acre per year. Other assumed unit amounts in table 99 are trees, 3.5; brush and grass, 2.5, and bare land, a depth equal to the annual rainfall.

The water surface evaporation (E_w) is based on actual evaporation measured in a standard Weather Bureau evaporation pan at State College and taken as 0.7 of the amount for each year.

Column 8 shows the consumptive use (K) in acre-feet by the integration method for Mesilla Valley. There is relatively little variation in the amounts of column 8, the maximum being only 6 percent higher than the average, and the minimum but 9 percent lower than the average.

The actual variation in the consumptive use from year to year is perhaps greater than the data of column 8 indicate because there is variability in the unit amounts consumed per acre by the different crops, whereas column 2 of table 99 (the major single item in column 8) is based on the assumption that the consumptive use of each crop does not vary from year to year.

It is of interest to note that the average by integration method B (table 99) for the 17-year period (297,291 acre-feet), is almost the same as the average for the same period as found by inflow-outflow method A, which is 297,756, as shown in table 92.

On the basis of the estimated amounts of consumptive use for various types of land as shown in table 99 (made by method B), it is apparent that 93,587 acre-feet of water estimated to be the average amount consumed by the native vegetation from 1919 to 1935 is approximately 31 percent of the average total consumptive use (K) of 297,291 acre-feet.

The average use by all other classes of land as shown in table 99 (method B) is 203,704 acre-feet. If this amount is subtracted from the average consumptive

TABLE 99.—*Consumptive use of water in Mesilla Valley, N. Mex. and Tex., as determined by integration method B, 1919 to 1935, inclusive*

Year	Consumptive use in acre-feet						
	Cropped land	Fallow land	Native vegetation (K_n)		Water surface	Bare land	Total area
	K_c	K_f	Trees	Brush and grass	E_w	E_l	K
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1919	125,711	3,034	57,315	85,203	36,900	2,820	310,983
1920	126,813	2,466	56,284	84,925	37,400	2,862	310,750
1921	131,403	5,073	52,776	78,295	37,900	2,672	308,119
1922	132,205	3,361	55,948	82,998	39,300	1,955	315,767
1923	154,916	3,932	53,448	79,295	19,920	3,620	315,130
1924	161,769	5,104	44,170	65,530	19,750	1,695	299,108
1925	175,247	[illegible]	37,930	56,268	18,220	2,730	294,951
1926	188,807	[illegible]	[illegible]	41,437	17,860	5,020	287,597
1927	193,519	2,053	31,266	46,382	19,450	3,310	295,980
1928	200,821	895	28,143	41,755	19,000	3,270	293,884
1929	203,992	697	27,332	40,548	18,140	3,220	293,929
1930	204,788	628	27,786	41,220	19,480	2,410	296,312
1931	202,736	1,406	27,386	40,632	19,260	4,630	295,552
1932	202,174	1,773	27,405	40,653	23,400	3,090	298,495
1933	201,433	1,229	27,003	40,060	24,420	1,646	295,791
1934	175,954	3,758	26,138	38,773	25,200	1,613	271,436
1935	159,924	3,508	31,707	47,040	24,070	4,430	270,679
Average	173,082	2,964	37,645	55,942	24,658	3,000	297,291
Percentage	58.2	1.0	12.7	18.8	8.3	1.0	100.0

use (K) of 297,756 acre-feet as determined by method A (see table 92), the average consumptive use of water by native vegetation is 94,052 acre-feet for the period 1919 to 1935.

Method C (based on Hedke).—A method of estimating consumptive use by means of a study of the heat units available to the crops of a particular valley has been suggested by Hedke (25) (26). This method assumes that there is a linear relation between the amount of water consumed and the quantity of available heat.[14] The assumed relation in mathematical language is as follows:

$$U_v = K_h \ (Q_h)^{15}$$

Hedke found the magnitude of K_h to be 4.23×10^{-4} for the Cache La Poudre Valley, Colo. For the crops grown on the Rio Grande Project he found, in 1924, a total heat requirement of 6,800 day-degrees (26), and a corresponding total valley water consumption of 2.88 acre-feet "per cropped acre."

[14] The application of the direct relation between water consumption and available heat, proposed by Hedke, to a valley in which the agricultural practices are of a high standard, appears to necessitate the following assumptions: (1) That the heat consumed by a particular crop, during any day or other time period, is determined by the amount of heat available to the crop above the germinating or minimum growing temperature; (2) That under favorable agricultural practices, each crop consumes water in direct relation to the heat available as defined; (3) That the soils considered are abundantly supplied with moisture and plant-food so that the yield of a crop will be limited only by the amount of heat available; (4) That the influence of variations in wind velocity, relative humidity, and vapor pressure on consumptive use of water are relatively small as compared to the influence of available heat (25, p. 1366).

[15] The symbols used by the Committee of the American Society of Civil Engineers in this equation are taken from reference 25, p. 1396. The meaning of each symbol follows: U_v = valley consumptive use, Q_h = quantity of available heat in day-degrees, K_h = the Hedke coefficient. The subscript "h" is added to the K in Reference 25 to distinguish Hedke's coefficient from the consumptive use (K) used by Bureau of Agricultural Engineering.

The constant K_h was evaluated on the basis of only two years' (1916 and 1917) actual measurement of valley consumptive use in the Cache La Poudre Valley. For what he designated the "normal year", Hedke found the consumptive use to be 2.03 acre-feet per cropped acre.

The normal rainfall in Cache La Poudre Valley is 1.16 feet, according to Hedke. Of this normal amount he considered one-half "effective" and, therefore, a part of the consumptive use.

Relation to Mesilla Valley—It is perhaps impractical to use the Hedke constant K_h evaluated on the basis of the Cache La Poudre Valley studies, to estimate closely the Valley consumptive use in Mesilla Valley. Reasons for this statement are:

a. Hedke used only one-half of the rainfall in evaluating his K_h.
b. Probably 75 to 80 percent of the Cache La Poudre Valley land was cropped in 1916 and 1917; whereas only 60 percent of Mesilla Valley area was cropped from 1919–35.
c. The cropped area of 225,000 acres for Cache La Poudre Valley is probably too large.
d. Not all the Cache La Poudre Valley outflow was actually measured in 1917.
e. The Cache La Poudre Valley studies did not continu... enough to give results comparable to the direct measurements of consumptive use in Mesilla Valley.

A direct application of the relation of available h... in Mesilla Valley to consumptive use of water du... the period 1919 to 1935 has enabled the Bureau to evaluate new constants for the Hedke equation. The estimated minimum growing temperatures used for various crops were: Alfalfa, 33° F.; cotton, 48°; forage, 44°; fruits, 46°; grains, 44°; pasture, 33°; vegetables, 40°; miscellaneous, 38°.

The average quantity of available heat (that is, Hedke's "thermal location") for the 17-year period, is 6,200 day-degrees. This is 9 percent lower than the quantity found by Hedke in 1924, but is based on much longer therefore and more reliable records of Mesilla Valley crop production.

In figure 91 the quantity of available heat Q_h is plotted against the Valley consumptive use in acre-feet per acre irrigated $\left(\frac{K}{A_i}\right)$ as determined by inflow-outflow method (table 92). The Hedke constant resulting from the straight line curve of figure 91 is 7.3×10^{-4}, or 0.00073.

In figure 92 the available day-degrees of heat each year are plotted aginst the crop consumptive use per acre of cropped land $\left(\frac{K_c}{A_c}\right)$ as determined by integration

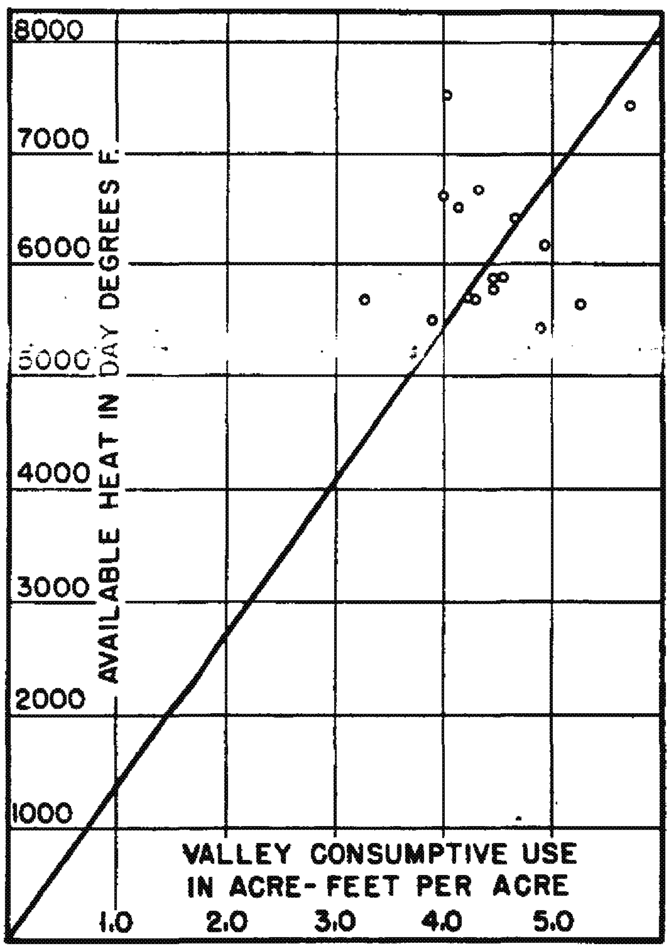

FIGURE 91.—Mesilla Valley consumptive use, method C (after Hedke), for 1919 to 1935, based on consumptive use in the entire valley per irrigated acre (K/A_i).

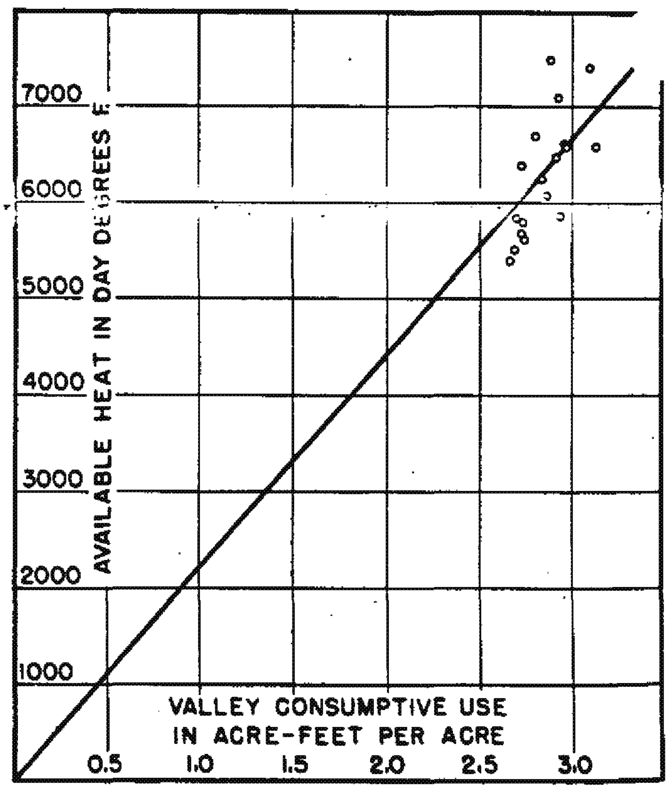

FIGURE 92.—Mesilla Valley consumptive use, method C (after Hedke), 1919 to 1935, based on crop consumptive use per cropped acre $\left(\frac{K_c}{A_c}\right)$.

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method (tables 94 and 96). A straight line through the origin and the points thus plotted, gives a value of equal to 4.4×10^{-4}, or 0.00044.

Application to Middle Rio Grande Valley.—For the Middle Valley Hedke found the available heat to be 6,200 day-degrees, the same amount found herein for the Mesilla Valley. The Bureau's analyses [16] for the Middle Valley are based on an average minimum growing temperature of 40°, assumed to be the average for all crops, and on mean monthly temperatures at Albuquerque, N. Mex. On these bases it is found that the average heat available is 5,600 day-degrees. With this quantity of available heat, and on the basis of Mesilla Valley consumptive-use studies during a 17-year period, as shown in figure 91, the Middle Valley consumptive use (based on method C) would be 4.1 acre-feet per irrigated acre $\left(\frac{K}{A_i}\right)$. Similarly using results shown in figure 92 the crop consumptive use per cropped acre $\left(\frac{K_c}{A_c}\right)$ would be 2.5. The latter value compares favorably with results obtained by method B in Middle Valley which range from 2.41 acre-feet per acre in the Cochiti division to 2.73 acre-feet per acre in the Belen division (tables 68 to 71).

Conclusion Regarding Methods

The inflow-outflow method is probably the most reliable method of estimating consumptive use in Mesilla Valley. However, if based upon careful estimates of unit consumptive use by the principal agricultural crops (now alfalfa and cotton) and native vegetation, and upon an accurate distribution of their acreages, it is likely that the integration method will produce satisfactory results.

[16] These analyses of Middle Valley are of a preliminary nature only.

Further and more comprehensive research into the relation of available heat to consumptive use of water must be carried out to make the Hedke method comparable in accuracy and reliability to the inflow-outflow and integration methods.

Consumptive Use in Mesilla Valley Area, 1936

The consumptive use of water in the Mesilla Valley area was determined by both the inflow-outflow method and the integration method, as follows:

Inflow-outflow method A.—The Mesilla Valley area was chosen for the 1936 study of consumptive use and stream-flow depletion because of the availability of reliable inflow and outflow records for many years, and for other reasons discussed on p. 379. The area as mapped by the Bureau of Agricultural Engineering in June 1936, has a total area of 110,418 acres and an irrigated area of 82,923 acres (table 101[17]).

The equation $K=(I+P)+(G_s-G_e)-R$ was used in computing Valley consumptive use (p. 347). By definition (p. 346) the items in this equation are for a period of 1 year. However, monthly values are used in the 1936 computations for the sake of greater accuracy and to show the seasonal variation.

Inflow.—The inflow (I) for Mesilla Valley area includes the Rio Grande inflow at Leasburg gaging station plus inflows of arroyos between Leasburg and Courchesne (El Paso). These measurements were made by the Bureau of Reclamation. The arroyo inflows are relatively small (table 100).

[17] This is the same section of the Lower Valley as that used in the 1919 to 1935 studies, but the total area of the tract is taken as mapped by the Bureau of Agricultural Engineering in 1936, rather than 109,000 acres as previously reported by the Bureau of Reclamation. However, the difference in acreages is relatively so small that either can be used without changing the unit consumptive use figures more than a few hundredths. The 1936 figures are therefore comparable with those for previous years.

TABLE 100.—*Consumptive use of water in the Mesilla Valley area, New Mexico and Texas, 1936 based on inflow-outflow method* [1]

Period	Leasburg inflow	Arroyo inflow	I	P	R	G_s-G_e	$I-R$	K	$\frac{I-R}{A_i}$	$\frac{K}{A_i}$	$\frac{I-R}{A}$	$\frac{K}{A}$
	Acre-feet								Acre-feet per acre			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
January	3,800	0	3,800	7,180	8,600	+3,310	−4,800	5,690	−0.06	0.07	−0.04	0.05
February	13,540	0	13,540	1,660	10,700	+1,660	2,840	6,160	.03	.07	.03	.06
March	50,840	0	50,840	1,200	29,400	−3,310	21,440	19,330	.26	.23	.19	.18
April	93,550	0	93,550	880	50,800	−9,940	42,750	33,640	.52	.41	.39	.30
May	89,850	8	89,858	4,050	62,500	−3,310	27,358	26,098	.33	.34	.25	.25
June	105,200	4	105,204	2,300	62,800	−1,660	42,404	43,044	.51	.52	.38	.39
July	122,660	639	123,299	9,850	76,500	−1,660	46,799	54,989	.56	.66	.42	.50
August	122,810	380	123,190	14,080	79,700	−3,310	43,490	54,260	.52	.65	.39	.49
September	63,320	512	63,832	22,540	50,500	+4,970	13,332	40,842	.16	.49	.12	.37
October	12,170	0	12,170	2,940	17,800	+4,970	−5,630	2,280	−.07	.03	−.05	.02
November	9,020	0	9,020	10,120	12,500	+6,620	−3,480	13,260	−.04	.16	−.03	.12
December	7,000	0	7,000	5,430	12,000	+1,660	−5,000	2,090	−.06	.03	−.05	.02
Total	693,260	2,043	695,303	82,180	473,800	0	221,503	303,683	2.67	3.66	2.01	2.75

[1] As determined by Bureau of Agricultural Engineering from inflow (I); precipitation (P); outflow (R); difference in ground-water storage (G_s-G_e); stream-flow depletion ($I-R$); valley consumptive use (K); irrigated area (A_i) = 82,923 acres; total area (A) = 110,418 acres; stream-flow depletion per irrigated acre $\left(\frac{I-R}{A_i}\right)$ and per acre for entire area $\left(\frac{I-R}{A}\right)$ consumptive use per irrigated acre $\left(\frac{K}{A_i}\right)$ and per acre for entire area $\left(\frac{K}{A}\right)$. By definition these items are annual amounts. The monthly increments are shown ...ations to illustrate method of computing.

Precipitation.—The quantity P is the product of precipitation in feet times the area of the Valley (110,418 acres). Records for the entire year are only available for State College and El Paso as shown in table 90. These were used together with records for part of the year from the stations established by the Bureau of Agricultural Engineering late in May 1936 (table 91) at Leasburg Dam, Mesilla Dam, La Union and Berino.[18]

Outflow.—For the quantity (R) only the discharge of the Rio Grande at Courchesne (El Paso) gaging station need be considered. Records of these measurements were furnished by the International Boundary Commission (table 100).

Ground-Water Storage.—The amount of change in ground-water storage ($G_s - G_e$) is estimated from monthly well records furnished by the Bureau of Reclamation and an assumed specific yield of 15 percent (p. 347).

Results.—The results of the 1936 consumptive-use-of-water and stream-flow-depletion studies, together with the monthly values for the various items used in the computations, are shown in table 100.

The total Valley consumptive use (K) for the year 1936 is 303,683 acre-feet and the stream-flow depletion ($I-R$) 221,503 acre-feet. These amounts agree closely with the 17-year averages of 297,756 acre-feet consumptive use (K) and 217,019 acre-feet stream-flow depletion ($I-R$).

The consumptive use on an acreage basis is 3.66 acre-feet per irrigated acre $\left(\frac{K}{A_i}\right)$ and 2.75 acre-feet per acre for entire area $\left(\frac{K}{A}\right)$. The same values for the 17-year period shown in table 92 are 4.52 and 2.75 acre-feet per acre, respectively. The increase in area of irrigated land in 1936 over previous years accounts for the lower value of $\left(\frac{K}{A_i}\right)$ in 1936.

The stream-flow depletion is 2.67 acre-feet per acre irrigated $\left(\frac{I-R}{A_i}\right)$ and 2.01 acre-feet per acre for entire area $\left(\frac{I-R}{A}\right)$.

Integration Method B.—The acreages of the different types of land mapped in the Mesilla Valley area by the Bureau of Agricultural Engineering in 1936 are shown in column 2 of table 101. Two sets of unit consumptive use values for various types of land, estimated from previous and 1936 experiments in the Valley, are shown in columns 3 and 5 for the purpose of comparison.

The unit values shown in column 3 are probably more nearly representative of present use of water in the Valley than those in column 5. The average consumptive use of 2.75 acre-feet per acre for the entire va[illegible] is the same as the amount determined by the i[illegible] outflow method (table 100). By deducting the [illegible] precipitation from the average consumptive use [illegible]), the stream-flow depletion would appear as about 2 acre-feet per acre or approximately the same as that obtained by the inflow-outflow method (table 100). The average use for irrigated cropped land amounts to 2.79 acre-feet per acre (column 3, table 101), while the use by native vegetation averages 3.27 acre-feet per acre.

TABLE 101.—*Consumptive use of water in Mesilla Valley area, New Mexico and Texas, as estimated by integration method, using different units, 1936*

Land classification	1936 area	Consumptive use[1]			
	(a)	(c)	(ca)	(c)	(ca)
	Acres	Acre-feet per acre	Acre-feet	Acre-feet per acre	Acre-feet
(1)	(2)	(3)	(4)	(5)	(6)
Irrigated crops:					
Alfalfa and clover	17,077	4.1	70,010	4.0	68,308
Cotton	54,513	2.5	136,282	2.5	136,282
Native hay and irrigated pasture	216	2.5	540	2.3	497
Miscellaneous crops	11,117	2.2	24,457	2.0	22,234
Entire area	82,923	2.79	231,295	2.74	227,321
Native vegetation:					
Grass	2,733	2.5	6,833	2.3	6,286
Brush	6,933	2.8	19,412	2.5	17,332
Trees—Bosque	3,532	4.8	16,954	5.0	17,660
Entire area	13,198	3.27	43,199	3.13	78
Miscellaneous:					
Temporarily out of cropping	5,569	1.0	5,569	1.5	8,354
Towns	1,523	2.0	3,046	2.0	3,046
Water surfaces, pooled, river, and canals	4,081	4.5	18,364	4.5	18,364
Bare land, roads, etc	3,124	.7	2,187	.7	2,187
Total (entire area)	110,418	2.75	[illegible]	[illegible]	300,550

[1] ca=the product of unit consumptive use in acre-feet per acre (c) times area in acres (a).

Soil-Moisture Studies—
Agricultural Crops, 1936

In recent years, by far the most extensive crop grown in the Lower Valley has been cotton. Alfalfa has occupied the next largest area. These two crops were chosen, therefore, for the studies of consumptive use as measured by soil-moisture determinations on selected plots.

Soil-moisture studies, centered at State College, were carried on in cooperation with the New Mexico Agricultural Experiment Station. Field plots for cotton experiments were selected at three locations: Agronomy farm, field EC, and field 9W. Suitable sites for alfalfa studies were limited, so the only plot selected was on the horticultural farm. Soil-moisture determinations were made in the college laboratory by standard methods, by the Bureau of Agricultural Engineering.

Soil samples were taken from each plot by m[illegible] of a Veihmeyer-type soil tube, before and after eac[illegible]

[18] Observations made through the courtesy of L. R. Flock, superintendent, and W. F. Resch, hydrographer, Rio Grande project.

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tion. From each hole seven samples were taken so as to give one sample from the surface to a depth of 6 inches, the next for the depth 6 to 12 inches, and the others for 1 foot increments thereafter to a final depth of feet. The samples were weighed and dried in an oven at 110° C. and the dry weights were determined. The moisture content of a sample was expressed as percentage of the oven-dry weight of the soil. From the moisture percentages thus obtained the amounts of water in acre-inches per acre removed from each foot were computed by using the formula $D=\frac{MVd}{100}$, where M represents the moisture percentage, V the apparent specific gravity (volume-weight) of the soil, d the depth of soil in inches, and D the equivalent depth of water in acre-inches per acre.

The average apparent specific gravity and moisture equivalent determinations of the soils in the various field plots are shown respectively in tables 102 and 103.

TABLE 102.—*Results of apparent specific gravity determinations of soils in cotton and alfalfa plots at State College, N. Mex., 1936*

Plot	Crop	Apparent specific gravity					
		First foot	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot
Agronomy farm:							
Group I	Cotton	1.30	1.31	1.38	1.43	1.50	1.50
Group II	do	1.34	1.39	1.38	1.59	1.57	1.57
Field EC	do	1.32	1.15	1.23	1.23	1.23	1.23
[illegible]W	do	1.36	1.48	1.29	1.37	1.37	1.40
[illegible]tural farm	Alfalfa	1.35	1.21	1.37	1.44	1.65	1.67

TABLE 103.—*Results of moisture equivalent determinations of soils in cotton and alfalfa plots at State College, N. Mex., 1936*

Plot	Crop	Moisture equivalent (percent)					
		First foot	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot
Agronomy farm:							
Group I	Cotton	28.94	19.55	13.25	7.25	4.66	3.17
Group II	do	16.32	15.34	11.74	7.81	6.07	4.38
Field EC	do	18.41	19.16	17.38	15.40	13.18	8.49
Field 9W	do	29.20	22.37	21.32	18.19	16.14	6.95
Horticultural farm	Alfalfa	23.89	31.18	13.75	13.07	3.46	2.85

Agronomy farm, cotton plots.—These plots were located on the cotton experimental field of the agricultural college agronomy department. The field was divided into 74 plots of one-fourteenth acre each. The soil ranges from a sandy loam to a clay loam. Soil samples were collected from 62 of the plots and soil moisture determinations were made. Each plot was irrigated with the same amount of water received by the others, the water applied being carefully measured over individual weirs.

For the purpose of this investigation, plots were divided into two groups, group I representing the heavier type soil and more luxuriant growth of cotton and group II a much smaller plant growth on a sandier soil. The difference in the surface 3 feet of soil in the two groups is indicated in table 103, which shows the average moisture-equivalent determinations for the different fields.

The average moisture content for the group I plots at various times during the 1936 season is given in table 104. The percent moisture loss during the sampling intervals was converted by means of the formula $D=\frac{MVd}{100}$, into soil moisture loss in acre-inches per acre, as shown in table 105. Rainfall was included in the total loss and the use (loss) of water per 30 days and for the interval between irrigations was calculated. The total use for the growing season, May 2 to October 19, was 29.63 acre-inches per acre. From evaporation records the use from October 19 to November 4 is estimated as 1.63 acre-inches per acre, making the total seasonal consumptive use 31.26 inches for group I cotton plots. The average yield for this group was 2,109 pounds of seed cotton per acre.

The data for group II are shown in like manner in tables 106 and 107. The use for the period between irrigations May 2 to June 6 has been estimated as 2.47 acre-inches per acre. For the period October 19 to November 4, the indicated use based on the preceding period is 2.30 inches. Thus the total seasonal consumptive use for group II plots is 25.67 acre-inches per

TABLE 104.—*Results of soil sampling and irrigation data, average for group I cotton plots, agronomy farm, State College, N. Mex., season 1936*

Dates of sampling	Average moisture content of soil (percent)							Dates of irrigation	Depth of irrigation water applied (inches)	Interval between irrigations (days)
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot			
May 19	19.97	19.97	16.82	13.69	9.80	10.00	9.75	May 2	5	
June 5	16.09	19.84	16.65	11.26	9.64	10.06	10.30	June 6	3	35
June 11	22.92	24.24	20.45	13.79	11.01	10.00	11.88			
July 1	13.03	17.31	16.95	11.98	9.88	9.14	8.24	July 8	3	27
July 7	26.40	22.63	17.82	13.71	9.69	9.77	8.61			
July 23	14.76	15.38	15.96	11.96	9.47	9.24	7.83	July 28	3	23
July 30	32.59	24.95	17.69	15.61	11.67	11.49	9.44			
Aug. 15	12.08	12.03	12.58	11.68	10.53	9.23	7.19	Aug. 15	4	20
Aug. 21	32.37	23.82	15.89	11.59	9.49	8.89	7.25			
Sept. 10	16.11	14.93	11.68	9.35	8.34	8.47	6.19	Sept. 13	4	29
Sept. 17	31.18	24.39	15.12	10.91	8.67	7.57	6.42			
Oct. 19	18.70	20.45	13.83	8.96	8.50	8.14	5.67	Oct. 19		36

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TABLE 105.—*Quantities of water used in intervals between irrigations, group I cotton plots, agronomy farm, State College, N. Mex., sea-* ...30

Interval	Number of days	Soil moisture loss (acre-inches per acre)										
		First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Rain in inches	Total	Between irrigations	days
May 19 to June 5	17	0.16	0.16	0.02	0.40	−0.82	−0.01	−0.08	0.60	1.28	2.55	2.19
June 11 to July 1	20	.77	.54	.65	.30	.19	.15	.65	.07	2.22	4.35	4.83
July 7 to July 23	16	.91	.56	.29	.29	.04	.09	.19	1.29	2.66	5.26	6.86
July 30 to Aug. 15	16	1.60	1.01	.80	.65	.19	.41	.41	.18	5.25	6.56	9.85
Aug. 21 to Sept. 10	20	1.27	.69	.58	.37	.20	.07	.19	1.06	4.43	6.42	6.65
Sept. 17 to Oct. 19	32	.97	.50	.30	.17	.02	−.10	.13	2.08	3.98	4.48	3.73

acre for the period May 2 to November 4. The average yield for this group was 1,228 pounds seed cotton per acre.

Field EC, Leding cotton plot.—This plot was located on the bench land south of the college buildings, where there was no possibility that a water table would influence the results. The soil is Anthony gravelly loam. The plant growth was unusually heavy on this plot. Soil sampling was not started until late in the season. The use of water on the Leding cotton plot for the period July 16 to October 21, 1936, is shown in table 108.

Field 9W, cotton plot.—This plot was located on the experimental field of the agricultural college's irrigation department. The area of the plot was 0.7 acre, and the soil is classed as Gila clay adobe, underlain by silt and sand. The water table ranged from 7 to 8 feet. Soil samples were taken at nine places uniformly spaced over the field. All irrigation water applied to this field was measured.

TABLE 106.—*Results of soil sampling and irrigation data, average for group II cotton plots, agronomy farm, State College, N. Mex., season 1936*

Dates of sampling	Average moisture content of soil (percent)							Dates of irrigation	Depth of irrigation water applied (inches)	Interval between irrigations (days)
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot			
May 19	13.36	13.36						May 2	5	
June 5	9.37	13.91	13.07	12.72	8.46	9.51	7.52	June 6	3	35
June 11	17.09	20.54	20.49	14.92	11.60	8.82	7.52			
July 1	9.70	13.03	17.65	13.12	10.49	10.19	6.23	July 3	3	27
July 7	18.20	17.27	17.34	15.83	9.55	9.51	7.55			
July 23	9.76	12.07	18.39	15.47	10.81	9.74	5.48	July 26	3	23
July 30	21.02	16.83	18.10	12.54	9.55	10.53	6.88			
Aug. 15	8.80	9.26	13.58	13.11	9.84	8.74	5.18	Aug. 15	4	20
Aug. 21	19.33	18.05	16.63	14.90	10.78	8.75	7.44			
Sept. 10	11.28	14.29	16.21	9.60	10.05	10.35	6.88	Sept. 13	4	29
Sept. 17	19.20	18.48	20.73	14.84	12.04	11.11	7.74			
Oct. 19	12.36	15.17	14.03	11.35	8.84	10.41	6.53	Oct. 19		36

TABLE 107.—*Quantities of water used in intervals between irrigations, group II cotton plots, agronomy farm, State College, N. Mex., season 1936*

Interval	Number of days	Soil moisture loss (acre-inches per acre)										
		First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Rain in inches	Total	Between irrigations	Per 30 days
May 19 to June 5	17	0.14	0.14						0.60	[1] 1.20	2.47	2.12
June 11 to July 1	20	.59	.62	0.47	0.34	0.18	−0.27	0.24	.07	2.24	3.02	3.36
July 7 to July 23	16	.68	.43	.16	.07	−.21	−.04	.36	1.29	2.74	3.94	5.14
July 30 to Aug. 15	16	.98	.63	.42	−.11	−.05	.34	.30	.18	2.69	3.36	5.05
Aug. 21 to Sept. 10	20	.65	.31	.07	1.01	.12	−.30	.10	1.06	3.02	4.38	4.53
Sept. 17 to Oct. 19	32	.55	.28	1.11	.67	.53	.13	.21	2.08	5.56	6.26	5.21

[1] Estimated.

TABLE 108.—*Quantities of water used in intervals between irrigations, Leding cotton plot, State College, N. Mex., season 1936*

Interval	Number of days	Soil moisture loss (acre-inches per acre)										
		First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Rain in inches	Total	Between irrigations	Per 30 days
July 16 to July 31	15	0.87	0.76	1.57	1.29	0.24	−0.08	−0.11	0.24	4.78	6.70	9.56
Aug. 5 to Aug. 22	17	.83	.67	1.61	1.47	1.06	.82	.60	.30	7.36	9.10	12.99
Aug. 26 to Sept. 19	24	.88	.71	1.57	.10	.31	.38	.28	1.04	5.27	5.27	6.59
Sept. 19 to Oct. 21	32	.06	.06	.11	.11	.03	.21	.13	2.08	2.79	2.79	[illegible] 62

Tables 109 and 110 summarize the soil moisture data for cotton field 9W. It was necessary to estimate the soil moisture loss for the period April 27 to June 15 because no samples were taken immediately following the irrigation on April 27. The estimated values are based on the assumption that the first 2 feet had the same moisture content following the irrigation on April 27 that they had when the field was sampled after irrigation on June 17. Following the same reasoning applied to data from the other plots, the loss for the 14-day

TABLE 109.—*Results of soil sampling and irrigation data, field 9W, cotton plot, State College, N. Mex., season 1936*

Date of sampling	Average moisture content of soil (percent)							Dates of irrigation	Depth of irrigation water applied (inches)	Interval between irrigations (days)
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot			
Apr. 27	17.60	17.60	12.10	10.61	8.31	10.30	6.54	Apr. 27	6.13	
June 13	15.55	25.95	18.82	11.30	8.07	10.52	3.68	June 15	5.99	49
June 17	28.04	29.13	21.34	15.20	8.73	9.98	4.58			
July 10	20.55	21.43	20.83	15.81	8.86	12.45	4.19	July 12	3.28	27
July 14	29.49	27.44	21.57	15.46	9.40	11.36	4.51			
Aug. 7	11.49	15.70	16.15	13.02	8.18	13.60	3.05	Aug. 8	4.76	27
Aug. 14	29.01	26.04	16.81	13.92	8.65	11.78	3.72			
Sept. 4	18.26	17.72	14.09	12.06	8.55	11.67	3.83	Sept. 5	3.78	28
Sept. 11	29.53	27.76	17.29	13.03	7.69	9.48	5.10			
Oct. 21	14.52	16.95	14.66	11.27	7.40	9.25	4.33	Oct. 21		46

TABLE 110.—*Quantities of water used in intervals between irrigations, field 9W, cotton plot, State College, N. Mex., season 1936*

Interval	Number of days	Soil moisture loss (acre-inches per acre)										
		First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Rain, inches	Total	Between irrigations	Per 30 days
Apr. 27 to June 13	47	1.04	0.31	0.41					0.77	[1] 2.53	[1] 2.64	[1] 1.62
June 17 to July 10	23	.60	.63	.09	0.08	−0.02	−0.40	0.07	1.36	2.39	2.81	3.12
July 14 to Aug. 7	24	1.47	.91	1.05	.40	.20	−.35	.24	.32	4.23	4.76	5.29
Aug. 14 to Sept. 4	21	.88	.69	.44	.30	.17	.17	−.17	1.30	3.78	5.04	5.40
Sept. 11 to Oct. 21	40	1.22	.88	.43	19	.05	.04	.13	2.09	5.03	5.79	3.77

[1] Estimated.

TABLE 111.—*Results of soil sampling and irrigation data, alfalfa plot, horticultural farm, State College, N. Mex., season 1936*

Dates of sampling	Average moisture content of soil, percent							Dates of irrigation	Interval between irrigation, days	Dates of cutting
	First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot			
										May 15
June 17	24.45	19.36	20.33	10.27	7.56	3.13	3.46	June 5		
June 25	21.10	11.30	14.13	4.79	4.31	3.01	3.43	June 26	21	June 23
June 30	23.26	20.31	21.24	13.78	4.73	3.36	3.62			
July 9	18.32	13.01	16.68	10.15	7.13	2.21	2.83	July 10	14	
July 14	21.93	17.94	12.79	7.55	5.97	2.43	3.33			
July 23	9.28	8.84	11.29	7.13	5.79	2.50	2.47	July 25	15	
July 30	21.25	15.59	12.42	10.08	8.39	2.67	4.27			
Aug. 5	Sampling lost							Aug. 6	15	Aug. 3
Aug. 11	23.82	21.18	14.63	7.81	6.77	2.93	3.14			
Aug. 20	13.71	12.88	16.11	6.81	7.27	2.54	2.81	Aug. 21	15	
Aug. 25	23.04	19.14	17.95	10.21	7.57	3.30	3.72			
Sept. 9	12.28	11.95	13.84	7.35	5.01	2.52	3.09	Sept. 13	23	Sept. 15
Sept. 16	22.04	16.95	12.93	6.98	7.06	2.75	3.54			
Oct. 2	21.61	19.58	16.59	6.73	6.04	2.88	3.59	Oct. 3	20	
Oct. 7	23.50	21.67	21.63	10.21	7.70	3.54	3.61			
Oct. 21	13.06	14.81	21.84	9.20	6.59	3.80	3.73	Nov. 4	32	Nov. 5

TABLE 112.—*Quantities of water used in intervals between irrigations, alfalfa plot, horticultural farm, State College, N. Mex., season 1936*

Interval	Number of days	Soil moisture loss (acre-inches per acre)										
		First 6 inches	Second 6 inches	Second foot	Third foot	Fourth foot	Fifth foot	Sixth foot	Rain in inches	Total	Between irrigations	Per 30 days
June 17 to June 25	8	1.05	0.65	0.90	0.34	0.32	0.02	0.01	0.07	3.26	3.56	12.22
June 30 to July 9	9	.40	.59	.66	.60	.28	.13	−.04	.98	3.60	5.60	12.00
July 14 to July 23	9	1.02	.74	.22	.07	.03	−.03	−.03	0	2.02	3.37	6.74
Aug. 11 to Aug. 20	9	.01	.67	−.21	.16	−.08	.08	.07	.15	.85	1.42	2.83
Aug. 25 to Sept. 9	15	.87	.57	.60	.47	.44	.16	.12	1.03	4.26	6.53	5.52
Sept. 16 to Oct. 2	16	.04	−.21	−.29	.02	.13	−.03	−.01	2.08	1.68	2.10	3.15
Oct. 7 to Oct. 21	14	.84	.55	.03	.16	−.15	−.05	−.02	0	1.36	3.11	2.92

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period October 21 to November 4 was estimated as 1.45 inches. On this basis the total consumptive use for the period April 27 to November 4 is estimated to have been 22½ acre-inches per acre.

Horticultural farm, alfalfa plot.—This plot was located in an alfalfa field on the horticultural farm. The soil is a Gila silt loam with sand at the lower depths. The average apparent specific gravity and moisture equivalent determinations are shown in tables 102 and 103. Samples were collected from six locations in the field plot. The alfalfa had been planted in 1935, and there was a good stand. The results of the soil moisture studies are summarized in tables 111 and 112. Because some of the early and midsummer soil samples were not taken before irrigation the records are not complete. However the results show monthly use of

FIGURE 93.—Cotton growing in tanks at State College.

water by alfalfa in the plot ranged from 12.22 in... in June to 2.92 inches in October. It is estimated that the use from May 1 to November would not exce... acre-inches per acre.

Cotton and Alfalfa Tank Experiments

In the latter part of May 1936, four tanks were installed at State College to determine the evapo-transpiration of cotton and alfalfa. Two tanks were used for each crop. The tanks were of the double type similar to those used in the Middle Valley (p. 371), but were not as deep (3). The inner tank, 23⅟₆ inches in diameter by 42 inches deep, was suspended in a water-tight outer tank (approximately 25½ inches in diameter by 48 inches deep) by means of a heavy angle-iron rim around the top. The inner tank had a removable bottom and was filled with soil by being driven down into the ground, so cutting out a core of the undisturbed soil. Soil was removed from around the tank as the shell was driven, and when the tank was filled nearly to the top, the removable bottom plate was replaced and bolted on the tank, which was then hoisted by means of a large tripod and chain block. The outer tank was set in place and the inner tank, full of soil, was lowered into it. Numerous holes in the sides and bottom of the inner tank allowed water to move freely to or from the soil.

In operation, water was added in the annular ... between the tanks until the soil was completely ... rated and water stood in both tanks at a zero point (p. 348). The excess water was then pumped out and measured. At the next irrigation the quantity of water necessary to bring the water level again to the zero point was measured. The difference between the quantity removed the previous time and that added gave the amount that had been used by evaporation and transpiration.

Cotton.—Two tanks were placed in the cotton field 9W plot, where soil moisture studies previously described were made (p. 390). The water level in the outer tank was kept below the soil column in the inner tank, so that no water would be supplied by capillary action. It was intended to have two plants in each tank, but one plant was destroyed in the west tank early in the season. The plants were smaller than the adjacent plants in the field. Use of water by the cotton tanks during the period June 6 to November 7, 1936, is shown in table 113.

For the west tank with one plant the use amounted to 25.96 inches, and for the east tank, with two plants, 32.22 inches; the average, 29.09 inches. By comparison with the use determined by the soil moisture work, it is estimated that the tanks would have lost 2.5 inches from May 1 to June 5, making the total season...

TABLE 113.—*Consumptive use of water for cotton tanks, State College, N. Mex., 1936*

Period	Number of days	Consumptive use, acre-inches per acre (inches) [1]				Precipitation, inches
		Inches		Average		
		West tank	East tank	Period	Per 30 days	
June 6 to July 5	19	3.12	5.94	4.53	7.15	0.14
July 5 to Aug. 8	34	8.61	8.26	8.44	7.45	1.58
Aug. 8 to Sept. 5	28	6.53	6.63	6.58	7.05	1.33
Sept. 5 to Nov. 7	63	7.60	11.39	9.54	4.54	2.49
Total	144	25.96	32.22	29.09	....	5.54

[1] Including precipitation.

including rain, 31.6 inches.[19] Yields of seed and cotton were 88.4 grams from 11 bolls for the east tank and 87.3 grams from 13 bolls for the west tank. Dry weights for the cotton stalks cut flush with the ground were 190 grams for the east tank and 99 grams for the west tank.

Alfalfa.—Two tanks were set near the center of the horticultural farm alfalfa field. The results indicated an excessive use of water and seem unreasonable. Thus, they are not included herein as they do not represent Valley conditions and would be misleading. However, they indicate that the maximum annual use of water by alfalfa with high water table may exceed 6 acre-feet per acre.

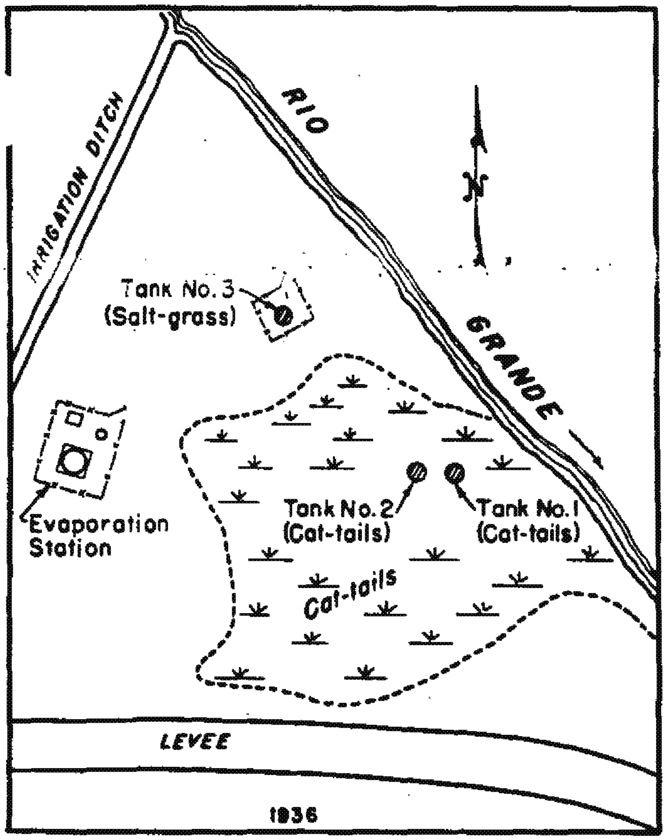

FIGURE 94.—Plan of Mesilla Dam station.

Native Vegetation and Evaporation Experiments

In some sections of the Lower Valley, growths of natural vegetation such as willows, salt cedar, cottonwoods, tules (cattails) and salt grass use considerable water. Perhaps the heaviest evapo-transpiration loss per unit area within the Valley occurs through the vigorous growths of cottonwood, tules, and willows along the river channels. No experiments prior to the 1936 group had been made to determine use of water by native vegetation in Lower Valley, such as those in the Middle Valley and San Luis Valley. However, records of evaporation from a standard Weather Bureau pan have been kept by the agricultural experiment station at State College for many years (table 118), and these records are of value in estimating past and future use of water if correlated with evapo-transpiration losses (3).

Early in May 1936, the Bureau of Agricultural Engineering established an evapo-transpiration and evaporation station at Mesilla Dam, about 5 miles southwest of State College, on a site made available by the Bureau of Reclamation.[20] The site was on low ground on the west bank of the Rio Grande, approximately 100 yards above the dam, in an area of tules (cattails) and salt grass. The exposure was open in all directions except to the west, where the mesa rises abruptly about 15 feet some 50 yards from the station. To the south were a few scattered trees, while the river bordered the northeast side. A sketch of the station site is shown as figure 94.

The two cattail tanks (nos. 1 and 2) were located in a tule swamp and completely surrounded by natural growth. Both tanks were 2 feet in diameter and 3 feet

FIGURE 95.—Mesilla Dam evaporation and transpiration station, Mesilla Valley.

[19] See p. 389 for consumptive use determined by soil moisture studies.

[20] Through the courtesy of L. R. Flock, superintendent, Rio Grande Project

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deep. The tanks were partly filled with sand before blocks of healthy broad-leaf cattails (*Typha latifolia* L.) were transplanted into them with as little shock to the plants as possible. The water level was maintained in the tanks above the surface of the soil. Each tank contained about 42 stalks of cattails. Both tanks developed a vigorous growth but the plants in tank no. 1 grew the larger.

Tank no. 3, containing salt grass, was installed in a nearby plot of salt grass where the ground water was close to the surface. The tank had a diameter and a depth of 3 feet. It was partly filled with sand before the salt grass (*Distichlis stricta* Hydb.) sod was transplanted. A Mariotte control provided an aut... supply of water to tank no. 3, keeping the wate... at a fairly constant depth of 14 inches below the surface of the soil. A thick growth of grass developed, covering the surface and attaining a height of 7 to 10 inches by midsummer.

A standard Weather Bureau evaporation pan and 8-inch rain gage were installed at the station. A thermograph, located at the station for a portion of the summer, did not function properly. Temperature records are therefore not available.

Table 114 shows weekly evapo-transpiration losses from cattail and salt grass tanks and evaporation records. A summary of monthly results at Mesilla Dam station for the 6-month period, June to December 1936, together with evaporation and meteorological data at State College station are shown in table 115.

TABLE 114.—*Weekly consumptive use of water, evaporation, and precipitation at Mesilla Dam station, Mesilla Valley, N. Mex., season of 1936*

Week ending	Consumptive use of water (inches)			Evaporation, inches (Weather Bureau pan)	Precipitation (inches)
	Tank no. 1, cattails in water	Tank no. 2, cattails in water	Tank no. 3, salt grass		
May 11				2.28	0
May 18				2.46	0
May 25				2.25	.07
June 1				2.30	.23
June 8	6.37			3.00	0
June 15	5.64			3.33	.15
June 22	6.35			3.80	0
June 29	5.82			3.06	.03
July 6	5.83			2.77	0
July 13	4.04			2.73	1.09
July 20	4.63		1.83	2.28	0
July 27	4.73	2.83	2.09	2.49	0
August 3	3.67	2.38	1.73	1.86	.16
August 10	4.29	2.87	2.09	2.14	.02
August 17	4.51	3.46	1.58	2.10	0
August 24	2.90	2.47	1.37	1.79	.31
August 31	3.57	2.40	2.12	1.84	.35
September 7	2.98	2.42	1.65	1.85	.05
September 14	2.58	2.32	1.54	1.70	.70
September 21	2.44	2.15	1.53	1.73	.97
September 28	1.71	1.38	1.17	1.04	0
October 5	1.35	1.20	1.07	1.25	0
October 12	1.27	1.17	1.11	1.33	0
October 19	.72	.68	.89	1.07	0
October 26	.66	.63	.67	.95	.35
November 2	.56	.48	.47	1.01	0
November 9	.81	.60	.33	1.12	0
November 16	.52	.45	[illegible]	.31	0
November 23	.50	.31	[1] .25	.31	.24
November 30	.72	.47	[1] .28	.35	.78
December 7 [2]	.47	.45	.40	.46	.54
December 14	.32	.30	.08	.38	0
December 21	.46	.32	.04	.60	0
December 28	.35	.31	.17	.43	.20

[1] Estimated.
[2] Observations in December made with the cooperation of L. R. Fiock and A. S. Curry.

Evaporation From Free Water Surfaces [21]

The processes of evaporation and transpiration are similar in that each is influenced by climatic conditions. Hence the relation between consumptive use of water by vegetation and evaporation from water surfaces is too apparent to be overlooked in any discussion of water requirements. In the Rio Grande Basin ... El Paso both evapo-transpiration and evapo... become progressively smaller as elevation increases and the growing season shortens.

Long Period Records [22]

The Weather Bureau has maintained standard evaporation stations at Santa Fe, Elephant Butte Dam, and State College for many years. Results of observa-

[21] Discussion of results was prepared principally by A. A. Young, associate irrigation engineer, Division of Irrigation, Bureau of Agricultural Engineering.
[22] Through the courtesy of E. L. Hardy, meteorologist in charge, U. S. Weather Bureau, New Mexico section.

TABLE 115.—*Summary of consumptive use of water by native vegetation, evaporation, and meteorological data in Mesilla Valley, N. Mex. July to December 1936*

Month	Consumptive use, Mesilla Dam (inches)			Evaporation, inches (Weather Bureau pan)		Meteorological data, State College station [1]					
						Temperature (° F.)			Wind movement		Average relative humidity (percent)
	Tank no. 1, cattails in water	Tank no. 2, cattails in water	Tank no. 3, salt grass	Mesilla Dam	State College	Mean maximum	Mean minimum	Mean	Total miles	Average m. p. h.	
July	19.62	[2] 14.90	[2] 9.20	10.53	12.60	93	66	80	2,105	2.83	47
August	16.10	12.26	7.90	9.04	10.43	91	63	77	2,169	2.91	54
September	9.87	8.49	6.11	6.56	7.29	82	58	70	1,601	1.96	64
October	4.40	4.02	4.12	4.37	5.63	74	43	58	1,447	1.94	69
November	2.58	1.98	1.21	3.04	3.65	61	32	46	1,392	1.93	59
December	1.69	1.47	.75	1.99	2.86	57	28	42	1,214	1.63	69
Total	54.26	34.12	29.29	36.53	42.16						

[1] State College station is 5 miles northeast of Mesilla Dam station.
[2] Estimated from evaporation record.

tions at Santa Fe (elevation 7,013 feet) are shown in table 116. This station was discontinued in 1933. Records at Elephant Butte Dam (elevation approximately 4,500 feet) collected in cooperation with the Bureau of Reclamation from January 1917 to December 1936, are given in table 117. Observations shown in table 118 for State College (elevation 3,863 feet), from January 1919 to December 1936, were made cooperatively with New Mexico Agricultural Experiment Station.

TABLE 116.—*Evaporation in inches, Weather Bureau pan, Santa Fe, N. Mex., January 1917 to December 1933, inclusive*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1917	3.138	2.884	5.883	7.216	7.642	11.890	9.955	9.038	6.786	5.937	3.355	2.391	75.815
1918	1.083	2.305	3.809	6.129	9.775	10.240	9.294	8.172	6.685	4.295	1.958	1.466	65.211
1919	1.587	1.023	2.699	5.496	8.289	9.381	6.810	7.467	5.434	3.837	2.803	1.571	56.397
1920	1.592	2.101	3.911	5.556	8.515	9.040	8.608	7.505	6.527	4.645	2.012	1.708	61.720
1921	1.381	2.324	4.532	6.439	8.879	8.683	8.129	6.636	6.913	4.930	3.256	1.478	63.580
1922	1.418	2.158	3.600	5.766	10.185	10.454	10.259	8.923	7.120	5.182	1.856	1.263	68.186
1923	1.807	.959	3.441	6.279	8.579	10.603	8.753	6.711	4.770	3.815	1.970	1.061	58.748
1924	.925	2.240	2.962	5.639	8.346	11.989	8.811	9.277	7.756	6.147	3.298	1.201	68.591
1925	1.537	2.280	5.075	8.216	9.007	10.286	9.533	7.470	6.751	4.473	2.026	.773	67.420
1926	.834	3.008	3.941	4.756	5.923	8.784	9.180	9.443	6.708	4.828	2.929	1.022	61.356
1927	1.715	2.098	4.029	6.698	12.244	9.312	9.206	8.094	5.463	5.286	2.873	1.084	68.202
1928	1.451	1.928	4.314	6.021	6.842	11.214	10.008	7.550	7.512	4.580	1.594	1.665	64.679
1929	1.259	1.947	3.733	7.049	9.666	11.852	8.411	6.865	6.620	4.511	1.893	1.407	65.213
1930	1.402	2.710	3.605	7.279	8.587	10.745	8.187	7.220	6.862	4.281	1.928	1.200	64.006
1931	1.232	2.464	3.731	5.502	8.629	10.780	8.992	7.429	5.534	4.510	2.174	1.822	62.749
1932	1.831	2.555	3.441	7.068	8.808	9.995	9.151	5.591	4.689	2.443	[1] 2.080	[1] 2.080	59.722
1933	[1] 1.350	[1] 2.360	4.355	[1] 6.470	7.658	8.360	8.888	7.648	6.393	3.907	[1] 1.130	[1] 1.130	59.649
Average	1.502	2.197	3.927	6.328	8.681	10.269	8.957	7.706	6.384	4.565	2.802	1.431	64.191
	[illegible]	2.2	3.[illegible]	5.65	5.15	10.19	6.24	5.97	6.39	4.41	4.43	2.[illegible]	[illegible]

[1] Estimated.

TABLE 117.—*Evaporation in inches, Weather Bureau pan, Elephant Butte Dam, N. Mex., January 1917 to December 1936, inclusive*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1917	2.143	4.135	9.642	12.923	13.498	15.289	13.247	11.908	9.003	8.918	5.122	3.962	109.892
1918	3.179	5.645	8.214	11.321	15.714	14.250	13.544	11.604	10.170	6.721	3.686	.994	105.042
1919	1.402	3.459	7.203	9.193	12.665	12.677	11.145	11.129	7.878	7.817	3.976	2.734	91.278
[illegible]	1.920	3.912	8.369	10.473	14.165	12.474	13.506	10.661	9.955	8.631	3.656	3.467	101.188
[illegible]	3.556	4.876	8.156	10.982	14.265	13.069	10.242	9.870	9.745	9.408	5.336	3.678	103.183
[illegible]	3.669	5.537	8.059	11.194	14.338	14.086	13.851	12.191	8.969	7.631	3.799	2.749	106.073
[illegible]	3.851	3.214	6.764	11.097	14.490	17.063	12.327	9.097	7.830	7.445	2.765	3.835	99.878
[illegible]4	2.548	3.882	7.644	8.755	11.569	14.966	10.737	11.395	10.568	8.650	5.044	2.784	98.512
1925	2.437	4.656	8.237	11.077	11.743	15.883	11.960	10.795	9.288	6.813	4.148	2.509	99.046
1926	1.734	4.901	5.295	6.992	9.829	13.163	12.016	11.005	7.269	5.933	4.152	1.958	84.247
1927	3.090	4.758	7.846	10.220	14.833	13.421	12.375	8.983	7.611	6.610	4.743	2.422	98.912
1928	2.797	2.801	7.707	9.098	9.814	14.483	12.101	9.624	8.316	5.866	2.752	2.184	87.641
1929	3.447	4.192	7.307	11.126	12.009	14.197	9.928	7.981	7.488	4.535	2.506	2.312	87.028
1930	2.515	4.369	6.229	9.750	11.713	12.009	9.580	9.100	8.093	6.366	3.051	1.783	84.558
1931	1.725	[illegible]251	[illegible]747	[illegible]712	10.338	11.360	10.419	[illegible]326	[illegible]539	5.395	[illegible]480	[illegible]285	[illegible]077
1932	2.242	4.378	[illegible]197	[illegible]306	[illegible]305	11.357	[illegible]720	[illegible]990	[illegible]370	4.715	[illegible]639	[illegible]228	[illegible]2.947
1933	2.337	3.179	7.219	3.287	11.768	9.932	13.105	11.174	9.892	6.647	4.508	3.841	91.889
1934	3.286	5.228	8.574	11.274	14.783	17.480	16.690	14.085	11.298	8.288	4.937	2.698	118.621
1935	3.224	4.175	9.199	12.304	12.576	16.805	15.967	10.850	8.049	8.502	4.855	2.404	108.910
1936	2.988	5.652	9.110	12.095	14.068	17.409	14.496	14.215	9.656	8.014	4.645	3.598	115.946
Average	2.704	4.278	7.686	10.224	12.769	14.786	12.348	10.644	8.774	7.170	4.040	2.706	97.423

TABLE 118.—*Evaporation in inches, Weather Bureau pan, State College, N. Mex., January 1919 to December 1936, inclusive*

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual
1919	2.652	4.187	7.751	8.910	12.251	13.502	12.892	11.477	7.474	5.531	3.895	2.664	94.186
1920	2.225	4.054	7.465	10.395	11.983	11.618	12.899	9.885	8.945	6.103	3.009	3.130	91.721
1921	3.797	4.584	8.597	10.232	11.638	13.353	10.535	9.596	7.843	6.352	4.379	3.228	93.134
1922	3.201	5.838	8.243	10.107	12.688	13.615	13.237	11.022	8.061	5.717	3.480	2.715	98.014
1923	2.374	2.934	6.863	9.561	12.359	11.275	11.300	8.946	7.094	6.179	3.003	1.852	84.750
1924	2.945	4.391	7.090	8.146	10.105	12.086	9.066	9.722	8.934	7.082	4.183	2.436	86.166
1925	2.734	5.343	8.077	9.888	8.691	10.238	9.139	8.351	6.805	4.990	3.496	2.387	78.639
1926	1.914	4.647	5.151	7.394	9.038	10.556	10.126	9.296	7.239	4.590	3.627	2.086	75.566
1927	3.216	4.424	7.349	9.378	11.638	10.276	10.294	7.886	6.840	5.802	4.378	2.173	83.452
1928	2.027	4.148	8.185	9.075	9.525	11.780	10.823	7.801	6.924	5.218	2.671	2.777	81.934
1929	3.210	4.314	7.109	8.877	10.410	11.604	9.134	7.749	7.052	5.008	2.594	3.580	79.601
1930	2.749	4.740	6.420	8.541	10.864	11.890	9.896	9.050	7.760	5.931	3.744	3.172	83.766
1931	2.586	2.902	7.150	7.728	10.841	11.921	10.247	8.487	7.484	6.883	3.557	2.345	82.721
1932	2.993	3.990	7.631	11.204	13.364	14.218	13.403	12.257	9.420	5.663	4.179	2.499	100.830
1933	2.747	4.158	9.413	10.280	14.152	13.394	13.542	11.077	9.787	6.202	4.139	3.543	101.324
1934	3.222	4.989	7.755	11.117	12.927	14.538	14.945	13.097	10.479	7.211	4.681	2.825	107.786
1935	3.454	3.934	8.413	11.807	11.863	15.097	15.374	12.019	7.426	7.184	4.411	3.622	103.206
1936	3.588	5.262	9.066	10.553	13.808	15.333	12.605	10.429	7.293	5.633	3.653	3.556	99.561
Average	2.985	4.386	7.647	9.644	11.525	12.455	11.635	9.807	7.937	5.960	3.725	2.814	90.410

1936 Records

During the season of 1936 the Bureau of Agricultural Engineering installed standard Weather Bureau pans at the San Luis Lakes, Parma, and West stations in San Luis Valley (pp. 361 and 362); at El Vado Dam, Isleta, and Socorro in the Middle Valley (pp. 375 and 376); and at Mesilla Dam (p. 393) in the Lower Valley, to correlate evapo-transpiration losses in wet areas with evaporation from free water surfaces. Weekly and monthly evaporation at various places in each of the three valleys are summarized in tables 119 and 120.

For further comparison, monthly evaporation at Parma, Isleta, Socorro, and Mesilla Dam has been computed as a percentage of the loss at State College for the season of 1936 and presented by months in table 121. At State College and at Mesilla Dam evaporation records were obtained ~~from the~~ middle of May to the end of December, but at other stations, because of freezing weather, records for the colder months are incomplete. The State College station is used as the basis of comparison because records are available for a 17-year period. A peculiar feature is that evaporation at Mesilla Dam is but 85 percent of that indicated by the State College record, despite the fact that the two locations are only 5 miles apart. This difference can be accounted for principally by the fact that State College station is located higher in the Valley in a bare field away from vegetation and fully exposed, while the Mesilla Dam station was located on the river bank in a wet area in the midst of vegetation. The stations at Parma, Isleta, Socorro, and Mesilla Dam were located in river areas having comparable environments.

TABLE 119.—*Weekly evaporation in inches, Weather Bureau pans, Upper Rio Grande Basin, season of 1936*

Week ending—	San Luis Valley, Colo.			Middle Rio Grande Valley, N. Mex.				Lower Valley, N. Mex.		
	San Luis Lakes	Parma	West	Therma [1]	El Vado Dam	Isleta	Socorro	Elephant Butte Dam	State College	Mesilla Dam
May 18	----	----	----	1.58	----	----	----	3.20	3.10	2.46
May 25	2.66	1.89	----	2.12	----	2.55	----	3.29	2.83	2.25
June 1	2.23	1.47	----	1.68	----	2.31	----	3.13	3.03	2.30
June 8	2.06	1.93	----	2.21	----	2.81	2.93	4.39	3.22	3.00
June 15	2.76	1.93	----	2.57	----	2.44	2.82	3.82	3.68	3.33
June 22	2.87	1.93	----	2.98	2.62	2.77	2.89	4.29	3.90	3.80
June 29	2.67	2.06	2.31	1.86	2.00	2.44	2.80	3.74	3.27	3.05
July 6	2.17	1.66	2.49	1.71	2.30	2.38	2.54	3.64	3.57	2.77
July 13	1.81	1.47	2.24	1.67	2.09	2.34	2.69	3.29	2.92	2.73
July 20	2.19	1.59	2.36	1.84	1.99	2.31	2.09	3.24	2.95	[illegible]
July 27	2.27	1.47	2.13	1.98	1.99	2.22	2.31	3.37	2.64	[illegible]
August 3	1.84	1.11	1.49	1.45	1.81	2.10	2.26	2.63	2.52	[illegible]
August 10	1.94	1.30	.84	1.48	1.43	2.03	2.30	3.56	2.86	[illegible]
August 17	1.98	[2] 1.96	1.89	1.76	2.07	2.34	2.44	3.93	2.57	[illegible]
August 24	1.42	[2] 1.40	1.44	1.60	1.54	1.81	2.09	2.95	1.85	1.79
August 31	1.89	1.39	1.56	1.34	1.96	2.06	1.69	2.60	1.80	1.84
September 7	1.88	1.70	1.82	1.79	1.61	1.81	1.84	2.92	2.09	1.85
September 14	1.64	1.15	1.46	1.45	1.18	1.63	1.67	2.47	1.89	1.70
September 21	1.44	.91	1.23	.97	1.41	1.50	1.45	2.02	1.74	1.73
September 28	.86	.71	.55	.88	1.58	1.60	1.08	1.84	1.25	1.04
October 5	.92	.77	.91	1.14	1.20	1.06	1.14	2.05	1.47	1.25
October 12	1.02	[2] .85	.38	.90	.95	1.16	1.17	2.09	1.53	1.03
October 19	1.33	[2] .58	----	.76	1.19	1.09	1.27	2.09	1.32	1.07
October 26	.51	.56	----	.83	.42	.87	.70	1.27	.93	.95
November 2	.61	.64	----	.60	.52	.88	1.00	1.74	1.24	1.01
November 9	.46	.42	----	----	----	.78	.89	1.36	.95	1.12
November 16	.28	.38	----	----	----	.74	.83	1.10	.97	.81
November 23	.43	.33	----	----	----	.94	.85	.90	.74	.61
November 30	.28	[2] .30	----	----	----	.24	.43	.48	.46	.35
December 7	----	----	----	----	----	----	----	.89	.57	.46
December 14	----	----	----	----	----	----	----	.66	.56	.38
December 21	----	----	----	----	----	----	----	.60	.51	.60
December 28	----	----	----	----	----	----	----	.84	.58	.43

[1] Therma station is just east of divide between Rio Grande drainage and Canadian River drainage. Elevation 8,210 feet.
[2] Partly estimated.

TABLE 120.—*Monthly evaporation in inches, Weather Bureau pans, Upper Rio Grande Basin, season of 1936*

Month	San Luis Valley, Colo.			Middle Rio Grande Valley, N. Mex.				Lower Valley, N. Mex.		
	San Luis Lakes	Parma	West	Therma	El Vado Dam	Isleta	Socorro	Elephant Butte Dam	State College	Mesilla Dam
May	[1] 4.89	[1] 3.36	----	[1] 3.80	----	[1] 4.86	----	[1] 6.42	[2] 8.96	[2] 6.41
June	10.84	8.26	----	10.32	[3] 9.93	11.07	12.17	17.41	15.33	14.11
July	9.33	6.82	9.47	7.96	8.90	10.05	10.60	14.50	12.80	10.53
August	7.76	[3] 6.61	6.67	6.79	7.89	9.05	9.27	14.22	10.43	9.04
September	5.60	4.70	5.35	5.27	6.18	6.62	6.19	9.66	7.29	6.56
October	2.74	[3] 3.22	----	3.85	3.64	4.60	4.64	8.01	5.63	5.37
November	1.56	[3] 1.49	----	----	----	2.95	3.20	4.64	3.65	3.04
December	----	----	----	----	----	----	----	3.60	2.56	1.99

[1] May 18 to June 1.
[2] May 11 to June 1.
[3] Partly estimated.

TABLE 121.—*Comparative monthly evaporation, Weather Bureau pans, Upper Rio Grande Basin, season of 1936*

Month	Evaporation at State College (inches)	Ratio of evaporation at other stations to evaporation at State College (percent)			
		Parma, Colo.	Isleta, N. Mex.	Socorro, N. Mex.	Mesilla Dam, N. Mex.
May	[1] 8.96	[2] 57.3	[2] 82.9	----------	[1] 71.5
June	15.33	53.9	72.2	79.4	92.0
July	12.60	51.7	79.8	84.1	83.6
August	10.43	63.4	86.8	88.9	86.7
September	7.29	64.5	90.8	84.9	90.0
October	5.63	57.2	81.7	82.4	95.4
November	3.65	40.8	80.8	87.7	83.3
December	2.56	----------	----------	----------	77.7
Average	8.31	55.5	82.1	84.6	85.0

[1] May 11 to June 1.
[2] May 18 to June 1.

The evaporation at Isleta, Socorro, and Mesilla Dam differs but little, although the locations are many miles apart. The close agreement of these three records and their departure from the records for State College indicate that evaporation at State College is not representative of evaporation in wet areas of the Valley below Albuquerque.

The evaporation in San Luis Valley (elevation 7,000 to 8,000 feet) is considerably less than that in the Middle Valley (elevation 4,890 feet) and Lower Valley (elevation 3,863 feet). The reason for this striking difference is apparent in part when the lengths of grow- asons and differences in elevations and tempera- are considered. In San Luis Valley the average frost-free period is 108 days, in Middle Valley at Albuquerque 196 days, at State College a minimum of 200 days.

Pan Coefficient

Previous to 1915, little attempt had been made to determine the relationship existing between pans of different sizes and large water surfaces. In 1915 the Bureau of Agricultural Engineering established a laboratory at Denver (57) for this purpose, and has carried on research studies of evaporation (3) (54) at various places since that time.

Coefficients for reducing standard Weather Bureau pan records vary, but for the Upper Rio Grande Basin it is recommended that 0.70 be used.

Relation of Evaporation to Consumptive Use

Meteorological conditions influencing evaporation from water surfaces likewise affect transpiration from vegetation and evaporation from soils. Both evaporation and transpiration freely respond to temperature, wind movement, and humidity, so that evaporation from water may, under certain conditions, be used as an index of transpiration or soil evaporation losses.

Observed evaporation data may be used as a means of estimating evapotranspiration by water-loving vegetation when the relation of the two values is known for a particular area. This relation, during the growing season, is not constant, yet it provides a means of making approximate comparisons of consumptive use, not only from year to year, but between adjacent localities.

As an example of the adaptability of the evaporation pan in estimating consumptive use, the results of an investigation by the Bureau of Agricultural Engineering at Victorville, Calif., may be cited (3). For tules growing in a large tank within the confines of a swamp area the percentage of consumptive use with reference to evaporation from a nearby exposed Weather Bureau pan was 95 percent.[23] Neglecting such factors as variety, density of growth, and seasonal variations in evaporation and transpiration, this percentage was applied to evaporation records in other portions of the same general locality. It is probable, however, that this relation is not a constant but varies from year to year and for different geographical areas. The fact that both evaporation and consumptive use do so vary lends support to this conclusion. The climate at Victorville is very similar to that of the Middle Rio Grande Valley.

Accepting such a ratio for the Victorville area, it is reasonable to suppose that it might be applied also to evaporation records from Weather Bureau pans in other areas in order to estimate consumptive use by tules growing in swamps in those areas. It should be emphasized, however, that comparisons of transpiration and evaporation should be extended only to those areas where vegetation is subject to similar seasonal climatic conditions.

[23] The percentage varied from month to month, increasing during the summer and becoming smaller in the cooler months, but 95 percent was the average obtained from a 2-year record.

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PART III

SECTION 5.—CANAL DIVERSIONS IN RELATION TO MAPPED AREAS

Because of differences in environment, diversions by a particular canal may or may not be closely related to consumptive use in an area served by a canal in another part of the Valley. Therefore the ditches and canals are grouped below in accordance with their environmental characteristics.

1. *Mountain valley ditches.*—These divert relatively large amounts of water, and irrigate lands immediately between them and the streams from which they divert. With the usual open mountain soils, narrow valleys, and steep lateral gradients, the amounts diverted are relatively unimportant because it can be assumed that nearly all water in excess of the actual consumptive use will return to the stream and become available for rediversion and use lower in the stream system. The total area under such irrigation is small compared with that under large canal systems in the main valleys.

2. *Valley floor canal systems.*—These are of three types: (a) Those irrigating lands topographically and geologically so situated that water diverted but not consumptively used can be assumed to return, in variable proportions, to the parent stream, or to the main river—a process which has been greatly aided by extensive drainage systems. This type comprises most of the land in San Luis Valley south of the closed area and all the land along the Rio Grande in New Mexico and Texas. (b) Those diverting water from the main Rio Grande or its tributaries, but conveying this water into the closed area in San Luis Valley from which there is no return flow to the main river system, except a small amount coming back through Rio Grande drain. (c) Those diverting waters from streams flowing into the closed area and irrigating lands subject to gravity return of waters to the sump of the closed area. There is, however, little or no surface return to the sump from the north and west except in very wet years. The measured diversions in this closed area are further complicated by the existence of several thousand artesian wells, most of which run wild the year round. Similar wells exist in the San Luis Valley areas southwest of the Rio Grande, outside of the closed area. (Pl. 11.)

San Luis Valley

In the closed area, the west and east sides have different characteristics.

Two streams, La Garita and Carnero Creeks, come out from the hills on the west and irrigate a small area above the Rio Grande Canal, bringing water from the Rio Grande. Return waters probably mingle with those from Saguache Creek and from Rio Grande Canal lands and contribute to the drainage waters of the Rio Grande Drainage Canal.

Saguache Creek heads in the Continental Divide and irrigates a large area of land around Saguache. In some years excess flow penetrates to the lower end of Saguache Creek where it joins San Luis Creek. The latter heads in Poncha Pass and one tributary of importance, Kerber Creek, enters from the west near Villa Grove.

From the eastern side a large number of small streams head in the Sangre de Cristo Mountains, debouch onto the Valley from steep mountain gorges and are used to irrigate lands along the fringe of the hills between San Luis Creek and the mountains. Hay and pasture are the principal crops. For many of the streams in this group the discharge records were first obtained in 1936. There has been much speculation in the past as to yield of these streams. The record of one year, of course, is not sufficient to use as the basis of determining the mean annual run-off from this part of the watershed. Furthermore, in years of plenty, the hay crop will be heavier and the consumptive use greater than in years of shortage. Under these conditions it is difficult to offer a set figure as the consumptive requirements. Return flow from this extensive area must all accumulate in the large sump of the closed area located in its southerly portion.

Much of the grasslands and low brush lands lying along lower San Luis Creek, while not irrigated in the usual sense of the word, undoubtedly thrive on a high water table, making pasture for livestock. This would be impaired by the lowering of the water table that would result from the development of a sump drain to convey the water from the sump to the Rio Grande.

The following paragraphs discuss specific conditions affecting use of water under specified systems operating in San Luis Valley.

Rio Grande Above South Fork

The irrigated lands largely comprise hay meadows, with heavy gross diversions and liberal return flow to the parent stream. The largest of these areas lies in the site of the proposed Vega-Sylvestre Reservoir. Construction of this storage would effect a change from hay use to the evaporation from a reservoir surface.

South Fork to Del Norte

Diversions from both banks of Rio Grande and from bank of South Fork irrigate crops more diversified than those in the higher valleys above Wagon Wheel Gap. Conditions are conducive to return flow to Rio Grande proper for reuse below. The Del Norte Irrigation District owns the Continental Reservoir of some 32,000 acre-feet capacity.

Near Del Norte

Within a few miles of this town are the headings of Rio Grande and Farmers' Union Canals and Prairie Ditch, which convey water across the gentle ridge into the closed basin to the north and east.

Monte Vista Canal

The Monte Vista Canal diverts from the south bank and irrigates lands that may yield return flow to the stream system. This is the high line canal from the Rio Grande. It skirts along the hillside apron to the south until it meets the Terrace Canal flowing northward from Alamosa Creek. The lands commanded lie mostly in a block operated under a water users' association. The Bowen-Carmel area, used for intensive study of water use, is under the lower part of this canal. The tabulation in the Geological Survey's report of its 1936 investigation gives the discharge at three locations h are depicted on the San Luis Valley map. (Pl.

The Survey's figures show the depletion in canal water from point to point. This canal is largely dependent on its diverted flow as there is very little irrigated land above it to contribute return water until it crosses Gunbarrel Road. (See U. S. Geological Survey record of current flow.) Likewise, being without storage it must rely on its quota in terms of priority and decreed right. Thus the 1936 record may be considered as applying to a conservative diversion duty, there being no sources of supply other than the river diversions except small contributions from Gato (Cat) Creek in times of flood and certain waters from the Terrace Irrigation District along the lower end of the Monte Vista Canal. Some water enters the Bowen-Carmel area from Alamosa Creek through the Scandinavian Ditch. However, there are also some irrigation wells in this area and their number was being materially increased during the summer of 1936 until unusual summer rains assured the potato crop without need of further well drilling. Tail water from this canal finds its way into the irrigated lands served by waters from Alamosa Creek.

Empire (Commonwealth) Canal

heading for this canal lies about 2 miles east of e Vista. It is the largest canal in the southwest area and third only in the Valley. It lies in Rio Grande, Alamosa, and Conejos Counties. Because the lands are below the area irrigated from Monte Vista and smaller systems, it is reasonable to assume that there is a material but unknown inflow as surface tail-water and as underground seepage from those systems. Thus the diversions probably fall short of the actual water inflow to the lands commanded by the main canal.

Likewise the use of water on the lands irrigated by the Empire Canal in Conejos County, isolated from the main block under this canal, is complicated by surface and underflow from Alamosa and La Jara Creeks and Conejos River. Thus it appears that the diversion figures can hardly be assumed as indicative of the gross duty under this canal.

Conejos River, Alamosa and La Jara Creeks and Tributaries

No large systems divert from these streams, but there is a storage reservoir on La Jara Creek and Terrace Irrigation District stores flood waters on Alamosa Creek. Otherwise the lands are irrigated by direct diversion of their quotas, based on their priorities and decreed rights. The many small diversions can hardly be used as criteria of diversion duties as they command relatively small areas in themselves and their waters are more or less mixed. (One exception to this is the area under Cove Lake Reservoir, a small system storing flood waters from Conejos and San Antonio Rivers.)

Closed Area Diversions

Most of the irrigated land north of the Rio Grande between Del Norte and Alamosa and north of the railroad from Alamosa to the county line between Alamosa and Costilla Counties, absorbs large amounts of water from the Rio Grande as well as all its own local drainage. The bulk of the irrigated land lies under the Rio Grande, Farmers' Union, San Luis Valley canals and Prairie ditch. Geological Survey tables show that the diversions from the Rio Grande Canal exceed the combined diversions from the Monte Vista and Empire canals, and the other diversions by main canals into the closed area are of the same order of magnitude as the largest diversions to the south.

Rio Grande Canal

This old and capacious main canal has a relatively early priority for 383 second-feet with total decreed rights of some 1,700 second-feet, thus exceeding the combined rights of the six largest canals diverting to the south of the Rio Grande and from which a reasonable return flow can be expected. It is also supplied by the Santa Maria Reservoir of some 48,000 acre-feet capacity. Therefore this canal is well equipped to divert relatively large flows completely away from all connection with the main basin of the river. A relatively small final return of this water is effected by the Rio Grande drain. So far as concerns the basin below the diversion dam of the Rio Grande Canal, the diverted water becomes the net water depletion, except for the minor influence of the Rio Grande drain. Such a return would be further increased by the construction of the sump drain.

For much of its course this is the high line canal on the north side of the river and is not subject to contribution of tail and return water. However, many artesian wells augment the river water, and the lands toward the northern end of the canal may receive flood and other contributions of flow from Carnero and La Garita Creeks. This canal extends to a junction with the channel of Saguache Creek. However, but little flow gets beyond township 42 north.

Farmers' Union Canal

This system diverts water a few miles below Del Norte from the north bank of Rio Grande. All its water is used in the closed area, after being conveyed across lands irrigated from the Rio Grande Canal. There is no return flow to the main river system. The diversions from Rio Grande are augmented by tail waters from higher canals. There are also many artesian wells. Most of the lands irrigated lie in the San Luis Valley Irrigation District.

This system shares water from Rio Grande Reservoir, of 51,000 acre-feet capacity, as well as having a right to direct flow from the river. Tail water and developed drainage can be used in the district served by the Farmers' Union Canal or pass out into the sump around San Luis Lakes.

San Luis Valley Canal

This canal diverts from the north bank of the Rio Grand due east of Monte Vista. It irrigates some land subject to return flow into the Rio Grande but the bulk of its water is conveyed directly into the closed basin and irrigates three scattered blocks of land comprising the Mosca Irrigation District. Between the two southerly blocks is a stretch of land covered by the Prairie ditch and between the two northerly blocks lies a belt in the San Luis Valley Irrigation District under the Farmers' Union canal. Like the latter system, San Luis Valley canal commands an area subject to inflow from adjoining irrigated lands while its tail and drainage water pass out into the sump area around San Luis Lakes. The irrigation district owns Beaver Creek Reservoir, of 4,434 acre-feet capacity.

Prairie Ditch

This canal diverts from the north bank of the Rio Grande a few miles east of Del Norte and flows due east out of the area draining back into the Rio Grande, thence through land watered from laterals of the Farmers' Union canal into a tract entirely surrounded by other irrigated areas, except for a short length on the east end which is open to the sump mentioned above. It can divert some additional water from Rio Grande drain.

Middle Valley

With Indian and Spanish-American peoples irrigating the same lands for many centuries, water usages have become so firmly established as not readily to yield to modern conceptions of water requirements. Fortunately, in New Mexico much of this type of irrigation is confined to the several mountain valleys on Rio Chama, Rio Puerco, and the Jemez River entering Rio Grande from the west and those on small tributaries entering from the east as far south as Santa Fe Creek. In general, usage in these valleys causes heavy return flow. Likewise, below the Puerco on the west are several small tributaries with narrow ribbons of irrigated land along their banks. These are important locally but not in relation to the total irrigated areas in the basin. None of the diversions from the streams mentioned could be classed as for a major canal. The only areas above San Marcial that could be so considered are in the Middle Rio Grande Conservancy District. (Pls. 13-16, incl.)

Irrigation in the basin of Rio Grande in New Mexico can be considered in two major groups, the mountain valleys above mentioned and two main blocks along the Rio Grande above and below Elephant Butte Reservoir.

The following major diversions above San Marcial serve the various divisions of Middle Rio Grande Conservancy District.

Cochiti Division

Canals for this division divert water from Rio Grande below White Rock Canyon, Sili Main Canal from the right bank just about the diversion dam, and Cochiti East Side Main from the left side. Nearly all the irrigated land lies in Indian pueblo grants. Inflow measured to the canals is sometimes augmented by heavy run-off from the side channels that flow intermittently during the summer months. Excess irrigation and groundwaters are accumulated by riverside drains on the east side and to a slight extent on the west side. This developed water is returned to the river and is available for diversion below. The diversion figure for this division may be taken as gross diversions attributable to Indian irrigation methods, modified by the inflow and drainage-canal influence mentioned above.

The lower end of the Cochiti Division is just above Angostura Dam, which diverts water for the Albuquer- · Division.

..aquerque Division

From Angostura Dam to Albuquerque most of the irrigated land lies on the east side of the river under Albuquerque Main Canal. To cover a minor area west of the river a short distance above Albuquerque, the Corrales Main conveys water across Rio Grande. Opposite Albuquerque the river makes an abrupt bend to the east, below which land on the west side is served by the Arenal Canal, diverting at Atrisco Heading, due west of Albuquerque. On the east side the irrigated area gradually pinches out as Isleta Dam is approached. Above Albuquerque the Albuquerque Main has tapered down until secondary canals only reach the city, but the Riverside drain has acquired Main canal proportions and its water is used to irrigate the land on the east side between Albuquerque and Isleta Dam by means of the Barr Canal, diverting from the drain opposite the south end of the city. Diversions to this division are not complicated by much inflow from side drainage. Riverside drains take away excess water from both sides of the river. Since these parallel the river closely, being separated from it by levees only, the measurements of outflow from them of doubtful significance, as it would appear that lifference in stage of water in the river and in the ...inage canals would have great influence on the amount of water carried by the drains and make its source uncertain. For the east side lands below Albuquerque the upper drainage water has likewise become the main source of supply. However, with these conditions understood, the diversions listed for the Albuquerque Main Canal can be taken as indicative of gross or diversion duty for lands that, to a marked degree, have been farmed under irrigation for many years. The lower end of Albuquerque Division is at Isleta Dam, the upper end of the Belen Division.

Belen Division

Just below the Albuquerque Division is the Belen Division. This heads near the Indian village of Isleta, founding of which antedated the conquest. Isleta Diversion Dam serves the Peralta Main (a new canal) and the Chical lateral, Chical acequia, and Cacique acequia, combined diversions from which must be considered as irrigating the land on the east side down to a point opposite Belen. This area is discussed elsewhere (page 365), being one of the intensive-study plats of the Bureau of Agricultural Engineering. (Fig. 83.). On the west side of the river a large new canal, the Belen high commands much old land and also an extensive area immediately below it which is not yet under cultivation. As in Albuquerque Division, the surplus waters are fed by interior drains into riverside drains. On the east side, Tome drain returns its water to Rio Grande through the Riverside drain, at a point approximately opposite Belen. On the upper west side the Belen riverside drain empties into the river at the Santa Fe Railroad bridge near Belen. Immediately below this bridge, on the west side, the Sabinal drain begins and finally discharges into Rio Grande just after crossing the line between Valencia and Socorro Counties.

The irrigated land on the east side, after pinching out opposite Belen, expands again during the last 3 or 4 miles in Valencia County. This area is served by the San Juan Canal, the head structure of which diverts without a river weir.

Throughout the portion of this division in Socorro County the irrigated land is protected by riverside drains, which collect water and return it to the river without any diversions being made from them for irrigation purposes.

Diversion and consumptive use of water in this division can best be studied from the records for the intensive area, referred to elsewhere. The other parts of the division are badly complicated by the many breaks in the system.

For the last 6 or 7 miles the bottom land is gradually pinched in by low mesas, finally opening up at San Acacia Dam, the upper end of Socorro Division.

Socorro Division

This is the lowest block in the Middle Rio Grande Conservancy District. The irrigated land lies wholly on the west side and is served at the upper end by water diverted at San Acacia Dam by the Socorro Main Canal North. This canal gradually approaches the Rio Grande and merges into the Socorro main center which skirts the Riverside drain, protecting the upper end of this division. It finally unites with this drain just before a secondary structure diverts water both from the tail end of the Socorro main and from the drain canal into the Socorro Main Canal South, which tails out into the Bosque del Apache Grant, lying just below the Middle Rio Grande Conservancy District. Since it has only one diversion from the river and is little affected by side drainage except that resulting from summer cloudbursts, this division probably provides good indications of diversion duty under New Mexico conditions.

Bosque del Apache Grant and River Bottom Land to San Marcial

Immediately below the Rio Grande Conservancy District lies the Bosque del Apache Grant, ending some

5 or 6 miles upstream from the old town of San Marcial. There is now practically no irrigation on the Bosque Grant, although a few irrigation ditches are shown and water rights for these are claimed. The bottom land is under consideration for use as a duck preserve by the United States Biological Survey. There now are no important diversions in this area. Since the construction of Elephant Butte Reservoir, upper end of which lies just below San Marcial, the river bed has been built up considerably by silt deposits. The flood of 1927 practically ruined the town of San Marcial and it has been largely abandoned.

Lower Valley

Palomas Valley

There are no diversions of moment in this area which extends from near Hot Springs, a few miles below Elephant Butte Dam, to the Percha Dam of the Rio Grande project. This valley will be largely submerged by the Caballo Reservoir, now under construction. The high water line for this reservoir is shown on the map of Palomas Valley (pl. 18).

Rincon Valley

This valley lies between the Percha Diversion Dam and the beginning of Selden Canyon. It is the upper end of the irrigated land under the Rio Grande project. This valley is a succession of narrow ribbons of irrigated land, alternating on the two sides of the river. Starting from the right bank, the Arrey Canal diverts water released from storage in Elephant Butte Reservoir and irrigates a strip 3 or 4 miles long, then is flumed across Rio Grande to merge into the Garfield Canal. From this main, land is irrigated on the left side of the river until Hatch Siphon is reached, where the canal is carried under the Rio Grande to emerge on the right bank again as the Hatch Canal. Water from this canal irrigates all the land on the right bank until the bottom land pinches out on that side. Part way down, the main canal has again been siphoned under the Rio Grande and comes out as the Rincon Canal, extending to the upper end of Selden Canyon.

The amount of the diversions to the main canal at Percha Dam should be fairly indicative of the gross diversion duty for this valley. The canal diversions can be adjusted by taking into consideration water returned to the river and drainage recovery at the outlets of Garfield, Hatch, and Rincon drains. None of the drainage water is taken into the main canal directly.

Mesilla Valley

This valley comprises two parts of the Rio Grande project, the Leasburg Division and the Mesilla Division. They have independent diversions and are discussed below as though they were two major systems.

The first-named extends from Leasburg Diversion Dam at the lower end of Selden Canyon, to cover the land above the two main canals diverting at Mesilla Dam, on either side of the river.

Leasburg Main Canal, covering the Leasburg Divi. diverts and remains on the east side of the Rio Grande, with water for certain lands on the west side of the river being flumed across the Rio Grande in the Picacho Canal a few miles northwest of Las Cruces. The diversions into the Leasburg Canal are indicative of the diversion duty for the Leasburg Division, if the amounts of water tailing into the Mesilla Division east side main can be determined. For certain studies, these amounts can be modified by the water returned to the river or discharged into the east side canal of the Mesilla Division and drainage recovery measured at the outlets of Selden, Picacho, and a portion of the Mesilla and Del Rio drains.

It is difficult, if not impossible, entirely to segregate the water at the disposal of the Mesilla Division from that for the Leasburg Division above it. In addition to water diverted and measured at the two canals on right and left ends of the Mesilla Diversion Dam, tail water enters the east side main from various laterals of the Leasburg Division. The west side system is not complicated in this way; its one diversion (the west side main) irrigates all the land on the west side of the Rio Grande from the Mesilla Dam to the place where the irrigated land pinches out on the right bank well as a small area on the left bank between Canut Tex., and El Paso by means of a siphon under the river below Canutillo. All the Mesilla Valley in Texas, together with its irrigation and drainage system, are included in the area organized as the El Paso County Water Improvement District No. 1, described below.

As shown on the map, the irrigation system in this valley is completely intermingled with the drainage system. In the Mesilla division there are several returns to the river and drainage recovery is measured at the outlets of Del Rio, La Mesa, East, and Montoya drains.

Mesilla Valley was the southerly intensive area tract studied by the Bureau of Agricultural Engineering for determination of consumptive use, and the details of the relationship of diversions to the irrigated lands are set out elsewhere in this report (pp. 379 to 381 and fig. 89).

El Paso Valley

This Valley comprises the portion of the Rio Grande project below El Paso. Above the pass this district is watered by Mesilla Division canals. Two major canals lead out from the Mexican Dam near the upper end of the city, Acequia Madre diverting on the Mexican side and the Franklin Canal serving the upper end of El P

Valley in Texas. A few miles below El Paso the Franklin Canal is reinforced with water diverted from the river at riverside heading, in the newly canalized river.

The distance from El Paso to Fort Quitman, Tex., by the meanders of the old river was some 155 miles. The flat gradient and the lack of flushing floods (attributable to storage in Elephant Butte Reservoir) built up the river bed with sand and silt, and caused an excessive flow of sand into the canals and obstructed the outlets of the drains by raising the river plane onto which they must discharge.

Rectification of the Rio Grande, now in progress, will shorten the distance to Fort Quitman to 88 miles. This will increase the gradient and thus the velocity of the river's flow. The first year in which the upper end of the straightened river was operative (1935) a local flood, originating below Elephant Butte Dam, caused an excessive flow in the lower river and gave a good start to the desired recession of grade in the sandy bed. Rectification of the river is expected to have great influence in the future on the outlets of the drains, as well as several other beneficial effects. The new international boundary follows the thread of the rectified channel. However, rectification of the channel is not complete and part of its projected course has not been definitely decided upon.

As the Valley approaches San Elizario Island, the and main takes off from Franklin Canal and crosses the old channel of Rio Grande in island flume. This canal quickly tapers down to a small lateral and water for "the island" is reinforced by two diversions in the old channel at Hansen heading. After the island canal leaves the Franklin main, the latter rapidly tapers as the irrigated land temporarily pinches out on the left bank at Fabens. Just below this point the Tornillo heading serves Tornillo Canal for the rest of the way on the left bank of Rio Grande to the lower end of the Rio Grande project.

All the diversions to these canals are measured and are indicative of the gross diversion duty in this valley. In order to ascertain the net use, it is necessary to deduct the waters returned to the Rio Grande and the drainage recovery from the main drains to which the irrigated lands contribute. Coming down the river from El Paso, the return water carried in the drainage canals is measured above Fabens. The situation may be made more complex by the influence of the irrigated land in Mexico.

The drainage water developed on "the island" is siphoned across the old river channel just above the location of the rectified channel as now (1936) projected but not yet constructed. This water joins the Tornillo drain, which later meets the Alamo Alto drain, located along the hillside edge of the valley from Fabens downstream. The combined drainage water return to Rio Grande at the lower end of the project is measured just above the outlet. Likewise, tail water at the lower end of Tornillo Canal is measured as it is delivered to the Hudspeth Canal or is discharged into the Rio Grande below the drainage outlet just mentioned. These three points of measurement are a short distance above the line between El Paso and Hudspeth Counties.

Hudspeth County Conservation and Reclamation District No. 1

The drain and tail water from the El Paso Valley system becomes the irrigation supply for most of the remaining valley lands above Fort Quitman. The Hudspeth County Main Canal extends throughout the length of the district system, and its diversion, as measured at the heading just above the line between El Paso and Hudspeth Counties, plus the Alamo Canal, may be taken as the gross diversion duty for this area. The Alamo diverts directly from the Rio Grande about 3 miles west of Fort Hancock. The Hudspeth County district is developing a drainage system.

Summation of Diversions and Areas

The irrigated areas for the entire Rio Grande Basin above Fort Quitman, with the adjacent areas in native vegetation, are summed up in table 122 by main canals or systems. In appropriate columns, the total amounts of water diverted are shown. The latter are compiled from measurements and computations by the Geological Survey, Division of Surface Waters, which are being published in Water Supply Paper No. 839. These amounts may be taken as generally indicative of the diversion or gross duty of water for the areas tabulated, but for many areas in San Luis Valley, intensive investigation would disclose necessary modification of the diversion figures because some of water comes to them at unknown times, and in unknown quantities, from adjoining canals or areas of land. Likewise, some of the water listed as diverted occasionally is not used on the land usually served, but may be used on areas other than those listed as subject to the diversion. Ascertainment of the inflow to many areas is likewise made complex, in undetermined amounts, by the unrestricted flow of several thousand artesian wells. However, the tabulated data furnish criteria applicable to other areas where the detailed diversions were not measured or where, because of the mixing of waters or areas, the irrigated lands could not be segregated in accordance with their appurtenant canals and ditches.

The aggregate areas for the canals in San Luis Valley, shown in table 122, are less than half the Valley's totals, but for New Mexico and Texas the systems are such that the areas listed cover most of the acreage on the main stem of the Rio Grande. In the Middle section the aggregate interior valley acreage is greater than that on the main stem, but complete records do not exist for the corresponding diversions.

TABLE 122.—*Canal diversions in Upper Rio Grande Basin, by major canal systems, 1936*

Major unit	Area mapped in 1936 (acres)	Area served in 1936 (acres)				1936 Canal diversions (acre-feet)			
		Irrigated	Temporarily out of cropping	Towns, etc.	Total	Total	Per acre irrigated	Per acre given water	Per acre of mapped area
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Colorado									
San Luis Valley: [1]									
Rio Grande Canal	142, 196	111, 844	3, 661	11	115, 516	182, 600	1.63	1.56	1.28
Farmers' Union Canal	94, 280	46, 267	2, 775	397	49, 439	45, 710	.99	.92	.48
Prairie Ditch	29, 471	12, 043	976	125	13, 144	10, 900	.91	.83	.37
San Luis Valley Canal	40, 524	8, 234	1, 159	14	9, 407	21, 790	2.64	2.31	.54
Monte Vista Canal	33, 512	24, 382	371	19	24, 772	37, 520	1.54	1.51	1.12
Empire Canal	64, 341	20, 794	925	12	21, 731	57, 370	2.76	2.64	.89
New Mexico									
Middle Rio Grande Conservancy District	187, 682	59, 159	2, 980	6, 165	68, 304	619, 989	10.48	9.06	3.30
Cochiti Division	19, 439	5, 208	169	401	5, 778	75, 058	14.41	12.99	3.86
Albuquerque Division [2]	56, 127	22, 819	913	4, 241	27, 973	234, 892	10.29	8.40	4.04
Belen Division	77, 044	23, 895	1, 165	530	25, 590	241, 993	10.13	9.46	3.14
Socorro Division [3]	33, 072	7, 237	733	993	8, 963	68, 046	9.40	7.59	2.06
New Mexico and Texas									
Rio Grande Project	211, 170	154, 552	11, 204	2, 191	167, 947	968, 218	6.26	5.77	4.59
Rincon Valley	27, 914	15, 206	2, 129	110	17, 445	78, 410	5.16	4.49	2.81
Mesilla Valley	110, 418	82, 923	5, 569	1, 523	90, 015	417, 058	5.03	4.63	3.78
El Paso Valley [4]	72, 838	56, 423	3, 506	558	60, 487	472, 750	8.38	7.82	6.49
Hudspeth County Conservation and Reclamation District No. 1	21, 595	13, 579	1, 817	....	15, 396	77, 154	5.68	5.01	3.57

[1] Areas here shown for San Luis Valley are those served by the principal canals diverting from the main stem of Rio Grande.
[2] Including Albuquerque.
[3] Including Socorro.
[4] Excluding El Paso.

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PART III

SECTION 6.—THE VEGETATIVE COVER SURVEY

The original plan for mapping the vegetative cover was much simpler than the plan approved in conference at Santa Fe. Essentially, however, the initial purpose—that of ascertaining the areas of irrigated land and other land representative of vegetation "using appreciable quantities of water"—was retained. It was finally decided to account, on a map, for 100 percent of the area between the lower fringes of the hills and bluffs along the main stem of Rio Grande through New Mexico and Texas, and to set such limits for the work in Colorado as would keep the map from including areas which could not meet the stipulation of "using appreciable quantities of water."

One object of this part of the Rio Grande study was to furnish an estimate of the total quantity of water completely removed from various parts of the stream basin during the season of 1936. This involved the determination of the consumptive use of the irrigated lands and towns and cities actually given water; the consumptive use of "native vegetation" not given water but taking it by virtue of access to water table; and the evaporation from river and .e surfaces and moist beds. It was assumed that roadways and railroad grades use little more than nominal quantities of water; a small allowance was set up for such lands to represent evaporation losses.

The following list of classes of vegetative and other areas was adopted for mapping:

1. Cotton.
2. Alfalfa and clover hay.
3. Native grass cut for hay.
4. Irrigated pasture.
5. Early season annual crops (field peas, small grains).
6. Late season annual crops (corn, sorghums, silage fodder, sugar beets, potatoes).
7. Miscellaneous (orchard, vineyard, tobacco, beans, onions, melons, chili peppers, garden truck).
8. Land normally irrigated but temporarily out in 1936 for various reasons.
9. Areas in native vegetation using water in appreciable quantities and river bed or open water.
   - *a.* Open grass.
   - *b.* Brush.
   - *c.* Trees—Bosque.
   - *d.* Open pooled water.
   - *e.* River and canal surfaces and exposed beds.
10. Double cropped areas.
11. Town and village areas.
12. Areas once irrigated but not now (largely San Luis Valley).
13. Bare land.

he original plan to ascertain the irrigable land, .n inside and outside the constructed irrigation systems, was revised to cover only those areas within the reach of the systems already constructed and planned minor additions and extensions to them. This curtailment was decided upon in recognition of the fact that there could not be any great quantity of water available for extensions of the irrigation system; that the arable land available would be many times greater than any gross area that could be regarded as feasibly irrigable. Thus the final stipulation holding the mapping of arable lands to the valley floor along Rio Grande in New Mexico and Texas, recognized that reclamation and irrigation of the dense growth of native vegetation areas merely changed the use of water from its natural nonbeneficial use in large quantities to a beneficial use by irrigated crops in appreciably smaller net quantities. In other words, such extension of the irrigated areas as would displace water-loving native vegetation would not increase the use of water by those areas but would, in fact, decrease it and make more water available for general purposes.

After the field mapping there remained the essential task of converting pictured type classifications into acreage and separating that acreage into summations, by counties, major canal systems, major tributary areas, and many other requested segregations. These summations appear in the tabulations which conclude this discussion.

Deductions for Roads, Railroads, Canals, etc.

It was appreciated that all of any irrigated land area is not actually in crop although to all appearances wholly comprised of irrigated lands, so 3 percent was deducted from the gross areas of irrigated lands mapped.

Irrigated land is pictured on the maps as nearly as possible to true scale but was tabulated on the basis of net acreage or 97 percent of the gross area mapped, the other 3 percent being computed by slide rule to the nearest number divisible by 6 and restored to the tabulation as follows: One-sixth to water areas; one-half to bare land areas, and one-third to grass areas. The water areas restoration was assumed to represent the water surfaces of irrigation and drainage channels; the bare land restoration as the traveled strip of roads, railroad roadbed, farm lanes, and other bare areas that consume small amounts of water, such as evaporation after precipitation in areas of high water table. The grass areas restoration accounted for the wide strips of grass along all roads, between the traveled strip and the fences confining the fields; and the similar strips along railroad tracks, between the roadbed and the right-of-way fence; also, the banks and berms of irrigation and drainage channels.

Native vegetation was also tabulated for net areas, 1 percent being deducted for bare land in terms of roads, lanes, and railroad beds and restored to the total in the bare land classification. No deduction nor restoration was made for the water areas. The deductions and restorations were uniformly applied throughout the basin, in accordance with instructions decided upon at the June conference in Santa Fe.

Practical Operation of The Mapping Plan

Original plans to conduct the mapping simultaneously in the three principal sections of the basin had to be changed because of the lateness of the season in Colorado and New Mexico as compared with that below El Paso. Indeed, although the mappers did not start their work in Hudspeth and El Paso Counties until May 4, their progress was impeded for a time by the fact that, even then, many of the crops had not been planted. However, the predominance of cotton and alfalfa in that part of the Valley, and other favorable circumstances, permitted a concentration of the mapping force in the area. Later, as conditions in the upper divisions permitted, the original mapping force was distributed and increased. Thus it was possible to start the mapping of the New Mexico areas above San Marcial early in June, and the San Luis area a few days later.

The following paragraphs describe the problems encountered by the mappers and how they were met.

In general, "land formerly irrigated" was found mostly in San Luis Valley, at least in terms of areas that may now be identified. In the Middle Valley, areas waterlogged and not farmed under irrigation for long years are being reclaimed by the Middle Rio Grande Conservancy District. In the map of Bosque Del Apache Grant, south of the district, irrigation canals are shown, but although some land was formerly irrigated it cannot now be definitely located, hence is not so tabulated.

It was found for the San Luis Valley that the lands formerly irrigated could nearly always be definitely located from aerial survey pictures,[1] as these areas are now covered with a more luxurious growth of grass and brush than that of other areas. Thus mappers may have designated an area as "9b and 12" which meant that the land was now in brush but evidence showed it to have been irrigated at some time in the past. In the tabulation such acreage appears in column headed "9b—brush"; also in the column "land formerly irrigated", but it is not taken into the summation twice. In other words, all the acreage listed as formerly irrigated stands by itself and, having appeared once, is not again added into the totals.

Within any irrigation system not all the irrigable land is farmed under irrigation in any one year. (Careful determinations in California disclosed that such land "temporarily out of cropping" for various reasons runs about 20 percent for highly developed diversified farming regions, and 25 percent for less intensively farmed regions.) This land is not to be confused with "land formerly irrigated." Apparently it was irrigated last year or the year before, and presumably will be irrigated next year or within a few years. It is now lying fallow, is involved in litigation, or is not farmed because the owner simply chooses otherwise for the current year. Such land is usually entitled to irrigation water and must be considered in allocating an "irrigation requirement" to the major area in which it appears.

San Luis Valley

The work in San Luis Valley was handled by three 2-man parties, all under the direction of the Bureau of Agricultural Engineering.

At first much difficulty was encountered in adapting and applying the predetermined classification to the crops and conditions existing in the Valley. While the classification served admirably in the area below the Elephant Butte Dam under the high type farming methods practiced there, it could not be followed so easily when applied to the type of agriculture prevalent throughout much of the San Luis Valley. It was difficult at times to tell whether water was artificially applied or not applied at all but merely expected to be present because of the practice of subirrigation on surrounding plots.

Since there is no cotton in San Luis Valley, the no. 1 classification was not used. Generally no trouble was experienced in identifying alfalfa and clover (no. 2). "Native grasses cut for hay" (no. 3) were, in the early part of the season, often indistinguishable from the next class, no. 4 (irrigated pasture), and sometimes were confused with no. 9 a (open grass). Both the former classes were flooded with water and usually appeared identical. In fact, in many cases, after the hay was cut, stock was turned in and pastured the remainder of the season. The presence of stack butts or hay corrals usually indicated hay, while grazing stock indicated

[1] Most of the mapping was done on prints, adjusted properly to scale, resulting from various recent aerial surveys. These were available at the start of the work for the area below Elephant Butte Dam and for much of the area in New Mexico above the dam. They did not become available for the Colorado areas until the work had made considerable progress on other bases, but were then used either as original bases or by having transferred to them the results shown on the other field sheets. (See page 409.)

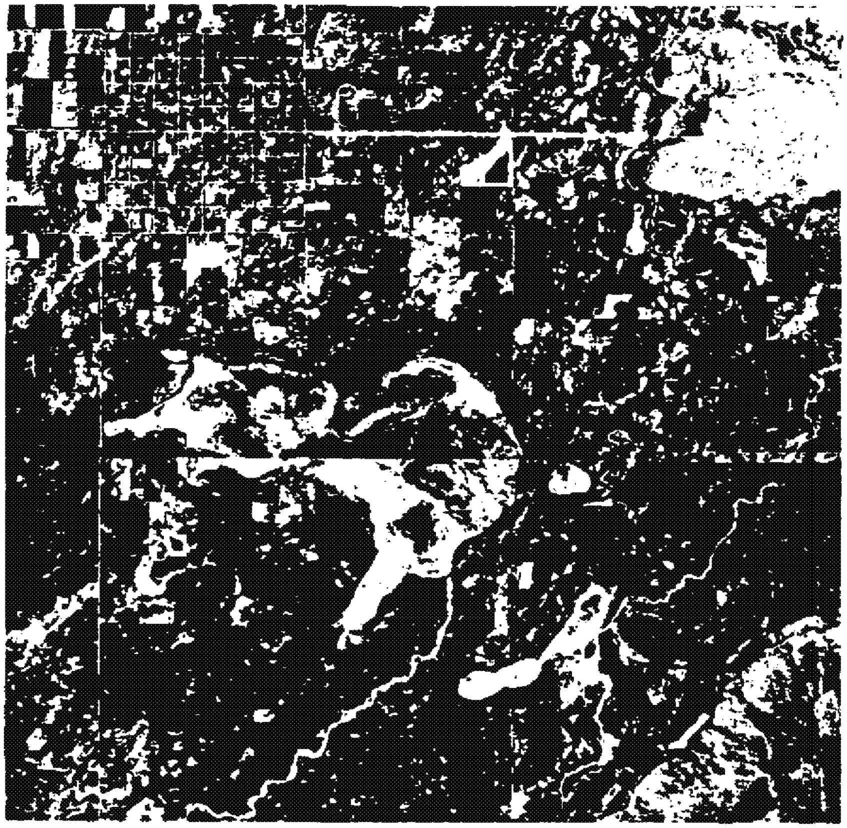

FIGURE 96.—Aerial view of area southeast of Manassa, Colo. (in upper left-hand corner), illustrating complexities of mapping problems. For instance, extreme upper left shows nicely squared fields, easily mapped, with offset roads clearly pictured. East of Manassa is the race track, then an alfalfa field being cut (white border around a dark patch). South and east of Manassa the fields blend into large areas of stream-bottom lands without means of identifying portions of sections. In the center is noted a large hill without appreciable vegetation cover.

FIGURE 97.—Aerial view of old Mexican irrigated area in San Luis Valley, Colo., near town of San Luis, illustrating ribbonlike shapes of the small farms. The dark areas near the bottom are clouds between the airplane and the ground, showing the need for clear days in aerial photography. Note that canals are dark and sandy roads are white. Extremely dark fields are usually alfalfa. Two streams enter the picture from the right. The irrigated lands, commanded by high-line canals, are definitely located on such a picture. The large canals with arrows divert in two directions and irrigate distant lands not shown on this view.

pasture. Where neither was in evidence the decision as to proper classification rested on the judgment of the mapper and was based on the roughness of the land, the apparent practice in the neighborhood, and occasionally only on guess. When the season was farther advanced, the presence of workmen in the hay fields and the new stacks removed any doubt. Patches of brush often appeared on high spots in meadow land. If large, they were sketched in and called such, but if small and scattered, they were ignored.

Application of the no. 5 classification (early season annual crops) was complicated by the practice of combining several crops for the purpose of feeding stock. This practice consisted in drilling a mixture of field peas and oats, barley, or other small grain into a field of volunteer or seeded clover. The resulting crop, its various parts distinguishable only on close inspection, often appeared to contain but one of them, and might be often mistaken for a field of either clover or grain. The classification was further complicated by the great mass of sunflowers often found in fields of the Valley. During the course of the summer, this combination might be either pastured or "hogged down" by herds of cattle or sheep, or if not fed thus during the summer, it might be cut with mowing machines and stacked as hay. After consideration as to whether this crop came under the classification of clover (no. 2) or, because of its use, might better be called a late season annual or silage crop (no. 6), it was finally classified as being mostly field peas and grain (no. 5).

Probably the only difficulty experienced with the no. 6, or late season annual group, was during the early part of the season before planting was finished. At that time fields were being plowed and leveled, and sometimes irrigated before being planted, but this procedure usually indicated one of the crops in this group, and the field was classified according to the indication.

The largest part of the no. 7 class was garden truck and garden peas. The latter were usually distinguished from field peas by being cultivated in rows. Occasionally a garden had been harvested before the area was classified, leaving only a patch of sunflowers. It was hard to tell whether it was this year's field or one remaining fallow from the year before. If other indications were not present, it sometimes became necessary to make inquiries. Where these patches had been plowed up and leveled they were sometimes confused with alfalfa, which may be plowed under at any time during the year. These cases were few, however, and if on closer inspection, evidence was not found to show which had been planted, inquiry was made at the farmhouse.

No. 8 (land normally irrigated but temporarily out of cropping in 1936) was occasionally confused with no. 12 (land formerly irrigated but not in recent years). It was often impossible to tell how long the land had been out of cultivation. If it were freshly plowed, or furrows and raw earth were in evidence from the last year's cropping, its classification was easy; but if a thic' growth of weeds covered the area it was not so readil identified. In this case, since the weeds indicated it had not been "out" for more than 2 or 3 years at the most, the benefit of the doubt was given to late cropping and classification no. 8 was applied. The condition of adjoining farm buildings and whether or not they were inhabited also influenced the decision. Because of shortage of water in the Valley, only rarely were any fields found being leached for reduction of alkali.

Very little that could strictly be called open grass (no. 9 a) was found. There was some along stream and overflow channels and between the waterline and brushline around lakes and ponds. Large areas readily identifiable as brush were often found in heavily alkalized areas, but grass and brush were mostly found together and were practically impossible to separate. This was especially true in the sump area, where the entire surface was a series of humps and hollows. Several humps or mounds of wind-drifted sand 15 to 100 feet across and 5 to 15 feet high, covered with greasewood brush, usually surrounded a hollow or depression. In the depression or pot hole a band of grass and a band of mud or alkali flat would encircle a pool of water. The pool might have remained there since the last rain, or it might be fed by a nearby artesian well. It migh also be completely dry, its bottom covered with gras or alkali.

Using aerial photos of the area, the mappers traveled along the numerous trails, identifying their position by the features shown on the map. The pools of water were marked as such if large enough to be identifiable; also the large tracts of grass if extensive enough. The remainder, including all areas too small to be separated and the large areas consisting of a mixture of both brush and grass, was lumped together and called brush and grass.

Trees were definitely identifiable and were so noted when in large enough groups to show on the map.

No double cropped areas were found in the Valley; hence, class 10 was not used. Towns and villages were outlined as closely as possible and classed as no. 11.

Classification no. 12 (land formerly irrigated but not in recent years) gave some trouble, being confused with both classification no. 8 (land temporarily "out") and no. 9 (native vegetation). In many cases, because of the practice of subirrigation, the land possibly had raised crops for many years with no surface irrigation whatever. It had later become seeped and alkalized as a result of irrigation above it, and consequently abandoned, thereupon reverting to brush and grass. Often the reversion was so complete as to defy distinc tion from adjacent areas of virgin soil. In such cases the presence of old irrigation ditches and borders, or the difference in elevation of what might have been the tilled field and the undisturbed border of the field, caused by wind erosion of the plowed part, and other such indications, were taken as evidence of former irrigation. If such evidences were lacking, the word of residents was taken or the condition of the surrounding areas was used as an index.

The question of a limiting line or upper boundary of the mapping often arose. At first it was thought that everything below 8,000 feet elevation would be mapped. It was found, however, that this practice could not always be followed. Rivers and canyons were followed up as far as there was any appreciable amount of crop land. Where the floor of the Valley ended at the foot of the mountain slope, the mapping was carried up to any high-line ditch or to include the flattest part of the land, which might possibly later be placed under irrigation. Where hills rose from the floor of the Valley, crops and abandoned crop lands were mapped as they appeared, native vegetation was mapped on the flatter slopes and the steep slopes and hill tops were marked as high land, above irrigation. On topographic sheets the work was sometimes carried up to a certain contour, but usually the limit lines were sketched in by eye between already established points. In this manner some land was included which was later eliminated in the transposition to the air photographs.

For instance, in an area of native vegetation, the limit on a mountainside was originally established by estimate and a general line was drawn. On the air photographs the changing slope and the condition of the vegetation usually indicated a far more distinct and better located line than the original, and the limit was then so altered as to conform to the air photographs.

On completion of the actual field work, part of the map was on sheets of various kinds, the remainder on the air photographs. The latter portion included large blocks for which the air pictures became available before work was done in the area by other means, the strips originally left along major streams, and scattered patches of several sections each, which had to be left from time to time because they were too difficult to traverse.

While considering means of arranging these various work sheets into a comprehensive map which could be easily handled during the subsequent office work, it was suggested that all the work be transposed to the air photographs, all of which were then available. Such transposition would necessarily have to be made sooner or later as the details in the final report would be based upon the aerial survey which, as had been discovered, occasionally differed somewhat from the original mapping. In the original work it had often been necessary to idealize some fields and lump others together. On the air maps it was generally possible to differentiate the various plots more clearly. It was thought that the work of transposition could therefore be best done by those familiar with the conditions. The results depicted would then be uniform over the entire San Luis Valley, and would compare favorably with those obtained in New Mexico and Texas.

This was decided upon as the best way to complete the work. The small aerial work sheets were pasted together into several large blocks each about 3 feet wide by 4 feet long. By comparison with the original field sheets, each plot was then identified and classified, corrections in size and shape being made where necessary.

Middle Valley

The field mapping of the West Side tributaries (including those south of San Marcial) was done by the Resettlement Administration under the immediate direction of Ralph Charles, land planning specialist, of Albuquerque. The areas along the main stem of the Rio Grande, largely comprising the Middle Rio Grande Conservancy District and most of the East Side tributaries, were covered by the Bureau of Agricultural Engineering's field party. During the final 6 weeks of the field work, a party of five men from the forces of both the Bureau of Agricultural Engineering and Resettlement Administration, covered the remaining areas in Espanola Valley and along the small streams entering the Valley from the east.

Field maps.—Throughout this region the field mapping was done on prints resulting from an aerial photographic survey of the Rio Grande Basin in New Mexico, north of the Thirty-third parallel, for the Soil Conservation Service. The flying for this survey was done by a western corporation during the 1935 season, but most of the fields were easily located on the prints, and identification of the crops according to the 1936 classification plan involved no general difficulty. Without these aerial photographs the field work would have been greatly increased because the farm descriptions do not conform to Federal land survey units. The present farms originally may have comprised large blocks of land, but in willing their property to their descendants, successive owners subdivided the places into as many pieces as there were heirs, each piece being so shaped as to have contact with the irrigation ditch and the road. This process, continued through many decades, resulted in irregularly shaped ribbons of land sometimes as narrow as 5 or 6 feet, but sometimes as long as a mile or even more. Accurate mapping of the crops on such farms was tedious and frequently difficult.

However, boundary lines were clear-cut, as was the case below Elephant Butte Dam. The leader of one

FIGURE 98.—Typical aerial view from the east of irrigated farming section in Middle Rio Grande Conservancy District, N. Mex.

of the parties had started his work in the latter area, and applied the same criteria that had been adopted there.

Scale of maps.—The scale of 2 inches to the mile, decided upon for the drafting of all the maps, was found to be infeasible for field-mapping parts of the Middle Valley, chiefly because of the peculiarity just described. Therefore, where the major areas were badly congested the photostats were made on a scale approximating 4 inches to the mile, or twice the original scale. On this scale a square 40-acre tract is 1 inch on the side; hence it permitted locating and proper classification of fields as small as 1 or 2 acres. The tabulation of areas was based on the field designations, even for very small patches. However, on the map intended for final reproduction, many of the smaller areas could not be marked with a class-symbol and had to be grouped together under a miscellaneous classification. Thus all areas along the tributaries in New Mexico and the main river from Embudo to Belen were field-mapped on the 4-inch scale. The southern portions of the areas along the river were mapped on the 2-inch scale.

Lower Valley

Although the Lower Valley served in a way as a training school for the mapping parties because the program was initiated in this area, the difficulties encountered were fewer than those occurring in the other sections. Favorable weather throughout May and June, coupled with a liberal assortment of good roads and the fact that the automobiles used were in serviceable condition, favored rapid coverage of the country. Equally favorable were the geographic circumstances characterizing a narrow and definitely bounded valley and the fact that clear aerial maps of recent date were available from the beginning of the work. These were in mosaics on the 2-inch to the mile scale except for the section between San Marcial and the thirty-third parallel, for which only contact prints were available. While these latter needed scale-correction before being worked into the finished map, they involved only a small area of agricultural lands, and ir use caused no delay in the field work.

he mosaics were made available by the Interna-tional Boundary Commission; the contact prints by the Soil Conservation Service. Also used in orienting the mapping parties and guiding the office draftsmen were various maps based upon accurate instrumental surveys by the International Boundary Commission and the Bureau of Reclamation. These maps likewise were of great assistance in forwarding all stages of the work.

The mosaics showed the survey course of the river below El Paso projected as well as partly constructed by the International Boundary Commission. As planned, the rectification would affect certain lands in bends of the unrectified channel by transferring some areas formerly in the United States to Mexico, and vice versa. To facilitate its program, the commission had acquired title to such lands, and pending completion of its project, had removed most of them from agricultural use. Such of these areas as were north of the new channel were mapped as in native vegetation or "temporarily out of cropping" according to their more prominent characteristics, if in fact they were either not actually farmed or were incapable of being farmed for various reasons.

The mapping parties were instructed to show on their os all land from the foot of the bluffs north of the to the new channel where the latter actually sted, and to the north bank of the river in those stretches where the projected canalization had not yet been effected. An important exception was made in the case of the "island" section below Ysleta, where a large intensively farmed area of Texas land lies south of the river, although north of the channel existent when the original international boundary was established. Adjustment of the boundary (in terms of the rectified channel) affecting this so-called island has still to be made; the map was therefore carried to the fringe of trees and other native vegetation which marks with approximate clarity the course of the old channel.

Similarly, since the construction of Caballo Reservoir, now under way, had not started when the mapping parties were at work, the area presently to be submerged by its storage was mapped in accordance with the scheme of classification applying to other areas, and so appears on the finished map. (Pl. 18.)

The principal handicap to accurate field work in the Lower Valley was the fact that planting had not been finished when the mapping was started, nor was it entirely finished for several weeks afterward. Similarly, the planted crops on many farms had not yet come up and could not be identified with assurance. further probably affecting the accuracy of the map his area was the uncertainty as to what cropping changes would be made under the operation of the Soil Conservation Act as successor of the Agricultural Adjustment Act. To a considerable degree, therefore, the mapping of this area was unavoidably based upon anticipated rather than realized plantings. Because cotton and alfalfa together represent the greater part of the cropped area, this complication resulted especially in the mapping of larger acreages of cotton and new alfalfa than those later harvested. While the field parties sought to resolve frequent doubts as to the crops by interviewing the farmers operating the areas in question, it was not always possible to do this without delaying the work unjustifiably; reliance was then upon their best judgment as guided by such indications as stalks remaining from the crop last planted or field preparations suggestive of the crops later to be grown.

These were doubtful guides in both El Paso and Mesilla Valleys because they applied to many areas included in the extensive cotton-reduction programs of 1935 and preceding seasons, which actually were not returned to cotton notwithstanding early indications that such return was planned for 1936. (See footnotes and accompanying discussion of table 15, p. 313.) Instead, many such areas are now known to have remained out of production entirely or to have been planted to other crops.

	Total area	Irrigated area	Cotton area	Alfalfa area
Rincon Valley:				
Bureau of Reclamation........acres..	26,621	13,528	5,504	2,800
Bureau of Agricultural Engineering, acres.	27,914	15,206	6,646	3,231
Difference..............acres..	1,293	1,678	1,142	431
Do..............percent..	5	12	21	15
Mesilla Valley, N. Mex.:				
Bureau of Reclamation........acres..	95,297	64,915	39,009	12,678
Bureau of Agricultural Engineering acres..	96,580	72,258	47,505	14,740
Difference..............acres..	1,283	7,343	8,496	2,062
Do..............percent..	1	11	22	16
Mesilla Valley, N. Mex., and Tex.:				
Bureau of Reclamation........acres..	109,123	74,813	45,266	14,822
Bureau of Agricultural Engineering acres..	110,418	82,923	54,513	17,077
Difference..............acres..	1,295	8,110	9,247	2,255
Do..............percent	1	11	20	15
Mesilla Valley, Tex.:				
Bureau of Reclamation........acres..	13,826	9,898	6,257	2,144
Bureau of Agricultural Engineering acres..	13,838	10,665	7,008	2,337
Difference..............acres..	12	767	751	193
Do..............percent..	0	8	12	9
El Paso Valley:				
Bureau of Reclamation........acres..	71,478	50,460	30,575	12,678
Bureau of Agricultural Engineering acres..	72,838	56,423	37,493	14,312
Difference..............acres..	1,360	5,963	6,918	1,634
Do..............percent..	2	12	23	13
Elephant Butte district:				
Bureau of Reclamation........acres..	121,918	78,443	44,513	15,478
Bureau of Agricultural Engineering acres..	124,494	87,464	54,151	17,791
Difference..............acres..	2,576	9,021	9,638	2,493
Do..............percent.	2	11	21	16
El Paso County water improvement district no. 1:				
Bureau of Reclamation........acres..	85,304	60,358	36,832	14,822
Bureau of Agricultural Engineering acres..	86,675	67,088	44,501	16,649
Difference..............acres..	1,371	6,730	7,669	1,827
Do..............Percent..	2	11	21	12
Rio Grande project:				
Bureau of Reclamation........acres..	207,222	138,801	81,345	30,300
Bureau of Agricultural Engineering acres..	211,170	154,552	98,652	34,620
Difference..............acres..	3,948	15,751	17,307	4,320
Do..............percent..	2	11	21	14

Mapped areas and corresponding acreages reported in the 1936 crop census of the Rio Grande project are set out above, without corrective adjustment to account for the complications already described and the equally important handicap to accuracy discussed in succeeding paragraphs of this chapter.

Mapping of the entire area below San Marcial was done by the Bureau of Agricultural Engineering, except for the valleys of the small West Side tributaries in New Mexico, which were mapped by the Resettlement Administration. No such tributary areas required mapping on the other side of the river in either New Mexico or Texas. The mapping included no areas in Mexico.

Results of the Mapping

The results of the mapping are summarized in table 123 from details appearing in tables A, B, and C.

The agreement of the mapped acreages of irrigated crops with other 1936 compilations is reasonably close in the case of the Middle Valley areas. (See p. 309)

The mapped areas for San Luis Valley are substantially less than the corresponding acreages reported by the water commissioners. (See table 1.) In this case the discrepancies appear to bear out the conclusions of previous investigators, that the commissioners' figures are generally too high. (See pp. 291 to 302.)

Partly for the reasons already mentioned on page 411 the irrigated crop acreages mapped for the areas between Elephant Butte Dam and Hudspeth County are in excess of those developed by the 1936 routine crop survey conducted by the management of the Rio Grande project, and are considered too high by the Bureau of Agricultural Engineering. However, as stated on page 406, a deduction of 3 percent was applied uniformly throughout the basin, to convert gross mapped areas of irrigated land, areas temporarily out of cropping, and areas in cities, towns, and villages, into net areas. In the case of the Rio Grande project, which has an excessive number of drains and canals, this deduction should have been increased—perhaps doubled. At the other extreme, the 3 percent deduction was undoubtedly too large for San Luis Valley. It is considered to have been about right for areas along the main stem of Rio Grande in Middle Valley, though too large for the interior valleys.

Since it was the decision of the May conference to apply a percentage deduction uniformly throughout the basin, 3 percent was about as fair a proportion as could have been selected.

For the Lower Valley, while a doubling of the deduction would not account wholly for the discrepancies, consideration of the appropriateness of such an increase and of the complications affecting the field work as set out on page 411, should establish a reasonable degree of harmony between the two compilations. The disagreements are not considered large enough to mak practical differences in determinations of consumptive use requirements for the project, especially since many areas temporarily out of cropping may be expected to return to production eventually if the water supply permits.

Map plates

The final vegetative cover maps in separate accompanying this report comprise plates 10 to 22, inclusive. Originally drawn to a scale of 2 inches to the mile, the printed results, in colors, are on a scale of 1 inch to the mile. They cover all areas showing irrigated land along the main stem of upper Rio Grande. In addition to the usual basic features, these maps show the vegetative cover and the stream- and canal-gaging stations that form important parts of this investigation.

Plate 10 "Mountain Valley of Rio Grande" begins at the upper limit of irrigated land as found in the field mapping and extends nearly to Del Norte. The balance of the area in Colorado is shown on the map of "San Luis Valley" (pl. 11, in two sheets, the "north half" and the "south half"). This plate shows, in green, the detailed location of the intensive study areas indicated for Colorado on figures 75 and 78. South of the canyon section in northern New Mexico all of the "plates" form complete units as known in the region. Española Valley (pl. 12) covers lands largely in three Indian Pueblo grants. The four operative divisions of Middle Rio Grande Conservancy District (Cochiti, Albuquerque, Belen, and Socorro) are covered in plates 13 to 16, inclusive. On the "Belen Division" (pl. 15) is shown in green, the detail of the "Isleta-Belen" intensive-study area indicated on figures 75 and 83. The "Bosque Del Apache Grant" (pl. 17) extends to the lower end of irrigation at the head of Elephant Butte Reservoir. The base maps for plates 14 to 17, inclusive, are repeated (as pls. 6–9) by the Geological Survey in its depiction, in red overprint, of the ground water conditions in the areas covered. Below Elephant Butte Dam, the irrigated land commences in Palomas Valley (pl. 18). The Rio Grande project of the Bureau of Reclamation is covered in three plates (19 to 21, inclusive), showing Rincon, Mesilla, and El Paso Valleys. Mesilla Valley (pl. 20) was used as a whole for the intensive-area study indicated on figures 75 and 89. The final map of "Hudspeth County" (pl. 22) shows but little irrigation not included in the boundaries of Hudspeth County Conservation and Reclamation District No. 1.

TABLE 123.—*Areas of vegetative and other cover in Upper Rio Grande Basin (Summary, tables A, B, C)*

Major unit	Total area mapped	Agricultural and other lands artificially given water				Other water-using areas, nonirrigated			
		Irrigated in 1936	Temporarily out of cropping	Cities, towns, and villages	Total irrigated, "out" and towns	Native vegetation	Water and river bed surfaces	Total nonirrigated	Bare land, roads, rights-of-way, etc.
Total, Upper Rio Grande Basin	2,092,817	923,594	46,319	18,913	988,826	948,171	69,295	1,017,466	86,525
Colorado (total)	1,446,652	600,243	18,979	6,029	625,251	737,199	13,762	750,961	70,440
Closed basin area	733,425	277,922	8,875	1,034	287,831	404,014	4,010	408,024	37,570
Live area	713,227	322,321	10,104	4,995	337,420	333,185	9,752	342,937	32,870
Southwest area as defined in Part I	482,531	270,350	7,228	4,103	281,681	176,191	6,549	182,740	18,110
Southeast area	230,696	51,971	2,876	892	55,739	156,994	3,203	160,197	14,760
New Mexico (total)	537,894	242,684	21,681	12,097	276,462	193,116	53,591	246,707	14,725
Colorado State line to Buckman	127,729	75,173	4,534	3,110	82,817	31,622	10,956	42,578	2,334
Areas on main stem of Rio Grande	12,878	5,891	374	233	6,498	3,651	2,336	5,987	393
West Side tributaries (to and including Rio Chama)	49,011	29,154	1,207	564	30,925	11,645	5,973	17,618	468
East Side tributaries	65,840	40,128	2,953	2,313	45,394	16,326	2,647	18,973	1,473
Buckman to south boundary Middle Rio Grande Conservancy District	221,786	76,690	8,323	7,141	92,154	96,507	25,532	122,039	7,593
Areas on main stem of river (Middle Rio Grande Conservancy District)	187,682	59,159	2,980	6,165	68,304	90,401	21,895	112,296	7,082
West Side tributaries (all below Rio Chama)	34,104	17,531	5,343	976	23,850	6,106	3,637	9,743	511
Bosque del Apache Grant	12,583	....	....	....	....	10,164	1,970	12,134	449
Bosque del Apache Grant to San Marcial	4,811	919	330	....	1,249	2,617	907	3,524	38
San Marcial to Elephant Butte Dam	26,147	....	....	....	....	22,071	3,384	25,455	602
Elephant Butte Dam to Texas State line	144,838	89,902	8,494	1,846	100,242	30,135	10,842	40,977	3,619
Palomas Valley	10,383	830	501	304	1,635	7,435	1,190	8,625	123
Elephant Butte Irrigation District	124,494	87,464	7,362	1,404	96,230	18,604	6,251	24,855	3,409
West Side tributaries	9,961	1,608	631	138	2,377	4,096	3,401	7,497	87
Texas (total)	108,271	80,667	5,659	787	87,113	17,856	1,942	19,798	1,360
El Paso County Water Improvement District No. 1	86,676	67,088	3,842	787	71,717	11,957	1,861	13,818	1,141
Hudspeth County	21,595	13,579	1,817	....	15,396	5,899	81	5,980	219

Measurement and Summation of Areas.

The field mapping resulted in pictured areas, to scale, of 18 classifications of land and water. It remained to convert these pictures to classified acreage, under various summations. The acreage of a single tract of al[illegible], say, was of no interest; the total acreage of alfalfa on a field sheet was desired. The method of measuring areas, in connection with field maps resulting from aerial photographs (p. 409), was fast and accurate and as far as known, unprecedented in such use.

Photostats from the aerial views were made to something approximating exact scale and these used in the field. A field was identified as to location and the crop-class number or color is penciled on the print.

Two methods of acreage determination were used in the Rio Grande work. Both employed sheet celluloid as a medium. For the more complex areas, the boundaries and class numbers of the tract were traced on drafting linen. This linen was then secured by small office staples, between two sheets of celluloid, each 0.0075 inch thick. The whole assembly was then weighed on a precision chain balance. The various areas were then cut out, opposite pieces of celluloid were dropped in numbered compartments, and the intervening piece of linen was saved. The celluloid fragments in each compartment were carefully weighed at one time and the weights were tabulated. From some unmapped part of the celluloid assembly sheet, areas of exactly 1,000 acres or some other known size, were cut [illegible]nd a template. This test block and the remnants [illegible]luloid and linen remaining after the cutting of the areas were also weighed. Obviously the sum of the weights of the classed fragments, test block, and remnants must equal the first weight of the whole assembly. If the variation was greater than one part in 1,000 the work was repeated until the error was found. Thus, the acreage of perhaps 50 tracts of alfalfa was determined at one operation, whereas the use of the planimeter would have permitted only one tract at a time to be measured. The field sheet itself remained as the permanent record.

Where the fields largely conformed to the sectionized land, in nicely squared tracts, a simpler method was used. Celluloid 0.015 inch thick was laid over the field sheet and the boundaries and numbers of classified lands were traced with a sharp point held at an acute angle with the sheet. This cut a mark without removing shavings. The celluloid was weighed and the weight was recorded. The various tracts and a test block were then broken out by bending on the scratched lines. The rest of the process was unchanged. The weight of the test block was then adjusted two ways: (a) The field photostat was compared for true scale with surveyed distances, such as highway or railroad tangent lengths. Thus a coefficient of area was determined. (b) The test block weight was then adjusted to include the 3-percent and the 1-percent deductions as explained on page 405. The tabulated computations of some 60 columns were then completed by means of a 20-inch slide rule. From these detail summations tables A, B, and C, shown on the following pages, were finally developed.

TABLE A.—*Lands under irrigation and other water-using*

Unit	Mapped areas: Total area mapped	Agricultural and other lands artificially given water: Irrigated in 1936	Temporarily out of cropping	Cities, towns, and villages	Total irrigated "out" and towns	Other water-using areas, nonirrigated: Native vegetation	Water and river-bed surfaces	Total nonirrigated	Areas formerly irrigated	Bare land, roads, rights-of-way, etc.
Live area, by streams—Continued.										
Southeast area, by streams—Continued.										
Culebra Creek	101,920	29,047	2,115	554	31,716	61,300	1,162	62,462	9,952	7,742
Costilla Creek	2,257	1,264	143	21	1,428	241	327	568	242	261
Culebra and Costilla Creeks, mixed	20,970	2,144	383	81	2,608	15,994	457	16,451	2,233	1,911
(Costilla Creek in Colorado and New Mexico)	5,621	3,960	158	81	4,199	510	623	1,133	242	289
(Costilla and Culebra Creeks mixed, in Colorado and New Mexico).	23,804	2,332	383	81	2,796	18,630	457	19,087	2,869	1,921
Rio Grande Basin in Colorado, by counties:[1]										
Mineral	7,999	6,673			6,673	115	1,122	1,237	23	89
Rio Grande	186,402	136,892	4,755	1,159	142,806	36,554	857	37,411	13,181	6,185
Alamosa	395,976	108,734	4,812	1,161	114,707	269,124	3,097	272,221	44,190	9,048
Conejos	213,806	125,652	4,661	2,065	132,378	68,522	2,979	71,501	36,185	9,927
Costilla	211,631	51,110	2,876	892	54,878	139,206	3,203	142,409	16,695	14,344
Saguache	430,838	171,182	1,875	752	173,809	223,678	2,504	226,182	48,420	30,847

[1] Small area in Hinsdale County included with Mineral County figures, as line could not be identified by mapping parties.

TABLE B.—*Lands under irrigation and other water-using areas in Rio Grande Basin,*

Unit	Mapped areas: Total area mapped	Agricultural and other lands artificially given water: Irrigated in 1936	Temporarily out of cropping	Cities, towns, and villages	Total irrigated, "out" and towns	Other water-using areas, nonirrigated: Native vegetation	Water and river bed surfaces	Total nonirrigated	Bare land road rights-of-ways, etc.
Total, State line to San Marcial (Middle Valley area)	366,909	152,782	13,187	10,251	176,220	140,910	39,365	180,275	10,414
Main stem of Rio Grande	217,954	65,969	3,684	6,398	76,051	106,833	27,108	133,941	7,962
West side tributaries	83,115	46,685	6,550	1,540	54,775	17,751	9,610	27,361	979
East side tributaries	65,840	40,128	2,953	2,313	45,394	16,326	2,647	18,973	1,473
Rio Grande, main stem	217,954	65,969	3,684	6,398	76,051	106,833	27,108	133,941	7,962
State line to Rinconada (above Embudo)[1]									
Rinconada to Embudo gage (Taos County)	378	191	3	8	202	31	138	169	7
Embudo to south line of Rio Arriba County	9,349	4,894	341	205	5,440	2,243	1,426	3,669	240
Rio Arriba-Santa Fe Counties line to Buckman	3,151	806	30	20	856	1,377	772	2,149	146
Buckman to Middle Rio Grande Conservancy District[1]									
Middle Rio Grande Conservancy District	187,682	59,159	2,980	6,165	68,304	90,401	21,895	112,296	7,082
Cochiti Division (all in Sandoval County)	19,439	5,208	169	401	5,778	11,232	1,528	12,760	901
Albuquerque Division	58,127	22,819	913	4,241	27,973	23,495	5,738	29,233	921
In Sandoval County	15,214	4,611	175	248	5,034	7,985	1,717	9,702	478
In Barnalillo County	42,913	18,208	738	3,993	22,939	15,510	4,021	19,531	443
Belen Division	77,044	23,895	1,165	530	25,590	40,794	6,779	47,573	3,681
In Bernalillo County	594	46			46	543		543	5
In Valencia County	55,388	20,335	865	441	21,641	27,451	2,731	30,182	3,565
In Socorro County	21,062	3,514	300	89	3,903	12,800	4,048	16,848	311
(Above Bernardo Bridge)	12,212	2,895	236	41	3,172	7,057	1,782	8,839	201
(Below Bernardo Bridge)	8,850	619	64	48	731	5,743	2,266	8,009	110
Socorro Division (all Socorro County)	33,072	7,237	733	993	8,963	14,880	7,850	22,730	1,379
Bosque del Apache grant	12,583					10,164	1,970	12,134	449
Bosque del Apache grant to San Marcial	4,811	919	330		1,249	2,617	907	3,524	38
Totals, main stem, by counties:									
Taos	378	191	3	8	202	31	138	169	7
Rio Arriba	9,349	4,894	341	205	5,440	2,243	1,426	3,669	240
Santa Fe	3,151	806	30	20	856	1,377	772	2,149	146
Sandoval	34,653	9,819	344	649	10,812	19,217	3,245	22,462	1,379
Bernalillo	43,507	18,254	738	3,993	22,985	16,053	4,021	20,074	448
Valencia	55,388	20,335	865	441	21,641	27,451	2,731	30,182	3,565
Socorro	71,528	11,670	1,363	1,082	14,115	40,461	14,775	55,236	2,177
Special areas:									
Total, Embudo to Buckman	12,500	5,700	371	225	6,296	3,620	2,198	5,818	386
Total, Embudo to Bernardo Bridge	159,260	57,003	2,554	5,349	64,906	73,398	13,977	87,375	5,979

[1] Canyon section.

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areas in Rio Grande Basin in Colorado, in acres, 1936—Continued

Identification of areas by classification numbers																	Remarks
Land irrigated in 1936								Cities, towns, and villages	Land temporarily out of cropping	Native vegetation			Water areas		Areas formerly irrigated	Bare land, roads, rights-of-way, etc.	
Cotton	Alfalfa and clover hay	Native hay	Irrigated pasture	Early annuals	Late annuals	Miscellaneous crops	Double cropped areas			Grass	Brush	Trees, bosque	Pooled water	River and canal surfaces and exposed beds			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(10)	(11)	(8)	(9a)	(9b)	(9c)	(9d)	(9e)	(12)	(13)	
....	5,427	1,436	4,722	14,175	221	3,066	....	554	2,115	16,422	44,114	764	522	640	9,952	7,742	For New Mexico portion see table B.
....	165	....	47	446	....	606	....	21	143	61	180	....	....	327	242	261	
....	445	....	48	645	....	1,006	....	81	383	197	15,797	....	444	13	2,233	1,911	Do.
....	496	618	99	1,484	180	1,083	....	81	158	143	180	187	....	623	242	289	Do.
....	491	....	45	732	5	1,056	....	81	383	2,833	15,797	....	444	13	2,869	1,921	Do.
....	....	3,884	2,638	151	....	....	....	....	....	99	....	16	424	698	23	89	
....	26,499	18,069	18,077	42,141	26,635	3,471	....	1,159	4,755	6,124	22,206	8,224	81	776	13,181	6,185	
....	27,320	25,438	31,356	17,475	6,757	388	....	1,161	4,812	82,269	184,161	2,694	1,054	2,043	44,190	9,048	
....	32,742	27,123	15,621	36,051	8,221	5,894	....	2,065	4,661	10,686	48,221	9,615	244	2,735	36,185	9,927	
....	9,300	4,266	11,250	19,479	309	6,506	....	892	2,876	35,925	98,985	4,296	1,908	1,295	16,695	14,344	
....	19,566	64,986	60,477	16,195	9,654	304	....	752	1,875	71,156	151,523	999	1,602	902	48,420	30,847	

from Colorado-New Mexico State line to San Marcial, N. Mex., in acres, 1936

Identification of areas by classification numbers																	Remarks
Land irrigated in 1936								Cities, towns, and villages	Land temporarily out of cropping	Native vegetation			Water areas		Areas formerly irrigated	Bare land, roads, rights-of-way, etc.	
	Alfalfa and clover hay	Native hay	Irrigated pasture	Early annuals	Late annuals	Miscellaneous crops	Double cropped areas			Grass	Brush	Trees, bosque	Pooled water	Riverand canal surfaces and exposed beds			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(10)	(11)	(8)	(9a)	(9b)	(9c)	(9d)	(9e)	(12)	(13)	
56	33,775	24,197	9,422	31,055	35,575	18,702	....	10,251	13,187	60,796	34,942	45,172	1,300	38,065	....	10,414	
56	18,621	7,278	3,130	8,210	18,862	9,812	....	6,398	3,684	45,202	21,517	40,114	584	26,524	....	7,962	
....	8,999	12,661	2,370	8,381	10,696	3,578	....	1,540	6,550	6,792	8,257	2,702	695	8,915	....	979	
....	6,155	4,258	3,922	14,464	6,017	5,312	....	2,313	2,953	8,802	5,168	2,356	21	2,626	....	1,473	
56	18,621	7,278	3,130	8,210	18,862	9,812	....	6,398	3,684	45,202	21,517	40,114	584	26,524	....	7,962	
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	No irrigation.
....	18	25	....	4	54	90	....	8	3	31	....	....	....	138	....	7	
....	775	715	430	540	1,162	1,272	....	205	341	302	1,269	672	....	1,426	....	240	
....	116	306	77	71	186	50	....	20	30	12	307	1,058	....	772	....	146	No irrigation.
56	17,434	6,232	2,333	7,402	17,460	8,242	....	6,165	2,980	43,968	19,639	26,794	154	21,741	....	7,062	
....	698	941	533	1,035	1,683	318	....	401	169	2,628	4,417	4,187	....	1,528	....	901	
....	7,221	2,240	815	1,854	6,683	4,006	....	4,241	913	10,487	4,968	8,040	....	5,738	....	921	
....	1,290	526	326	488	1,133	848	....	248	175	2,396	1,657	3,932	....	1,717	....	478	
....	5,931	1,714	489	1,366	5,550	3,158	....	3,993	738	8,091	3,311	4,108	....	4,021	....	443	Includes Albuquerque.
....	7,883	2,529	735	2,951	6,331	3,466	....	530	1,165	26,540	7,149	7,105	140	6,639	....	3,881	
....	4	40	....	....	2	....	....	....	....	261	200	82	....	....	....	5	
....	7,224	2,296	315	2,289	5,340	2,891	....	441	865	18,228	6,231	2,992	52	2,679	....	3,565	
....	655	193	420	682	989	575	....	89	300	8,051	718	4,031	88	3,960	....	311	
....	506	164	283	899	849	494	....	41	236	4,937	201	1,919	62	1,720	....	201	
....	149	29	137	83	140	81	....	48	64	3,114	517	2,112	26	2,240	....	110	
56	1,632	522	250	1,862	2,763	452	....	993	783	4,313	3,105	7,462	14	7,836	....	1,379	Including Socorro.
....	....	....	....	....	....	....	....	....	....	784	....	9,380	....	1,970	....	449	
....	278	....	380	193	....	158	....	....	330	106	302	2,210	430	477	....	88	
....	18	25	....	4	54	90	....	8	3	31	....	....	....	138	....	7	
....	775	715	430	540	1,162	1,272	....	205	341	302	1,269	672	....	1,426	....	240	
....	116	306	77	71	186	50	....	20	30	12	307	1,058	....	772	....	146	
....	1,988	1,467	859	1,528	2,816	1,166	....	649	344	5,034	6,074	3,119	....	3,245	....	1,379	
....	5,935	1,754	689	1,366	5,552	3,158	....	3,993	738	8,352	3,511	4,190	....	4,021	....	448	
....	7,224	2,296	315	2,289	5,340	2,891	....	441	865	18,228	6,231	2,992	52	2,679	....	3,565	
56	2,565	715	960	2,437	3,752	1,185	....	1,082	1,363	13,258	4,125	28,083	532	14,243	....	2,177	
	891	1,021	507	611	1,348	1,322	....	225	371	314	1,576	1,780	....	2,198	....	386	
	18,544	6,702	2,453	6,368	15,905	9,031	....	5,349	2,554	36,855	17,893	18,980	114	18,863	....	5,979	

Table B.—*Lands under irrigation and other water-using areas in Rio Grande Basin,*

Unit	Mapped areas								
	Total area mapped	Agricultural and other lands artificially given water				Other water-using areas, nonirrigated			
		Irrigated in 1936	Temporarily out of cropping	Cities, towns, and villages	Total irrigated, "out" and towns	Native vegetation	Water and river bed surfaces	Total nonirrigated	Ba[re] land, roads, rights-of-ways, etc.
Rio Grande, west side tributaries	83,115	46,685	6,550	1,540	54,775	17,751	9,610	27,361	979
Areas in New Mexico served by streams entering Rio Grande in Colorado.	1,076	541	51	8	600	451	25	476	----------
San Antonio River in New Mexico	119	56	----------	8	64	33	22	55	----------
Rio de los Pinos	957	485	51	----------	536	418	3	421	----------
(San Antonio and Los Pinos in New Mexico and Colorado)	5,843	3,870	200	9	4,079	1,442	44	1,486	278
Rio Chama and tributaries	47,935	28,613	1,156	556	30,325	11,194	5,948	17,142	468
Rio Chama and tributaries above El Vado Dam	14,454	7,921	122	316	8,359	4,179	1,731	5,910	185
Rio Chama and Rio Brazos	13,448	7,179	122	316	7,617	3,986	1,728	5,714	117
Nutritas Creek	1,006	742	----------	----------	742	193	3	196	68
Rio Chama and tributaries between El Vado Dam and Abiquiu	16,914	9,582	812	159	10,553	4,767	1,437	6,204	157
Rio Chama	2,425	977	321	28	1,326	586	493	1,079	20
Tributaries	14,489	8,605	491	131	9,227	4,181	944	5,125	137
Nutrias Creek	956	356	----------	----------	356	588	2	590	10
Cebolla, Gallina, Poelo, Rito Encino, Arroyo del Agua, Agua Sarco, Canjilon, and Vallecitos Creeks.	6,977	4,392	211	117	4,720	2,002	186	2,188	69
El Rito Creek	6,556	3,857	280	14	4,151	1,591	756	2,347	58
Rio Chama and tributaries below Abiquiu	16,569	11,110	222	81	11,413	2,248	2,780	5,028	126
Rio Chama	4,663	2,342	150	----------	2,492	1,003	1,111	2,114	57
Tributaries	11,904	8,768	72	81	8,921	1,245	1,669	2,914	69
Rio Ojo Caliente [2]	1,014	438	----------	17	455	126	428	554	5
Tusas River	7,246	5,996	27	8	6,031	637	542	1,179	36
Rio Valecitos	3,566	2,281	20	56	2,357	482	699	1,181	28
Bear Creek	78	53	25	----------	78	----------	----------	----------	----------
Jemez Creek	6,644	2,496	379	2	2,877	1,984	1,736	3,720	47
Rio Puerco and tributaries (in Sandoval and Valencia Counties)	27,142	14,972	4,951	948	20,871	4,122	1,685	5,807	464
Rio Puerco	6,526	4,600	927	151	5,678	680	104	784	64
Tributaries	20,616	10,372	4,024	797	15,193	3,442	1,581	5,023	400
Blue water Creek	5,922	3,227	1,125	14	4,366	1,169	332	1,501	55
San Jose River and tributaries below Grant	14,694	7,145	2,899	783	10,827	2,273	1,249	3,522	345
San Jose River	10,145	5,072	1,597	505	7,174	1,534	1,133	2,667	30
Tributaries	4,549	2,073	1,302	278	3,653	739	116	855	[illegible]
Totals, west side tributaries, by counties:									
Rio Salado	318	63	13	26	102	----------	216	216	----------
Rio Arriba	49,011	29,154	1,207	564	30,925	11,645	5,973	17,618	468
Sandoval	13,170	7,096	1,306	153	8,555	2,664	1,840	4,504	111
Bernalillo	----------	----------	----------	----------	----------	----------	----------	----------	----------
Valencia	20,616	10,372	4,024	797	15,193	3,442	1,581	5,023	400
Socorro	318	63	13	26	102	----------	216	216	----------
Rio Grande, east side tributaries	[illegible]	[illegible]	2,953	[illegible]	45,394	16,326	2,647	18,973	1,473
Areas in New Mexico served by streams entering Rio Grande in New Mexico via Colorado (Costilla and Culebra Creeks mixed): [3]	2,834	188	----------	----------	188	2,636	----------	2,636	10
Costilla (River) Creek alone	3,364	2,696	15	60	2,771	269	296	565	28
(Costilla and Culebra Creeks mixed, in New Mexico and Colorado)	23,804	2,332	383	81	2,796	18,630	457	19,087	1,921
(Costilla Creek alone, in New Mexico and Colorado)	5,621	3,960	158	81	4,199	510	623	1,133	289
Latir Creek (Cerro Mesa area)	3,875	2,402	152	24	2,578	1,236	25	1,261	36
Rio Colorado (Red River) and tributaries	4,161	2,846	150	180	3,176	846	15	861	124
San Cristobal Creek	669	576	38	5	619	31	13	44	6
Llama village	384	263	----------	----------	263	116	3	119	2
Rio Hondo alone	1,028	764	65	11	840	174	4	178	10
Rio Hondo and Arroyo Seco mixed	5,481	2,912	579	18	3,509	1,927	15	1,942	30
Arroyo Seco and tributaries of Taos Creek (Taos Mesa)	14,815	11,191	817	322	12,330	2,253	87	2,340	145
Embudo Creek and tributaries [4]	8,035	5,828	182	176	6,186	1,468	303	1,771	78
In Taos County	7,366	5,362	149	121	5,632	1,444	218	1,662	72
Rio Pueblo in Picuris Pueblo grant	2,759	2,083	35	82	2,200	392	141	533	26
Rio Pueblo outside Picuris Pueblo grant	4,607	3,279	114	39	3,432	1,052	77	1,129	46
In Rio Arriba County	669	466	33	55	554	24	85	109	6
Rio Ojo Sarco	987	676	----------	10	686	189	104	293	8
Rio Truchas and tributaries	2,587	1,449	97	22	1,568	936	8	944	25
Rio Santa Cruz and tributaries	5,602	3,628	202	64	3,894	990	372	1,362	346
In Rio Arriba County	1,117	875	27	17	919	111	4	115	83
In Santa Fe County above Santa Clara Pueblo Grant	4,485	2,753	175	47	2,975	879	368	1,247	263
Rio Pojoaque, Rio Nambe, and Rio Tusuque	6,180	3,174	254	131	3,559	1,334	967	2,301	320
Santa Fe Creek (including City of Santa Fe)	5,361	1,496	360	1,253	3,109	1,525	435	1,960	292
City of Santa Fe	1,082	----------	----------	1,082	----------	----------	----------	----------	----------
Rio Galisteo	518	39	42	37	118	396	----------	396	4
Totals, east side tributaries by counties:									
Taos	43,977	29,200	1,965	741	31,906	10,932	676	11,608	463
Rio Arriba	5,310	3,466	157	104	3,727	1,260	201	1,461	122
Santa Fe	16,553	7,462	831	1,468	9,761	4,134	177	5,904	888

[2] Below junction of Tusas River and Rio Vallicitos.
[3] Costilla Creek rises in New Mexico, flows into Colorado, and thence reenters New Mexico. Culebra Creek water mixes with this.
[4] Not including Rio Ojo Sarco, which enters Embudo Creek at the county line.

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from Colorado-New Mexico State line to San Marcial, N. Mex., in acres, 1936—Continued

Identification of areas by classification numbers																	
Land irrigated in 1936										Native vegetation			Water areas				
Cotton	Alfalfa and clover hay	Native hay	Irrigated pasture	Early annuals	Late annuals	Miscellaneous crops	Double cropped areas	Cities, towns, and villages	Land temporarily out of cropping	Grass	Brush	Trees, bosque	Pooled water	River and canal surfaces and exposed beds	Areas formerly irrigated	Bare land, roads, rights-of-way, etc.	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(10)	(11)	(8)	(9a)	(9b)	(9c)	(9d)	(9e)	(12)	(13)	
......	8,999	12,661	2,370	8,381	10,696	3,578	......	1,540	6,550	6,792	8,257	2,702	695	8,915	......	979	
......	54	85	......	134	213	56	......	8	51	112	65	274	......	25	......	......	For Colorado areas see table A.
......	6	33	......	......	15	2	......	8	......	33	......	......	......	22	......	......	Do.
......	48	52	......	134	198	53	......	......	51	79	65	274	......	3	......	......	Do.
......	560	506	344	1,872	374	214	......	9	200	167	80	1,195	......	44	......	278	
......	4,665	10,027	2,355	5,312	4,011	2,343	......	556	1,156	3,165	5,884	2,145	15	5,933	......	468	
......	1,897	1,853	936	2,404	427	404	......	316	122	1,601	1,908	670	......	1,731	......	185	
......	1,872	1,334	923	2,294	394	362	......	316	122	1,444	1,872	670	......	1,728	......	117	
......	25	519	13	110	83	42	......	......	......	157	36	......	......	3	......	68	
......	1,801	2,047	1,097	1,676	1,910	1,051	......	159	812	1,103	2,880	784	15	1,422	......	157	
......	242	40	224	104	240	127	......	28	321	74	34	478	......	493	......	20	
......	1,559	2,007	873	1,572	1,670	924	......	131	491	1,029	2,846	306	15	929	......	137	
......	60	109	......	103	64	20	......	......	......	147	154	287	......	2	......	10	
......	829	1,041	46	1,136	721	619	......	117	211	670	1,332	......	......	186	......	69	
......	670	857	827	333	885	285	......	14	280	212	1,380	19	15	741	......	58	
......	967	6,127	322	1,232	1,674	788	......	81	222	461	1,096	691	......	2,780	......	126	
......	414	415	311	133	746	823	......	......	180	142	310	551	......	1,111	......	57	
......	553	5,712	11	1,099	928	465	......	81	72	319	786	140	......	1,669	......	69	
......	127	87	......	69	114	41	......	17	......	6	120	......	......	428	......	5	
......	131	5,083	6	402	280	94	......	8	27	273	345	19	......	542	......	36	
......	295	529	5	605	524	323	......	56	20	40	321	121	......	699	......	28	
......	......	13	......	23	10	7	......	......	25	......	......	......	......	......	......	......	
......	492	135	8	861	732	268	......	2	379	656	1,095	233	59	1,677	......	47	
......	3,783	2,414	......	2,074	5,700	1,001	......	948	4,951	2,859	1,213	50	621	1,064	......	464	
......	1,205	75	......	1,111	1,870	339	......	151	927	386	283	11	61	53	......	64	All irrigated land is in Sandoval County.
......	2,578	2,339	......	963	3,830	662	......	797	4,024	2,473	930	39	570	1,011	......	400	
......	1,071	261	......	716	1,032	147	......	14	1,125	744	425	......	58	274	......	55	Bluewater Creek becomes San Jose River near Grant
	1,507	2,078	......	247	2,798	515	......	783	2,899	1,729	505	39	512	737	......	345	
	1,025	1,945	......	133	1,688	281	......	505	1,597	1,214	320	......	486	647	......	304	All irrigated land is in Valencia County.
......	482	133	......	114	1,110	234	......	278	1,302	515	185	39	26	90	......	41	
......	5	......	7	......	40	11	......	26	13	......	......	......	......	216	......	......	All irrigated land is in Socorro County.
......	4,719	10,112	2,355	5,446	4,234	2,298	......	564	1,207	3,277	5,949	2,419	15	5,958	......	468	
......	1,697	210	8	1,972	2,602	607	......	153	1,306	1,042	1,378	244	110	1,730	......	111	
......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	No irrigation on west side tributaries.
......	2,578	[illegible]	[illegible]	963	[illegible]	[illegible]	......	797	4,024	[illegible]	930	39	570	1,011	......	400	
......	5	......	7	......	40	11	......	26	13	......	......	......	......	216	......	......	
......	6,155	4,258	3,922	14,464	6,017	5,312	......	2,313	2,953	8,802	5,168	2,356	21	2,626	......	1,473	
......	46	......	......	87	5	50	......	......	......	2,636	......	......	......	......	......	10	
......	331	618	52	1,038	180	477	......	60	15	82	......	167	......	296	......	28	
......	491	......	48	732	5	1,056	......	81	383	2,833	15,797	......	444	13	......	1,921	
......	496	618	99	1,484	180	1,083	......	81	158	143	180	187	......	623	......	289	
......	484	83	25	1,272	174	364	......	34	152	216	779	241	13	12	......	36	
......	373	370	244	1,642	160	57	......	180	150	390	39	417	......	15	......	124	
......	71	96	90	223	81	15	......	5	38	10	21	......	......	13	......	6	
......	34	49	82	39	75	14	......	......	......	100	16	......	......	3	......	2	Irrigation from seepage.
......	23	95	217	236	126	68	......	11	65	145	29	......	......	4	......	10	
......	425	33	215	1,366	309	564	......	18	579	455	823	649	......	15	......	30	
......	2,107	1,020	2,068	3,875	1,424	677	......	322	817	1,214	832	207	......	87	......	145	No irrigation from Taos Creek.
......	282	1,144	288	2,490	997	627	......	176	182	873	646	49	......	303	......	78	
......	279	1,095	270	2,477	736	505	......	121	149	864	533	47	......	218	......	72	
......	124	400	126	862	356	215	......	82	35	336	50	6	......	141	......	26	
......	155	695	144	1,615	380	290	......	39	114	626	483	41	......	77	......	46	
......	3	49	18	13	261	122	......	55	33	9	13	2	......	85	......	6	
......	29	146	......	378	64	59	......	10	......	119	70	......	......	104	......	8	
......	81	134	10	757	229	238	......	22	97	488	414	34	......	8	......	25	
......	707	280	314	831	888	1,106	......	64	202	333	457	170	......	372	......	346	
......	131	54	128	44	181	337	......	17	27	12	87	12	......	4	......	83	
......	576	236	186	387	707	771	......	47	175	321	400	158	......	368	......	263	
......	958	105	230	600	696	576	......	131	254	583	436	315	4	963	......	329	
......	201	85	88	131	602	389	......	1,253	360	670	568	87	4	431	......	292	
......	......	......	......	......	......	......	......	1,082	......	......	......	......	......	......	......	......	
......	3	......	......	......	7	29	......	37	42	268	108	......	......	......	......	4	
......	4,173	3,459	3,253	12,254	3,270	2,791	......	741	1,965	6,112	3,072	1,748	13	663	......	463	
......	344	383	156	1,192	785	756	......	104	157	628	564	48	......	201	......	122	
......	1,738	416	513	1,018	2,012	1,765	......	1,468	831	2,062	1,512	560	8	1,762	......	888	

TABLE C.—*Lands under irrigation and other water-using areas in Rio Grande*

Unit	Mapped areas: Total area mapped	Agricultural and other lands artificially given water: Irrigated in 1936	Agricultural and other lands artificially given water: Temporarily out of cropping	Agricultural and other lands artificially given water: Cities, towns, and villages	Agricultural and other lands artificially given water: Total irrigated "out" and towns
Total, San Marcial to Fort Quitman	[1] 279, 256	170, 569	14, 153	2, 633	187, 355
New Mexico	170, 985	89, 902	8, 494	1, 846	100, 242
Texas	108, 271	80, 667	5, 659	787	87, 113
New Mexico, by streams and canal systems:					
Rio Grande, main stem	161, 024	88, 294	7, 863	1, 708	97, 865
San Marcial to Socorro-Sierra Counties line	23, 357	....	....	....	....
Socorro-Sierra Counties line to Elephant Butte Dam	2, 790	....	....	....	....
Palomas Valley (Elephant Butte Dam to Apache Canyon)	10, 383	830	501	304	1, 635
Elephant Butte Irrigation District (Rio Grande project in New Mexico)	124, 494	87, 464	7, 362	1, 404	96, 230
Rincon Valley (in Sierra County only)	5, 635	2, 666	445	....	3, 111
Rincon Valley (in Sierra and Dona Ana Counties)	27, 914	15, 206	2, 129	110	17, 445
Mesilla Valley in New Mexico	96, 580	72, 258	5, 233	1, 294	78, 785
Mesilla Division in New Mexico	54, 216	40, 571	3, 402	295	44, 268
Leasburg Division	42, 364	31, 687	1, 831	999	34, 517
Rio Grande, West Side tributaries in New Mexico	9, 961	1, 608	631	138	2, 377
Alamosa Creek	3, 072	693	249	15	957
Cuchillo Negro Creek	2, 860	245	134	35	414
Palomas Creek	968	409	144	....	553
Animas Creek	2, 238	227	90	....	317
Percha Creek	823	34	14	88	136
Mesilla Valley in New Mexico and Texas	110, 418	82, 923	5, 569	1, 523	90, 015
Texas, by streams (there are no tributaries)	108, 271	80, 667	5, 659	787	87, 113
Mesilla Valley in Texas (Mesilla Division in Texas)	13, 838	10, 665	336	229	11, 230
El Paso Division, Rio Grande project	72, 838	56, 423	3, 506	558	60, 487
El Paso County Water Improvement District no. 1	86, 676	67, 088	3, 842	787	71, 717
Hudspeth County Conservation and Reclamation District no. 1 [2]	21, 595	13, 579	1, 817	....	15, 396
Rio Grande project U. S. Bureau of Reclamation (New Mexico and Texas)	211, 170	154, 552	11, 204	2, 191	167. 947
Elephant Butte Reservoir	[3] 16, 674	....	....	....	....
New Mexico, by counties:					
Socorro (small part only)	23, 357	....	....	....	....
Sierra	18, 808	3, 496	946	304	4, 746
Dona Ana	118, 859	84, 796	6, 917	1, 404	93, 119
Texas, by counties:					
El Paso (Rio Grande project in Texas)	36, 676	37, 088	3, 342	787	71, 717
Hudspeth	21, 595	13, 579	1, 817	....	15, 396
City of El Paso	6, 210	....	....	6, 210	6, 210

Unit	Other water-using areas, nonirriga.: Native vegetation	Other water-using areas, nonirriga.: Water and river bed surfaces	Other water-using areas, nonirriga.: Total nonirrigated	Other water-using areas, nonirriga.: Bare land, roads, rights-of-way, etc.
Total, San Marcial to Fort Quitman	70, 062	16, 168	86, 230	5, 671
New Mexico	52, 206	14, 226	66, 432	4, 311
Texas	17, 856	1, 942	19, 798	1, 360
New Mexico, by streams and canal systems:				
Rio Grande, main stem	48, 110	10, 825	58, 935	4, 224
San Marcial to Socorro-Sierra Counties line	19, 281	3, 384	22, 665	692
Socorro-Sierra Counties line to Elephant Butte Dam	2, 790	....	2, 790	....
Palomas Valley (Elephant Butte Dam to Apache Canyon)	7, 435	1, 190	8, 625	123
Elephant Butte Irrigation District (Rio Grande project in New Mexico)	18, 604	6, 251	24, 855	3, 409
Rincon Valley (in Sierra County only)	2, 145	379	2, 524	....
Rincon Valley (in Sierra and Dona Ana Counties)	7, 310	2, 665	9, 975	494
Mesilla Valley in New Mexico	11, 294	3, 586	14, 880	2, 915
Mesilla Division in New Mexico	6, 201	1, 653	7, 854	2, 094
Leasburg Division	5, 093	1, 933	7, 026	821
Rio Grande, West Side tributaries in New Mexico	4, 096	3, 401	7, 497	87
Alamosa Creek	1, 407	684	2, 091	24
Cuchillo Negro Creek	1, 182	1, 248	2, 430	16
Palomas Creek	46	363	409	6
Animas Creek	1, 121	785	1, 906	15
Percha Creek	340	321	661	26
Mesilla Valley in New Mexico and Texas	13, 198	4, 081	17, 279	3, 124
Texas, by streams (there are no tributaries)	17, 856	1, 942	19, 798	1, 360
Mesilla Valley in Texas (Mesilla Division in Texas)	1, 904	495	2, 399	209
El Paso Division, Rio Grande project	10, 053	1, 366	11, 419	932
El Paso County Water Improvement District no. 1	11, 957	1, 861	13, 818	1, 141
Hudspeth County Conservation and Reclamation District no. 1 [2]	5, 899	81	5, 980	21[illegible]
Rio Grande project U. S. Bureau of Reclamation (New Mexico and Texas)	30, 561	8, 112	38, 673	4, 5[illegible]
Elephant Butte Reservoir	....	[3] 16, 674	....	....
New Mexico, by counties:				
Socorro (small part only)	19, 281	3, 384	22, 665	692
Sierra	12, 370	1, 569	13, 939	123
Dona Ana	16, 459	5, 872	22, 331	3, 409
Texas, by counties:				
El Paso (Rio Grande project in Texas)	11, 357	1, 361	13, 318	1, 141
Hudspeth	5, 899	81	5, 980	219
City of El Paso	....	....	....	....

[1] Not including city of El Paso.
[2] Including all acreages in Budspeth County. see p. 299.
[3] Average lake area covered by water in June, 1936, as reported by U. S. Bureau of Reclamation.

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Basin, from San Marcial, N. Mex., to Fort Quitman, Tex., in acres, 1936

Identification of areas by classification numbers																	
Land irrigated in 1936										Native vegetation			Water areas				Remarks
Cotton	Alfalfa and clover hay	Native hay	Irrigated pasture	Early annuals	Late annuals	Miscellaneous crops	Double-cropped areas	Cities, towns, and villages	Land temporarily out of cropping	Grass	Brush	Trees, bosque	Pooled water	River and canal surfaces and exposed beds	Areas formerly irrigated	Bare land, roads, rights-of-way, etc.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(10)	(11)	(8)	(9a)	(9b)	(9c)	(9d)	(9e)	(12)	(13)	
110,853	36,069	154	871	3,062	7,199	11,967	394	2,633	14,153	9,902	27,806	32,354	1,126	15,042	....	5,671	Water areas exclude Elephant Butte Reservoir.
54,151	18,342	150	731	2,597	6,468	7,380	83	1,846	8,494	5,636	18,958	27,612	828	13,398	....	4,311	
56,702	17,727	4	140	465	731	4,587	311	787	5,659	4,266	8,848	4,742	298	1,644	....	1,360	
54,151	18,059	104	668	2,354	5,827	7,061	70	1,708	7,863	5,479	16,853	25,778	819	10,006	....	4,224	Do.
....	....	....	....	....	....	....	....	....	....	1,725	460	17,096	772	2,612	....	692	Do.
....	....	....	....	....	....	....	....	....	....	66	2,350	374					
....	88	43	306	89	51	253	....	304	501	419	5,700	1,316	....	1,190	....	123	
54,151	17,971	61	362	2,265	5,776	6,808	70	1,404	7,362	3,269	8,343	6,992	47	6,204	....	3,409	
866	336	42	208	573	223	418	....	....	445	207	507	1,431	....	379	....	....	
6,646	3,231	44	255	1,122	2,428	1,480	....	110	2,129	1,010	2,672	3,628	47	2,618	....	494	
47,505	14,740	17	107	1,143	3,348	5,328	70	1,294	5,233	2,259	5,671	3,364	....	3,586	....	2,915	
27,966	8,625	17	69	198	1,387	2,281	28	295	3,402	1,856	2,892	1,453	....	1,653	....	2,094	
19,539	6,115	....	38	945	1,961	3,047	42	999	1,831	403	2,779	1,911	....	1,933	....	821	
....	283	46	63	243	641	319	13	138	631	157	2,105	1,834	9	3,392	....	87	
....	97	17	....	120	301	140	9	15	249	43	878	486	....	684	....	24	
....	119	11	....	13	61	41	....	35	134	6	1,011	165	....	1,248	....	16	
....	47	16	7	79	195	63	....	....	144	9	37	....	7	356	....	6	
....	11	....	55	21	70	61	....	....	90	96	100	925	2	783	....	15	
....	9	....	1	1	5	14	4	88	14	3	79	258	....	321	....	26	
54,513	17,077	17	199	1,210	3,709	6,128	70	1,523	5,569	2,733	6,933	3,532	4	4,077	....	3,124	
56,702	17,727	4	140	465	731	4,587	311	787	5,659	4,266	8,848	4,742	298	1,644	....	1,360	
7,008	2,337	....	92	67	361	800	....	229	336	474	1,262	168	4	491	....	209	
37,493	14,312	4	48	398	370	3,787	11	558	3,506	3,031	4,794	2,228	294	1,072	....	932	
44,501	16,649	4	140	465	731	4,587	11	787	3,842	3,505	6,056	2,396	298	1,563	....	1,141	
	1,078	....	....	....	....	....	300	....	1,819	761	2,792	2,346	....	81	....	219	
	34,620	65	502	2,730	6,507	11,395	81	2,191	11,204	6,774	14,399	9,388	345	7,767	....	4,550	
....	....	....	....	....	....	....	....	....	....	....	....	....	[2] 16,674	....	....	....	
....	....	....	....	....	....	....	....	....	....	1,725	460	17,096	772	2,612	....	692	Do.
866	424	85	514	662	274	671	....	304	946	692	8,557	3,121	....	1,569	....	123	Do.
53,285	17,635	19	154	1,692	5,553	6,390	70	1,404	6,917	3,062	7,836	5,561	47	5,825	....	3,409	
44,501	16,649	[illegible]	140	465	731	4,587	11	787	3,842	3,505	6,056	2,396	298	1,563	....	1,141	Exclusive of City of El Paso.
12,201	1,078	....	....	....	....	....	300	....	1,817	761	2,792	2,346	....	81	....	219	
....	....	....	....	....	....	....	....	6,210	....	....	....	....	....	....	....	....	

PART III

SECTION 7.—CONSUMPTIVE USE OF WATER REQUIREMENTS

Before the available water resources of the Upper Rio Grande Basin can be satisfactorily determined, a careful consideration must be given to the present consumptive use requirements for water in the various subbasins. It is desirable that these requirements be related to the present irrigated and other water-consuming acreage in such a way that reliable consumptive use and stream-flow depletion figures can be derived for use in determining the probable draft upon the available water resources when the Basin is completely developed.

Data for determining the use of water by the inflow-outflow method are obtainable only in certain areas of the basin, and are not always equally reliable. Therefore, with the data available it is believed that, considering the entire Upper Basin, the integration method (p. 345) offers the best (or most feasible) means of estimating the present consumptive use requirements for the major subdivisions of the basin.

Application of the integration method produces the estimates appearing in the concluding tables of this report (124 to 129). Hence these estimates are to be understood as representing the present judgment of the Bureau of Agricultural Engineering based not only on its investigations in Upper Rio Grande Basin in 1936 but also, and to an important degree, on its own previous work and the previous work of others in various Western States over a long period of years. Estimates thus based on many studies and long experience, together with the results of the 1936 work in the upper basin, are believed to be a safer guide for studying the irrigation possibilities of the basin than estimates based on the work of only 1 year, especially since the work during that year could not be begun until after the irrigation season was well started.

In arriving at the estimates, no conclusion was involved regarding quantities of water that may be needed in some parts of the upper basin to maintain a proper salt balance in the soil solution of the irrigated areas, the salinity phase of the problem having been delegated to the Bureau of Plant Industry (part IV).

TABLE 124.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, San Luis Valley, Colorado and New Mexico*

Location	Irrigated lands			Native vegetation			Miscellaneous			
	Alfalfa, clover	Native hay, pasture	Miscellaneous crops	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
Closed basin area:										
Saguache County	2.5	1.5	1.5	1.0	1.3	3.8	1.5	1.5	3.5	0.7
Rio Grande County (part)	2.5	2.0	1.5	1.5	2.0	3.8	1.5	1.5	3.5	.7
Alamosa County (part)	2.5	2.0	1.5	1.5	1.8	3.8	1.5	1.5	3.5	.7
Southwest area:										
South Fork, Schraders, Pinos Creeks and areas above	2.0	1.5	1.5	.8	.8	3.5	1.5	1.5	3.3	.7
Monte Vista Canal, Empire Canal, and small canals	2.5	2.0	1.5	1.5	1.5	3.8	1.5	1.5	3.5	.7
Alamosa Creek, La Jara Creek, and Terrace Irrigation District	2.3	1.8	1.5	1.5	1.5	3.8	1.5	1.5	3.5	.7
Conejos River and tributaries, San Antonio River, and Los Pinos River	2.0	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	.7
Rio Grande Canal, SanLuis Canal, and small canals (south closed area)	2.5	2.0	1.5	1.5	2.0	3.8	1.5	1.5	3.5	.7
Southeast area:										
Trinchera Creek and tributaries	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	.7
Blanca, Ute, and Sangre de Cristo Creeks	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	.7
Culebra Creek and Costilla Creek	2.2	1.5	1.5	1.0	1.0	3.8	1.5	1.5	3.5	.7

TABLE 125.—*Estimate of consumptive water requirements in the San Luis Valley, Colo. (including precipitation), based on 1936 acreage*

Location	Irrigated lands			Native vegetation			Miscellaneous [1]			Total area mapped		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
Closed basin area:												
Saguache County	171,182	272,426	1.59	223,678	271,932	1.22	35,978	34,297	0.95	430,838	578,655	1.34
Rio Grande County (part)	56,792	101,212	1.78	4,227	8,668	2.05	4,008	6,048	1.51	65,027	115,928	1.78
Alamosa County (part)	49,948	101,992	2.04	176,109	300,214	1.70	11,503	14,852	1.29	237,560	417,058	1.76
Entire area	277,922	475,630	1.71	404,014	580,814	1.44	51,489	55,197	1.07	733,425	1,111,641	1.52
Southwest area:												
South Fork, Schraders, Pinos Creeks and areas above	20,438	31,616	1.55	3,429	8,610	2.51	2,823	5,310	1.88	26,690	45,536	1.71
Monte Vista Canal, Empire Canal, and small canals	84,851	165,362	1.95	77,809	132,693	1.71	9,404	12,678	1.35	172,064	310,733	1.81
Alamosa Creek, La Jara Creek, and Terrace Irrigation District	49,018	88,409	1.80	43,339	71,113	1.64	8,063	10,823	1.34	100,420	170,345	1.70
Conejos River and tributaries, San Antonio River, and Los Pinos River	82,389	132,871	1.61	25,614	45,105	1.76	12,471	17,546	1.41	120,474	195,522	1.62
Rio Grande Canal, San Luis Canal, and small canals (south closed area)	33,654	64,575	1.92	26,000	48,817	1.88	3,229	5,966	1.85	62,883	119,358	1.90
Entire area	270,350	482,833	1.79	176,191	306,338	1.74	35,990	52,323	1.45	482,531	841,494	1.74
Southeast area:												
Trinchera Creek and tributaries	16,847	27,185	1.61	73,173	77,936	1.07	5,955	7,436	1.25	95,975	112,557	1.17
Blanca, Ute, and Sangre de Cristo Creeks	2,669	4,390	1.64	6,286	11,412	1.82	619	1,063	1.72	9,574	16,865	1.76
Culebra Creek and Costilla Creek	32,455	52,909	1.63	77,535	79,674	1.03	15,157	18,697	1.23	125,147	151,280	1.21
Entire area	51,971	84,484	1.63	156,994	169,022	1.08	21,731	27,196	1.25	230,696	280,702	1.22
Total or average	600,243	1,042,947	1.74	737,199	1,056,174	1.43	109,210	134,716	1.23	1,446,652	2,233,837	1.54

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces—pooled water, river and canal surfaces, and exposed beds; bare land, roads, rights-of-way, etc.

TABLE 126.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, Colorado-New Mexico State line to San Marcial, N. M.*

Location	Irrigated lands			Native vegetation			Miscellaneous			
	Alfalfa	Native hay, pasture	Miscellaneous	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
State line to Rinconada [1]										
Rinconada to Embudo	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Embudo to Santa Fe County line	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Santa Fe County line to Buckman	3.5	2.5	1.5	2.5	2.5	4.0	2.0	2.0	3.7	1.0
Middle Rio Grande Conservancy District:										
Cochiti Division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Albuquerque Division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Belen Division	4.0	2.5	2.0	2.5	3.0	5.0	2.0	2.0	4.3	1.0
Socorro Division	4.0	2.5	2.0	2.5	3.0	5.2	2.0	2.0	4.5	1.0
Bosque del Apache Grant	4.0	2.5	2.0	2.5	3.5	5.8	2.0	2.0	5.0	1.0
Bosque del Apache to San Marcial	4.0	2.5	2.0	2.5	3.5	5.8	2.0	2.0	5.0	1.0

[1] Canyon section.

TABLE 127.—*Estimate of consumptive water requirements, main stem of Rio Grande, Colorado-New Mexico State line to San Marcial, N. Mex. (including precipitation), based on 1936 acreages*

Location	Irrigated lands			Native vegetation			Miscellaneous [1]			Total area mapped		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
State line to Rinconada [2]												
Rinconada to Embudo	191	349	1.83	31	78	2.50	156	540	3.46	378	967	2.56
Embudo to Santa Fe County line	4,894	10,037	2.05	2,243	6,615	2.95	2,212	6,608	2.99	9,349	23,260	2.49
Santa Fe County line to Buckman	806	1,823	2.26	1,377	5,030	3.65	968	3,102	3.20	3,151	9,955	3.16
Middle Rio Grande Conservancy District:												
Cochiti Division	5,208	12,549	2.41	11,232	40,756	3.63	2,999	8,611	2.87	19,439	61,916	3.19
Albuquerque Division	22,819	61,608	2.70	23,495	81,322	3.46	11,813	35,902	3.04	58,127	178,832	3.08
Belen Division	23,895	65,188	2.73	40,794	123,322	3.02	12,355	36,421	2.95	77,044	224,931	2.92
Socorro Division	7,237	18,124	2.50	14,880	58,899	3.96	10,955	40,156	3.67	33,072	117,179	3.54
Bosque del Apache Grant				10,164	56,364	5.55	2,419	10,299	4.26	12,583	66,663	5.30
Bosque del Apache to San Marcial	919	2,539	2.76	2,617	14,137	5.40	1,275	5,233	4.10	4,811	21,909	4.55
Total or average	65,969	172,217	2.61	106,833	386,523	3.62	45,152	146,872	3.25	217,954	705,612	3.24

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces—pooled water, river and canal surfaces, and exposed beds; bare land, roads, rights-of-way, etc
[2] Canyon section.

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TABLE 128.—*Units assumed in estimating consumptive water requirements, in acre-feet per acre, San Marcial, N. Mex., to Fort Quitman, Tex.*[1]

Location	Irrigated lands				Native vegetation			Miscellaneous			
	Cotton	Alfalfa	Native hay, pasture	Miscellaneous crops	Grass	Brush	Bosque, trees	Cities, towns, villages	Temporarily out of cropping	Water surfaces	Bare land
San Marcial to Elephant Butte Dam					2.5	3.2	5.8			5.5	0.8
Palomas Valley (Elephant Butte Dam to Apache Canyon)		4.0	2.5	2.0	2.5	3.2	5.0	2.0	2.0	4.5	.8
Rincon Valley (in Sierra and Dona Ana Counties)	2.5	4.0	2.5	2.0	2.5	3.0	4.8	2.0	2.0	4.5	.7
Mesilla Valley in New Mexico and Texas	2.5	4.0	2.5	2.0	2.5	2.8	4.8	2.0	2.0	4.5	.7
El Paso Division, Rio Grande project	2.5	4.2	2.5	2.0	2.5	3.0	4.8	2.0	2.0	4.5	.7
Hudspeth County Conservation and Reclamation District No. 1	2.5	4.2		2.0	2.5	3.2	5.0		2.5	4.5	.7

[1] Results of Bureau of Plant Industry salinity studies were not available when these estimates were made. Part IV

TABLE 129.—*Estimate of consumptive water requirements, main stem of Rio Grande, San Marcial, N. Mex., to Fort Quitman, Tex. (including precipitation), based on 1936 acreages*

Location	Irrigated lands			Native vegetation			Miscellaneous[1]			Total area mapped		
	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre	Acres	Acre-feet	Acre-feet per acre
San Marcial to Elephant Butte Dam				22,071	114,796	5.20	[2] 20,750	110,873	5.34	[2] 42,821	225,669	5.27
Palomas Valley (Elephant Butte Dam to Apache Canyon)	830	2,011	2.42	7,435	25,868	3.48	2,118	7,063	3.34	10,383	34,942	3.37
Rincon Valley (in Sierra and Dona Ana Counties)	15,206	40,346	2.65	7,310	27,955	3.82	5,398	16,817	3.12	27,914	85,118	3.05
Mesilla Valley in New Mexico and Texas	82,923	227,365	2.74	13,198	43,199	3.27	14,297	34,735	2.43	110,418	305,299	2.76
El Paso Division, Rio Grande Project	56,423	163,105	2.89	10,053	32,654	3.25	[3] 6,362	14,927	2.35	[3] 72,838	210,686	2.89
Hudspeth County Conservation and Reclamation District No. 1	13,579	35,631	2.62	5,899	22,567	3.83	2,117	5,061	2.39	21,595	63,259	2.93
Total area or average	168,961	468,458	2.77	65,966	267,039	4.05	[2,3] 51,042	189,476	3.71	[2,3] 285,969	924,973	3.23

[1] Cities, towns, and villages; land temporarily out of cropping; water surfaces—pooled water, river and canal surfaces, and exposed beds; bare land, roads, rights-of-way, etc.
[2] Includes water surface area of Elephant Butte Reservoir (16,674 acres) as averaged for June 1936.
[3] Exclusive of city of El Paso (6,210 acres).

NOTE.—Results of Bureau of Plant Industry salinity studies were not available when estimates were made. (Part IV.)

BIBLIOGRAPHY

(1) Abbe, Cleveland.
1905. A First Report on the Relations Between Climates and Crops. U. S. Dept. Agr., Weather Bureau Bul. 36, 386 p.

(2) Bates, C. G., and Henry, A. J.
1928. Forest and Stream-Flow Experiment at Wagonwheel Gap, Colo. Final Report on Completion of the Second Phase of the Experiment. Monthly Weather Review, Supplement 30, U. S. Weather Bureau.

(3) Blaney, Harry F., Taylor, Colin A., Nickle, Harry G., and Young, A. A.
1933. Water Losses Under Natural Conditions from Wet Areas in Southern California. Calif. Dept. of Pub. Wks., Div. of Water Resources Bul. No. 44, 176 p.

(4) Blaney, Harry F., Taylor, Colin A., and Young, A. A.
1930. Rainfall Penetration and Consumptive Use of Water. Calif. Dept. of Pub. Wks., Div. of Water Resources Bul. 33. Sacramento.

(5) Bloodgood, Dean W.
1921. Drainage in the Mesilla Valley of New Mexico. N. Mex. Agr. Expt. Sta. Bul. 129, 37 p.

(6) ———
1930. The Ground Water of Middle Rio Grande Valley and Its Relation to Drainage. N. Mex. Agr. Expt. Sta. Bul. 184, 60 p.

——— and Curry, Albert S.
1925. Net Requirements of Crops for Irrigation Water in the Mesilla Valley, N. Mex. N. Mex. Agr. Expt. Sta. Bul. 149, 47 p.

(8) ——— ———
1931. The Influence of Irrigation Head and Length of Run on the Use of Water for Alfalfa. N. Mex. Agr. Expt. Sta. Bul. 197, 10 p.

(9) Burkholder, Joseph L.
1928. Report of the Chief Engineer, Middle Rio Grande Conservancy District, N. Mex. 248 p.

(10) Colorado Cooperative Crop Reporting Service (U. S. Bureau of Agriculture Economics, Colorado State Planning Commission, and Predecessor Agencies).
Agricultural Statistics for Colorado, 1924, 1929 and 1934. Buls. 64, 87 and 92.

(11) Cone, V. M., and Kezer, Alvin.
1915. Irrigated Agriculture in San Luis Valley. Colo. Agr. Expt. Sta. Bul. 209, 32 p.

(12) Conkling, Harold, and Debler, E. B.
1919. Water Supply, Irrigation, and Drainage above El Paso. U. S. Dept. of the Int., Reclam. Service, 135 p., also charts, tables and maps (unpublished).

(13) Curry, Albert S.
1931. A Comparison of Methods for Determining the Volume-weight of Soils. Reprint, 1931, from Jour. Agr. Research, Vol. I, No. 1.

(14) ———
1934. Results of Irrigation Treatments on Acala Cotton Grown in the Mesilla Valley, N. Mex. N. Mex. Agr. Expt. Sta. Bul. 220, 43 p.

(15) Debler, E. B.
1924. Water Supply Requirements. U. S. Dept. of Int., Bur. of Reclam. (unpublished).

(16) ———
1929. Use of Water on Federal Irrigation Projects. Paper No. 1755. Trans. Am. Soc. C. E. Vol. 94, p. 1213.

(17) ———
1932. Final Report on Middle Rio Grande Investigation. U. S. Dept. of Int., Bur. of Reclam. (unpublished).

(18) ——— and Elder, C. C.
1927. Preliminary Report on Investigations in Middle Rio Grande Valley, N. Mex. Middle Rio Grande Conservancy District. 157 p. (unpublished).

(19) ——— and Walker, A. W.
1924. Water Supply for Rio Grande Project. U. S. Dept. of Int., Bur. of Reclam. 31 p. (unpublished).

(20) Follett, W. W.
1898. Equitable Distribution of the Waters of the Rio Grande. U. S. S. Doc. 229, 55th Cong., 3 pts., 287 p., 10 maps.

(21) Fortier, Samuel.
1925. Irrigation Requirements of the Arable Lands of the Great Basin. U. S. Dept. Agr. Bul. 1340, 56 p.

(22) ——— and Young, A. A.
1930. Irrigation Requirements of the Arid and Semiarid Lands of the Columbia River Basin. U. S. Dept. Agr. Tech. Bul. 200, 56 p.

(23) ——— ———
1933. Irrigation Requirements of the Arid and Semiarid Lands of the Pacific Slope Basins. U. S. Dept. Agr. Tech. Bul. 379, 70 p.

(24) ——— ———
1930. Irrigation Requirements of the Arid and Semiarid Lands of the Southwest. U. S. Dept. Agr. Tech. Bul. 185, 56 p.

(25) Harding, S. T. (chairman Society Committee et al.).
1930. Consumptive Use of Water in Irrigation. Paper No. 1760, Reprinted from Trans. Am. Soc. C. E., Vol. 94, p. 1349, 59 p.

(26) Hedke, C. R.
1924. Consumptive Use of Water by Crops. New Mexico State Engineer's Office. 26 p. (unpublished).

(27) ———
1925. Irrigation Development and Water Supply of the Middle Rio Grande Valley, N. Mex. The Rio Grande Valley Survey Commission. 38 p. (unpublished).

(28) Hemphill, Robert G.
1913. Irrigation in San Luis Valley. U. S. Bur. Agr. Eng. (unpublished).

(29) ———
1922. Irrigation in Northern Colorado. U. S. Dept. Agr. Bul. 1026, 85 p.

(30) Henny, D. C.
1925. Part of Statement of District to El Paso County Water Improvement District No. 1. Elephant Butte Irrigation District. 55 p., appendix 12 p. (unpublished).

(31) Hinderlider, M. C.
1922-1934. Biennial Reports. Colorado State Engineer's Office.

(32) Hosea, R. G.
1928. Irrigation in the Rio Grande Valley—1928. New Mexico State Engineer's Office. 90 p. (unpublished).

(33) Israelsen, Orson W.
1932. Irrigation Principles and Practices. John Wiley & Sons, Inc. New York. 422 p.

(34) Linney, Charles E., Garcia, Fabian, and Hollinger, E. C.
1930. Climate as It Affects Crops and Ranges in New Mexico. N. Mex. Agr. Expt. Sta. Bul. 182.

(35) McClure, Thomas M. (and predecessors).
Biennial Reports of State Engineer of New Mexico.

(36) Meeker. R. I.
1922. (May) Review and Brief Report, Rio Grande Interstate Water Conflict. Colorado State Engineer's Office, 18 p. (unpublished).

(37) ———
1924. (May) Water Supply, Irrigation, and Drainage, Present and Future Conditions, San Luis Valley, Colo. Colorado State Engineer's Office, 40 p. (unpublished).

(38) ———
1924. (August) Review of Water Supply, Drainage, Irrigated Area, and Consumptive Use of Water; Rio Grande Basin Above Fort Quitman, Texas. Colorado State Engineer's Office, 36. p. (unpublished).

(39) ———
1926. (February) Report on Gaging Stations on the Rio Grande, San Marcial, N. Mex., to Fort Quitman, Tex. Colorado State Engineer's Office (Unpublished).

(40) ———
1926. (June) Progress Report No. 2, Interstate and International Phases, Rio Grande Water Utilization, Colorado, New Mexico, Texas, and Mexico. Colorado State Engineer's Office, 54 p. (unpublished).

(41) ———
1928. (February) Progress Report No. 12, Rio Grande Interstate Investigations. Colorado State Engineer's Office, 45 p. (unpublished).

(42) ———
1928. (June) Progress Report No. 13, Rio Grande Investigational Studies. Colorado State Engineer's Office, 25 p. (unpublished).

(43) ———
1928. (November) Water Supply and Water Consumption, San Luis Valley, Colo. Colorado State Engineer's Office. 85 p. (unpublished).

(44) ——— and Burgess, L. T.
1928. (November) 1925–28 Investigational Studies of Water Uses Under Elephant Butte Reservoir in New Mexico, Texas, and Mexico. Colorado State Engineer's Office, 164 p. (unpublished).

(45) Meeker, R. I.
1928. Rio Grande Basin, Above Fort Quitman, Tex., Stream Flow Records, 1889 to 1927, Colorado, New Mexico, and Texas. Colorado State Engineer's Office, 46 p. (unpublished).

(46) Mortensen, E., and Hawthorn, L. R.
1933. The Use of Evaporation Records in Irrigation Experiments with Truck Crops. Reprint from Am. Soc. for Horticultural Science, Vol. 30, 4 p.

(47) National Research Council.
1934. Transactions of the American Geophysical Union. Part II.

(48) National Resources Committee.
1936. Deficiencies in Basic Hydrologic Data. Report of the Special Advisory Committee on Standards and Specifications for Hydrologic Data. 66 p.

(49) Newcomer, A. W.
1930. Depletion of Flow of Rio Grande at Colorado-New Mexico State Line. New Mexico State Engineer's Office, 5 p. and 10 tables (unpublished).

(50) Osgood, E. P.
1928. Preliminary Report, Use, Control, etc., Waters Above Fort Quitman. New Mexico State Engineer's Office, 16 p. and 1 map of San Luis Valley (unpublished).

(51) ———
1928 Report on Water Supply, Irrigation, and Drainage in the San Luis Valley, Colo., 1928. New Mexico State Engineer's Office, 200 p. (more or less) (unpublished).

(52) ———
1928. (August) Effect of Rains on Consumptive Use of Irrigation Water, Rio Grande Project, 1919–27. New Mexico State Engineer's Office (unpublished).

(53) Robbins, Wilford W.
1917. (February) Native Vegetation and Climate of Colorado in Their Relation to Agriculture, Colo. Agr. Expt. Sta. Bul. 224, 56 p.

(54) Rohwer, Carl.
1931. Evaporation from Free Water Surfaces. U. S. Dept. Agr. Tech. Bul. 271, 96 p,

(55) ——— and Follansbee, Robert.
1933. (February) Evaporation from Water Surfaces, a Symposium. Paper No. 1871, reprinted from Trans. Am. Soc. C. E., Vol. 99, 41 p. and discussions by 12 authorities.

(56) Siebenthal, C. E.
1910. Geology and Water Resources of the San Luis Valley, Colo. U. S. Dept. Int. Geological Survey, Water Supply Paper 240, 125 p.

(57) Sleight, R. B.
1917. Evaporation from the Surfaces of Water and River-Bed Materials. Jour. Agr. Research, Vol. X, No. 5, pp. 209–261.

(58) Slichter, C. S.
1905. Observations on the Ground Waters of Rio Grande Valley. U. S. Dept. Int. Geological Survey, Water Supply Paper 141. 83 p., 5 pls.

(59) Stout, O. V. P., Fowler, F. H., and Debler, E. B.
1935. (February) Report of San Luis Valley Drain Committee. U. S. Dept. Int., Bur. of Reclam. 26 p. (mimeographed).

(60) Summers, Thomas H., and Smith, E. D.
1927. An Agricultural Program for the San Luis Valley of Colorado. Colo. Agr. Col. Ext. Ser. 64 p.
Thompson, C. A., and Barrows, E. L.
1920. Soil Moisture Movement in Relation to Growth of Alfalfa. N. Mex. Agr. Expt. Sta. Bul. 123, 38 p.
(62) Tinsley, J. D., and Vernon, J. J.
1901. Soil and Moisture Investigations (for Year 1900). N. Mex. Agr. Expt. Sta. Bul. 38, 39 p.
(63) ——— and Vernon, J. J.
1903. Soil Moisture Investigations (for Year 1901-02). N. Mex. Agr. Expt. Sta. Bul. 46, 46 p.
(64) ——— ———.
1905. Soil Moisture Investigations (for Year 1904). N. Mex. Agr. Expt. Sta. Bul. 54, 27 p.
(65) Tipton, R. J.
1924. Soil Conditions and Drainage in San Luis Valley. Colorado State Engineer's Office, 58 p. (unpublished).
(66) ———
1924. Deduction of Acreage in San Luis Valley. Colorado State Engineer's Office, 4 p. (unpublished).
(67) ———
1930. (March) San Luis Valley, Present Method of Irrigation; Its Relation to Water Consumption and Waterlogging of Land; Change Through Additional Storage and Drainage Development Essential. Colorado State Engineer's Office, 64 p. (unpublished).
(68) ———
1933. (August) Synopsis of Engineering Report on Interstate Phases of Rio Grande River and Proposed "Sump" Drain and State Line Reservoir. Colorado State Engineer's Office, 26 p. (unpublished).
(69) ———
1935. Résumé of the Problem Concerning the Rio Grande above Fort Quitman, Tex. Colorado State Engineer's Office, 37 p. (unpublished).
(70) ——— and Hart, F. C.
1931. (March) San Luis Valley, Field Investigations, 1930 Consumptive Use Determination Evaporation Experiments, Drainage Measurements. Colorado State Engineer's Office, 17 p., charts, tables, and 1 map (unpublished).
(71) ——— ———
1932. Field Investigations, 1931 Consumptive Use Determination, Evaporation Experiments, Drainage Measurements—Sump Area Investigations, 1932. Colorado State Engineer's Office, 14 p., 19 tables, 2 charts (unpublished).
(72) ——— ———
1933. San Luis Valley, Field Investigations of 1932 Consumptive Use Determinations, Evaporation Experiments, Drainage Measurements, Sump Area Investigations. Colorado State Engineer's Office, 11 p., 24 tables, 2 charts (unpublished).
(73) Trimble, Robert E.
1928. The Climate of Colorado (a 41-year record). Colo. Agr. Expt. Sta. Bul. 340.
(74) United States Congress.
1893. A Report on Irrigation and the Cultivation of the Soil Thereby. 52d Cong., 1st sess., S. Doc. No. 43. Four parts with maps.
(75) ———
1890. Report of the Special Committee on Irrigation and Reclamation of Arid Lands, and Views of the Minority. 51st Cont., 1st Sess., S. Rep. No. 928.
(76) ———
1928. Middle Rio Grande Conservancy Project, Albuquerque, N. Mex. Letter from the Secretary of the Interior. 70th Cong., 1st Sess., H. Doc. No. 141. 22 p. and map.
(77) United States Department of Agriculture, Bureau of (Chemistry and) Soils.
1904. Soil Survey of San Luis Valley, Colo. 25 p. and map.
(78) ———
1914. Soil Survey of Mesilla Valley, New Mexico-Texas 39 p. and map.
(79) ———
1914. Soil Survey of the Middle Rio Grande Valley Area, New Mexico. 52 p. with map.
(80) ———
1929. Soil Survey of the Socorro and Rio Puerco Areas, New Mexico. 27 p. with map.
(81) United States Department of Commerce, Bureau of the Census (and Predecessor Agencies).
Fifth to Fifteenth Censuses of the United States and 1925 and 1935 Censuses of Agriculture for Statistics of Agriculture; Eleventh to Fifteenth Decennial Censuses for Statistics of Irrigation; Fourteenth and Fifteenth Decennial Censuses for Statistics of Drainage.
(82) United States Department of State.
1934. Rectification of the Rio Grande. Convention between the United States of America and Mexico, and Exchange of Notes. Treaty Series. No. 864. 56 p.
(83) University of New Mexico Bulletin (unnumbered).
1935. Resources and Opportunities of the Middle Rio Grande Valley.
(84) Willard, R. E., and Humbert, E. P.
1913. (April) Soil Moisture. N. Mex. Agr. Expt. Sta. Bul. 86.
(85) Yeo, H. W.
1928. (About) Irrigation in Rio Grande Basin in Texas and New Mexico. New Mexico State Engineer's Office (unpublished).
(86) ——— and Black, R. F.
1931. (February) Report on Water Supply, Irrigation, and Drainage in the San Luis Valley and Adjacent Mountain Areas in the State of Colorado. New Mexico State Engineer's Office. Vol. 1, 325 p.; Vol. 2, p. 326 to 541; Vol. 3, 5 maps (unpublished).

PART IV
QUALITY OF WATER IN UPPER RIO GRANDE BASIN

Report of the United States Bureau of Plant Industry [1]

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[1] By C. S. Scofield, Principal Agriculturist.

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PART IV
PREFACE

As originally prepared the report on the quality of the water of the Rio Grande Basin consisted of two parts; the analytical data and the interpretive report. The analytical data were assembled first in a volume of 296 pages, of which 70 copies were reproduced by multilith in January 1937 and distributed to cooperators. The interpretive report was prepared subsequently and with the expectation that the two reports would be published together. It was later decided to publish the interpretive report as a part of the report of the Rio Grande Joint Investigation and to publish the Analytical Data as Water Supply Paper No. 839 of the United States Geological Survey.

The introductory statement of the analytical data is reproduced below because it contains information needful to an understanding of the terms and tables of this report.

Introduction

The analytical data of this report have been obtained in part from field investigations conducted in 1936 by the United States Geological Survey and in 1935 and 1936 by the State of Texas, and in part from an investigation conducted since 1930 by the United States Bureau of Plant Industry in cooperation with the State engineer of Colorado, the United States Geological Survey, the United States section of the International Boundary Commission United States and Mexico, and the United States Bureau of Reclamation. In general the authority for the data is shown in the table headings or with the descriptive statements.

The locations from which the water samples have been obtained are described in the text that accompanies the tables of analyses. For the most part these descriptions are based on surveys of the type used by the General Land Office. For areas that have not been surveyed by the General Land Office, a similar net of sections and townships has been superimposed on the maps of this report. For convenience of cross-reference between this section of the report and the maps, the descriptive list includes an index number for each location. In this hyphenated index number the first number refers to the section, the second to the township, and the third to the range.

The tables of analytical data fall into three major groups as follows:

Group I. Tables that relate to conditions along the main stem of the Rio Grande as it has been sampled at nine gaging stations from Del Norte, Colo., to Fort Quitman, Tex., for several years past.

Group II. Tables that relate to conductance determinations on series of samples from a large number of stations representing both surface and ground waters. Mostly collected in 1936.

Group III. Tables that report the detailed analyses of samples from a smaller number of stations selected from among those for which conductance determinations have been made but including also some stations for which no additional conductance determinations have been made.

The tables of groups II and III are further subdivided so as to conform to the natural subdivisions of the drainage basin as follows:

1. The San Luis Valley comprises that portion of the drainage basin tributary to the main stream above the southern boundary of the State of Colorado.
2. The Middle Valley comprises that portion of the drainage basin tributary to the main stream between the southern boundary of the State of Colorado and the San Marcial, N. M., gaging station.
3. The Elephant Butte project is the designation used for that portion of the drainage basin between the San Marcial gaging station and the Fort Quitman, Tex., gaging station.

It should be noted that certain surface water stations in the San Juan drainage basin, and some stations on tributaries of the Rio Grande that enter the main stream below San Marcial, have been included in the tables for the Middle Valley.

For each of the subdivisions of the drainage basin there are tables for surface waters and for ground waters. The demarcation between these two sources is not always clear. Surface waters include not only all natural streams and irrigation canals diverted from them but also drains which latter are largely fed by ground water. Ground waters include samples from wells whether shallow (subsoil waters) or deep (underground waters). With ground waters have been included samples from springs when taken at the spring and samples from certain small ponds in the San Luis Valley where the water appears to be derived, at least in part, from artesian wells.

Methods of Analysis

In general the methods of analysis used in this investigation have been those adopted for use with irrigation waters by the Rubidoux Laboratory of the United States Bureau of Plant Industry.[1]

[1] U. S. Department of Agriculture, Bureau of Plant Industry. Methods of Analysis used in the Rubidoux Laboratory, Riverside, Calif., 11 pp. Revised Mar. 20, 1933 (Mimeographed.)

The tabulated analyses include some or all of the following determinations:

1. Specific electrical conductance, expressed as $K \times 10^5$ at 25° C.
2. Total dissolved solids, expressed as tons per acre-foot of water.
3. Hydrogen-ion concentration, expressed as pH.
4. Calcium (Ca), expressed as milligram equivalents per liter.
5. Magnesium (Mg), expressed as milligram equivalents per liter.
6. Sodium (Na), expressed as milligram equivalents per liter.

NOTE.—In some of the analyses the values reported for sodium are the results of the direct determination of that constituent, in other analyses the values have been obtained by difference, i. e., by subtracting the sum of the calcium and magnesium from the sum of the anions, bicarbonate, sulphate, chloride, and nitrate, all these constituents being expressed as milligram equivalents per liter.

7. Potassium (K), expressed as milligram equivalents per liter.
8. Carbonate (CO_3), expressed as milligram equivalents per liter.
9. Bicarbonate (HCO_3), expressed as milligram equivalents per liter.

NOTE.—Because the normal carbonate (CO_3) occurs infrequently in irrigation water it is not reported separately in most of the tables. Where it is reported by the analyst the values are added to the values for the bicarbonate in the tables.

10. Sulphate (SO_4), expressed as milligram equivalents per liter.
11. Chloride (Cl), expressed as milligram equivalents per liter.
12. Nitrate (NO_3), expressed as milligram equivalents per liter.
13. Silica (SiO_2), expressed as parts per million.
14. Boron (B), expressed as parts per million.

NOTE.—In general, the boron values reported in the tables of group I were determined at the Rubidoux Laboratory by the method of electrometric titration, while those in the tables of group III were determined at the Water Resources Laboratory of the United States Geological Survey by the colorimetric, turmeric method.

15. Fluoride (F), expressed as parts per million.

NOTE.—In general the fluoride values reported only in some of the tables of group III were determined at the Water Resources Laboratory of the United States Geological Survey by the ferric thiocyanate colorimetric method.

16. Silt (total suspended matter), expressed as tons per acre-foot of water.

NOTE.—Since the chief objective of the investigations here reported has been to learn the conditions of salinity in the area, only incidental consideration has been given to the silt burden of the streams. In collecting the water samples no serious effort has been made to obtain samples that would adequately represent the silt conditions and consequently the data on silt content here reported should not be taken as the best obtainable.

Computations and Interpretations

The tables of detailed analyses in groups I and III generally include one column headed percent sodium and another headed percent chloride. The values reported in these columns are derived from the analytical data reported in the tables. The values for percent sodium are obtained by dividing the sum of the values for all the cations, calcium, magnesium, and sodium (including potassium if reported) into the values for sodium (and potassium) multiplied by 100; i. e.—

$$\frac{\mathrm{Na}\ (+\mathrm{K}) \times 100}{\mathrm{Ca}+\mathrm{Mg}+\mathrm{Na}(+\mathrm{K})} = \text{percent sodium}$$

Similarly the values for percent chloride are obtain by the formula

$$\frac{(\mathrm{Cl}+\mathrm{NO_3}) \times 100}{\mathrm{HCO_3}+\mathrm{SO_4}+\mathrm{Cl}+\mathrm{NO_3}} = \text{percent chloride}$$

The significance of the derived value, percent sodium, is due to the role of the basic or cation constituents in the exchange reactions that occur when water containing dissolved salts comes in contact with the soil. The use in irrigation of waters containing high sodium percentages tends to impair the physical condition of the soil while the use of waters of low sodium percentages tends to maintain good physical condition or to improve poor physical condition where that condition has been caused by the deflocculation of the clay fraction.

The significance of the value, percent chloride, is less directly agricultural. It is probably true that with equal concentrations of total dissolved solids the water having the higher chloride percentage would be the less desirable because the chloride constituent is regarded as more toxic than the sulphate or bicarbonate. Probably the chief value of reporting the chloride percentage is that together with the percent sodium it indicates the general character of the water involved or the degree or relationship between waters from different sources.

The fact that the conductance (specific electrical conductance, $K \times 10^5$ at 25° C.) of water samples is extensively used in this report as a measure of the concentration of the dissolved salts, warrants an explanation of the meaning of the term and of the significance of the measurement. Speaking technically, the conductance of a water sample is the reciprocal of its electrical resistance. The electrical resistance is what is actually measured. The resistance, measured in ohms, is determined by means of a Wheatstone bridge and a suitable vessel in which two platinum electrodes are immersed in the water to be tested. With suitable means of temperature control or of compensating for differences of temperature of the water, the electrical resistance may be measured and the result of this measurement may be computed into the equivalent reciprocal of the resistance, which is the conductance, and the value stated as of a definite temperature. Because the measured resistance is more than 1 ohm and often several hundred ohms, the reciprocal is a decimal number. The letter K is the conventional symbol for electrical conductance; when it is followed by the symbol "$\times 10^5$" it means that the decimal point has been moved 5 places to the right. The expression "at 25° C." means that the resistance was determined with the solution at 25° centigrade or that the resistance reading was compensated to its equivalent at that temperature.

Conductance is a relative measure of the concentration of total dissolved salts, or more specifically, of the dissolved electrolytes in the water sample. It is .easure of the ionic concentration and because the various ions have different weights when measured gravimetrically the results of a conductance determination may not be converted precisely into a gravimetric measure of concentration such as parts per million or tons per acre-foot. There is, however, an approximate relationship between the two measurements, when applied to the systems of mixed salts that occur in natural waters. This relationship is such that, in general, natural waters having a conductance of 100 have a concentration of total dissolved salts of 0.90 to 1.0 ton per acre-foot. With any group of water samples of the same type or from the same general source, it becomes possible to make a close approximation of the gravimetric equivalent of a conductance value by determining both values for a number of representative samples.

In this report conductance determinations have been given for a large number of samples in the tables of group II. In the tables of groups I and III detailed analyses are reported. These detailed analyses include the values both for conductance and for total dissolved solids. When it is desired to convert the conductance values found in the tables of group II into gravimetric 'valents it is suggested that recourse be had to the es of detailed analyses where samples similar in source or type may be found and a conversion factor obtained by taking the mean of the ratios between the conductance and gravimetric values for a number of such samples.

Water analysts usually report gravimetric concentrations of total salts or total dissolved solids as parts per million. In the present report such concentrations are reported as tons per acre-foot. The conversion from one scale to the other may be made by the factor 0.00136. In other words, parts per million is multiplied by 0.00136 or 136×10^{-5} to obtain the value, tons per acre-foot. Similarly the silt content of water samples is usually reported by analysts as percentage or parts per hundred. In the tables of this report, when the silt constituent is included, it is expressed as tons per acre-foot by using the conversion factor 13.6. These conversion factors are derived from the assumption that an acre-foot of water weighs 2.72 million pounds.

In case it is desired to convert the values here reported as milligram equivalents per liter into the scale of parts per million (milligrams per liter) that may be done by the use of appropriate factors. These factors are the combining weights of the several ions related to hydrogen as 1. The factors conventionally used to multiply the milligram equivalent values are: for calcium, 20.0; for magnesium, 12.15; for sodium, 23.0; for potassium, 39.0; for carbonate, 30.5; for bicarbonate, 61.0; for sulphate, 48.0; for chloride, 35.5, and for nitrate, 62.0. If it is desired to compute the "total hardness" of a water sample to be expressed as the equivalent of calcium carbonate in parts per million, this may be done by taking the sum of the milligram equivalents of calcium and magnesium multiplied by 50.

PART IV
SECTION 1.—INTRODUCTION AND SUMMARY

The present report is based on an investigation conducted during the summer of 1936 under the auspices of the Rio Grande Joint Investigation together with certain cooperative investigations conducted since 1930 by the United States Bureau of Plant Industry; the United States Bureau of Reclamation; the United States Geological Survey; the United States section of the International Boundary Commission, United States and Mexico; and the State engineer of Colorado. This latter cooperative investigation was confined chiefly to conditions along the main stream while the investigations of 1936 included also the tributary streams and the ground waters in the irrigated areas of the basin.

The analytical data of this report include also certain analyses of water samples published in Water Supply Paper 240, United States Geological Survey, copies of which are not now readily obtainable, and certain analyses of water samples from stations in Elephant Butte project made by the United States Bureau of Reclamation but not hitherto published. Certain other analyses, of samples collected at the San Marcial and Courchesne (El Paso) stations 1905–7, are reported in Water Supply Paper 274, United States Geological Survey, and are not here included. Water Bulletins Nos. 1 to 5, published by the International Boundary Commission, 1931 to 1935, also include certain analytical data, most but not all of which are here included. Finally there are some analyses of water samples, collected from the Rio Grande near Las Cruces, N. Mex., in 1893–94, published in Bulletin 30 of New Mexico College of Agriculture and Mechanic Arts, June 1900, that are not here included because of uncertainty as to the discharge conditions represented.

The data of this investigation show that the Rio Grande collects annually from its headwaters in the high mountains of southern Colorado approximately a half million acre-feet of water of very low salinity. Some of this water is diverted for irrigation use in the San Luis Valley of Colorado and as the river leaves that valley it carries, in addition to its residual channel flow, the discharge of drains from the irrigated lands of the San Luis Valley together with the contributions from several tributary streams that originate in the mountains surrounding the valley. The salinity of these valley contributions is such as to increase materially the concentration of the water of the river as it leaves the San Luis Valley and the State of Colorado, but this concentration is still low as compared with conditions found farther down the stream.

As it leaves the San Luis Valley the river enters a canyon section in northern New Mexico in which it is joined by several tributaries which increase its volume of discharge to somewhat less than a million acre-feet annually but do not change its salt concentration materially. Below this canyon section water is diverted at successive stations to irrigate lands contiguous to the river channel above and below Albuquerque, N. Mex. In this section, known as the Middle Valley, the river is joined by several tributaries chiefly from the west and also it regains drainage water from the irrigated lands. The net effect of these diversions and contributions during the period covered by this investigation has been to diminish slightly the volume of river water annually leaving Middle Valley as compared with the volume that enters it at its upper end but to increase its concentration about threefold.

The stream waters leaving the Middle Valley are collected in Elephant Butte Reservoir the storage capacity of which is approximately 2.5 million acre-feet, or about three times the annual discharge of the stream at this point. Water is released from this reservoir chiefly during the summer months, as it is required irrigation on the lands of the Elephant Butte proj. which lie along the stream for 200 miles.

During the period of the investigation here reported, 1931 to 1936, the mean annual volume of water released from Elephant Butte Reservoir has been slightly more than 750,000 acre-feet. This water is practically all diverted from the stream channel for irrigation use, some of it being allocated for use in Mexico. There are no important tributary contributions between Elephant Butte Reservoir and the lower end of the El Paso Valley but the drainage waters from the upper divisions are returned to the stream channel and rediverted to the lower divisions.

The discharge of the stream at the Fort Quitman gaging station, the lower limit of the basin covered by this investigation, consists largely of drainage water returned to the stream from the lower divisions. Its mean annual volume for the period of this investigation, 1931–36, has been about 175,000 acre-feet, as compared with 750,000 acre-feet annually released from Elephant Butte Reservoir. Its mean concentration at the Fort Quitman station, 2.75 tons of dissolved solids per acre-feet, is more than three times as high as that of the water released from Elephant Butte Reservoir.

The conditions of salinity found in the ground waters of areas contiguous to the main stream are in gener similar to those found in the stream itself. In the present investigation more attention has been given to quality of the shallow or subsoil waters for the rea- that those are thought to be more closely related to irrigation conditions. Except in the San Luis Valley practically no use is made of the deeper ground waters for irrigation. The deeper ground waters of the San Luis Valley as obtained through artesian wells were formerly used to some extent for irrigation. Some of these artesian waters contain dissolved salts that differ strikingly in composition from the surface waters of that area. They are characteristically "soft" waters, i. e., they have high sodium percentages and their use for irrigation has been injurious to the soil. This is not true for all of the artesian waters of the San Luis Valley but only of the waters obtained in certain areas.

In summarizing the data obtained by this investigation an attempt has been made to estimate the quantities of total dissolved solids and of each of the more important constituents carried by the stream past each of the principal gaging stations. These estimates show not only that the quantities of the total dissolved solids passing each station differ greatly but also that the quantities of each constituent differ even more, so that the composition of the dissolved solids changes appreciably from station to station. Probably the most striking of these changes is the progressive increase in the quantity of the chloride constituent in the down-stream direction. For 1936 the only year for which data are available for all nine stations the quantity of chloride increased from 2,800 tons at the Del Norte station to 137,000 tons at the Fort Quitman station. The increase in sodium, from 4,400 tons to 92,000 tons was also large.

It seems obvious that the increasing quantities of these salt constituents reported for the successive stations may be due in part at least to the contributions from tributary streams. But this source of origin can hardly be invoked to explain large increases that occur between stations where no tributaries join the stream, as for example within divisions of the Elephant Butte project. In order to explain the phenomenon of the local gains of the chloride constituent, associated as it is with local losses of other constituents, the theory of displacement is proposed. According to this theory it is suggested that the ground water held in the sediment-filled valleys of the river, as in the El Paso Valley, may be highly concentrated in respect to chloride and that the irrigation water percolating from the distribution system displaces some of this saline ground water which in turn passes out through the drains. The agricultural implications of this theory are referred to briefly.

Scope of Report

This report deals with the quality of the water, both surface and underground, in the drainage basin of the Rio Grande above Fort Quitman, Tex. The constituents of the water here reported are those that relate to its agricultural use rather than to its use for domestic or industrial purposes. The area involved includes 34,450 square miles, of which all but 834 square miles is in the United States, the remainder being in Mexico. Within this area water samples have been obtained for analysis from 1,215 stations within the basin and from 7 stations in the basin of San Juan River, a tributary of the Colorado River, making a total of 1,222 stations covered by the report.

For the purpose of this investigation the drainage basin above Fort Quitman has been divided into three areas:

(1) The San Luis Valley, Colo.;

(2) The Middle Valley, N. Mex., extending from the Colorado State line to the San Marcial gaging station and including the stations in the San Juan [1] basin; and

(3) The Elephant Butte project, New Mexico and Texas, including the area below San Marcial and above Fort Quitman gaging station

According to these subdivisions there are 486 sampling stations in the San Luis Valley, 621 in the Middle Valley, and 115 in the Elephant Butte project. For the water samples obtained from these stations two kinds of analyses were made:

(1) A determination of the concentration of dissolved salts either by electrical conductance or by evaporating a filtered aliquot and weighing the dried residue; and

(2) A detailed analysis by which, in addition to the concentration, a number of the more important constituents were determined.

The present report gives the results of 12,074 analyses, of which 9,564 are of concentration only and 2,510 are detailed analyses.

In respect to the three subdivisions of the basin, the number and kind of analyses are as follows:

For the 486 stations in the San Luis Valley there are 1,552 analyses for concentration only and 283 detailed analyses—a total of 1,835.

For the 621 stations in the Middle Valley, including the San Juan stations, there are 4,481 analyses for concentration only and 739 detailed analyses—a total of 5,220.

For the 115 stations of the Elephant Butte project there are 3,531 analyses for concentration only and 1,488 detailed analyses—a total of 5,019.

[1] In connection with the present investigation it was deemed advisable to include the examination of a few water samples from the headwaters of San Juan River, a tributary of the Colorado, because of the possibility that some of these waters might be diverted into the adjacent basin of the Rio Grande. The locations of these samples and their analyses are given on pp. 220 and 221 of the analytical data. These samples were all of low salinity, with conductances ranging from 5.5 to 31.2 and with low sodium percentages, ranging from 17 to 34. In general they are similar in quality to those collected from the upper tributaries of the Rio Grande that discharge into the San Luis Valley.

PART IV

SECTION 2.—THE HEADWATERS OF THE RIO GRANDE

The headwaters of the Rio Grande come from the eastern crest of the Continental Divide in the eastern part of San Juan County, Colo. Tributaries join it from the high mountains of Hinsdale and Mineral Counties as it makes its tortuous way eastward to enter the San Luis Valley in Rio Grande County some 65 miles east of its head. This part of the basin above the Del Norte gaging station comprises 1,320 square miles of rough topography and all above 8,000 feet in elevation. The precipitation collected in this area, largely winter snows and early spring rains, yields annually 707,000 acre-feet of water, or approximately 0.72 acre-foot per acre of drainage area. About 64 percent of this volume passes the Del Norte gaging station during the 3 months, May, June and July.

In the present investigation, 1936, water samples were obtained from eight stations on the main stream and its tributaries above Del Norte. From three of these stations, viz, the main stream at Wason, South Fork, and Pinos Creek, samples were taken periodically during the summer for conductance determinations. From the other five stations individual samples were taken for partially detailed analyses. These samples all show that these headwaters are remarkably low in dissolved salts. The conductances range from 4.6 to 12.8; the latter equivalent to 0.13 ton of total dissolved solids per acre-foot of water.

During 1936 the volume of water passing the Del Norte gaging station was 472,300 acre-feet, or approximately two-thirds of the normal flow for the 46 years of record. This discharge as represented by 47 samples, taken at approximately weekly intervals, ranged in conductance from 5.6 in June to 16.0 in January with a weighted mean for the year of 8.46. The weighted-mean total dissolved solids was 0.11 ton per acre-foot. These values show that the headwaters of the river are remarkably pure, and the detailed analyses show that the chief dissolved constituents are calcium bicarbonate and silica.

From Del Norte, where the river enters the San Luis Valley near the center of its west side, the stream flows southeast and south to cross the State line into New Mexico at a point about 30 miles east and 40 miles south of Del Norte. In this section the stream is joined by several tributaries that drain both the east and west sides of the south end of the San Luis Valley. The streams that drain the slopes of the northern half of the valley yield little water and that is mostly dissipated locally by evaporation from the valley floor, which is somewhat lower than the channel of the Rio Grande.

The drainage area of the Rio Grande tributary to the section of the stream between Del Norte and the New Mexico State line comprises approximately 3,500 square miles exclusive of closed basins. This area includes the major portion of the half million acres of irrigated land in the San Luis Valley. Unlike the uppermost section of the drainage basin this area makes no addition to the stream flow. On the contrary, it consumes more water than it contributes. The mean annual discharge, for the 46 year period, is 707,000 acre-feet at Del Norte, while at the Lobatos station just above the State line the mean annual discharge is 550,000 acre-feet. During 1936 the difference was even greater, 472,300 acre-feet at Del Norte and 281,000 acre-feet at Lobatos.

Water is diverted from the main stream and from its tributaries in this section for irrigation in the San Luis Valley. Not all the stream flow is diverted and some of the diverted water returns to the stream as drainage from the irrigated lands. The effect of these drainage returns is to increase the salinity of water of the main stream. In 1936 its conductance at the Lobatos station, based on 50 consecutive samples, ranged from 13.3 in April to 70.9 during a period of low flow in July. The weighted mean conductance for that station for the year as shown in table 17 was 26.5 as compared with 8.46 at Del Norte. The total dissolved solids increased between the two stations from 0.11 to 0.265 ton per acre-foot.

The conditions of salinity found in the tributary streams in this section of the basin are discussed in the next chapter. It may be noted here that the effect on the main stream of these tributary contributions is not only to increase the concentration of its dissolved salts but also to change the composition of these salts.

The diversion and use of water for irrigation in the San Luis Valley appears to have an appreciable regulatory effect on the regimen of the stream between the Del Norte and Lobatos stations in addition to diminishing the total flow and increasing the concentration of the dissolved salts. At the Del Norte station in 1936 the discharge during the summer months, April to September, inclusive, comprised 85 percent of the total annual discharge leaving only 15 percent for the 6 months, October to March. At the Lobatos station the corresponding percentages were 60 and 40.

PART IV
SECTION 3.—THE SAN LUIS VALLEY

Surface Waters

San Luis Valley lies near the middle of the southern part of Colorado. It is bounded on the west by the main range of the Rocky Mountains and on the east by the Sangre de Cristo Mountains. Peaks in both ranges of mountains extend above 13,000 feet. The Valley extends northward from the southern State line about 90 miles to Villa Grove and the greatest width of its gently sloping plain is about 45 miles. Its elevation is about 7,500 feet at its lowest point with arable land rising to 8,000 feet. The Rio Grande, which enters the Valley near the center of the west side, has deposited a delta cone that extends into the valley trough and cuts off the free outflow of the streams that discharge into the northern half of the Valley so that their waters are dissipated locally by evaporation and transpiration.

In the present investigation, water samples have been taken from six of the streams that discharge into the northern part of the valley from the Sangre de [illegible]o Mountains on the east, from Crestone to Sand [illegible]k. The conductance of these is very low, ranging from 4.6 to 10.4. The dissolved constituents are chiefly silica and calcium bicarbonate, so that these waters probably contribute very little salinity to the valley lands. Of the streams entering the northern part of the Valley from the west, four have been sampled, from Kerber to La Garita Creeks. The conductances of these samples range higher than those from the streams on the east, from 9.1 to 64.1, with the highest conductance found in Kerber Creek. Detailed analyses of samples from Saguache and Carnero Creeks show that here also the chief dissolved constituents are silica and calcium bicarbonate. These findings indicate that currently the streams discharging into the northern part of the San Luis Valley are contributing very little potential salinity to the Valley lands.

In the southern part of the Valley the drainage from the east is collected by two streams that discharge into the Rio Grande, Trinchera Creek and Culebra Creek. On Trinchera Creek there are two small reservoirs, one at Mountain Home, above the 8,000-foot contour line and above any important diversion, and Smith Reservoir at the junction of Ute and Sangre de Cristo Creeks [illegible] Trinchera Creek. Samples taken from four sta[illegible] on Trinchera and Ute Creeks above the 8,000-foot contour line show conductances ranging from 7.7 to 21.1. Sangre de Cristo Creek sampled at two stations above Smith Reservoir shows conductances ranging from 23.6 to 40.2; while Trinchera Creek sampled at a station below Smith Reservoir range from 24.5 to 36.1. Detailed analyses of samples from this station show that calcium bicarbonate is the chief constituent of the dissolved solids. On Culebra Creek the waters from some of the upper tributaries are stored in Sanchez Reservoir. The stream has been sampled at one station near the town of San Luis, 5 miles below the reservoir. These samples showed conductances ranging from 9.2 to 25.3, and a detailed analysis shows that here also the dissolved solids are chiefly silica and calcium bicarbonate. No samples were taken from the lower sections of Trinchera and Culebra Creeks as they join the Rio Grande.

On the west side of the southern part of the San Luis Valley the natural drainage and much of the artificial drainage from the irrigated land is collected by three streams that empty into the Rio Grande. These are Alamosa, La Jara, and Conejos Rivers. The upper tributaries of Alamosa River are collected in Terrace Reservoir, above any important diversions. Water samples from a station just below this reservoir show conductances ranging from 12.0 to 24.2. One sample taken lower down the stream but above any irrigation drain had a conductance of 10.6. On Rock Creek, a tributary of the Alamosa, samples were taken from four stations. One of these stations located above the 8,000-foot contour line showed conductances ranging from 6.8 to 13.1. Spring Creek is a tributary of Rock Creek that originates below Monte Vista canal. Samples from a station near its source showed conductances of 24 to 38. In its lower section, Rock Creek collects drainage from irrigated land and samples from two stations a few miles above its mouth showed conductances ranging from 46.3 to 106, and detailed analyses of samples from these stations show the presence of appreciable quantities of sulphate, chloride, and sodium.

La Jara River has been sampled at three stations. At the upper one of these, located above the irrigated land, the conductances ranged from 10.6 to 16.9. At Diamond Springs which, like Spring Creek, originates below an irrigation ditch, the conductances were 32.9 and 36.3. At a station on the main stream farther down near Sanford the conductance range was 24.6 to 42.4, and a detailed analysis showed appreciable quantities of sodium and sulphate.

On Conejos River and its tributaries samples were obtained from seven stations. From three of those stations on the main stream above the irrigated land and from one station on Los Pinos Creek, also above irrigation, the conductances were all very low, ranging from 4.6 to 11.4. One sample from the main stream in the irrigated area north of Antonito had a conductance of 6.0. Samples from a station on Rio San Antonio, near Manassa, where it joins the Conejos, had conductances of 11.1 and 22.2, while samples from a station on the main stream near its junction with the Rio Grande had conductances ranging from 14.8 to 23.4.

These data show that of the five streams in the San Luis Valley that discharge into the Rio Grande, all carrying some drainage from the irrigated lands, the salinity is low in all except in Rock Creek, and it is not excessively high even in the lower section of that stream.

In addition to the surface waters of natural streams the present investigation included the sampling of a number of drains on the west side of the San Luis Valley. On the delta cone north of the Rio Grande where some of the cropped land has a very permeable subsoil, the method of irrigation is to fill the subsoil with water by percolation from field ditches, controlling the elevation of the water in the subsoil by means of a system of outlet ditches or shallow open drains. In the area between the Rio Grande, north of Monte Vista, and the town of Center, this system of irrigation is extensively used. This area is served by the Rio Grande drain. Samples from two stations on this drain show conductances ranging from 27.5 to 56.9. The area north of Center is served by the Gibson drain which has been sampled at two stations, where the conductances ranged from 29.6 to 36.6. The area lying to the east of Center, toward the Valley trough, is served by the San Luis Valley irrigation district drain which discharges into San Luis Lake. This drainage system has been sampled at six stations with conductances ranging from 39.3 to 67.8. Samples have been taken also from two stations on San Luis Lake where conductances ranging from 63.9 to 108 were found. Detailed analyses of samples from the lake show that the chief salt constituents are sodium and magnesium combined with bicarbonate, sulphate, and chloride. Fluoride also was reported for these samples in concentration of approximately 1.5 p. p. m. The Hall drain in the northern tip of the valley was sampled at one station with conductances of 49.3 and 61.1.

In that portion of the Valley south and west of the Rio Grande samples have been taken from seven stations on five drains. At two stations on the Bowen drain the conductances ranged from 56.4 to 98.1, being slightly higher from the station near the drain outlet. Samples from one station on Waverly drain ranged from 96 to 186. From two stations on Carmel drain the range was 85.5 to 161. Morgan drain, sampled at one station, gave the highest conductances reported, ranging from 126 to 310; while those from one station on La Jara drain ranged from 68.6 to 89.7.

The data in respect to the surface waters of San Luis Valley show that the streams flowing into the Valley contain relatively very little dissolved material. The water leaving the Valley through the Rio Grande seldom contains more than half a ton of dissolved solids per acre-foot and frequently less than 500 pounds per acre-foot. The water in the drains north of the river is also of relatively low salinity. In some of the drains south of the river the salinity is relatively high and it is doubtless from this area that most of the salt is derived that the river carries out of the Valley.

Ground Waters

The San Luis Valley is a sediment-filled depression between the Rocky Mountains on the west and the Sangre de Cristo Mountains on the east. In dimensions it is approximately 90 miles from north to south and about 40 miles from east to west. The present surface slopes gently from both sides to the Valley trough which, at its lowest point is about 7,500 feet above sea level. The sediments of the Valley fill are apparently saturated with water. The surface of the saturated zone is generally within a few feet of the ground surface, and through much of the lower area the deeper water is under pressure from the higher intake areas at the sides of the Valley so that flowing artesian wells are common.

In the present investigation concerning the quality of the ground waters of the Valley there were two objectives: (1) to measure the concentration of the total dissolved salts, and (2) to ascertain the composition of these salts. The data bearing on the first objective are reported on pages 66 to 99 of the Analytical Data. The results of the detailed analyses are reported on pages 198 to 219 of that report. In both groups the data are given in respect to surface areas without attempting to make a definite segregation between shallow or subsoil waters and the deeper waters. Samples were taken from 280 shallow or observation wells, often only 6 to 8 feet deep. These samples manifestly represent only the subsoil water. Among the deeper wells, numbering 121, there is wide range of depth. Some of these were dug wells of various depths from 15 feet to 80 feet or more, but not tightly cased and probably drawing water from each permeable stratum penetrated. Even among the drilled wells it is not always certain that the water comes chiefly from near the bottom of the well because some of them are ·ightly cased to the full depth. In addition to the , samples were taken from 10 springs and from 1 small lake, making a total of 412 stations.

In collecting the data in respect to concentration only the aim was to take three samples, a month or more apart, from each well. It was known that such consecutive samples, particularly from shallow wells, might show different concentrations as local conditions changed during the season. Sometimes these differences are so great that it becomes difficult to decide on an acceptable single value for the concentration of the water from a given well. It is possible that there may have been occasional errors in recording the location data for certain samples which might explain some of the discrepancies. However, it is known from similar investigations elsewhere that pronounced changes do occur in the concentration of consecutive samples from the same shallow well. Such changes are uncommon in consecutive samples from deep wells and from many of these only individual samples are reported.

In the present interpretation of the conductance data from the wells of the San Luis Valley the location of each well was spotted on a map of the area, with an indication as to whether the well was regarded as shallow or deep. The conductance data for each well were then ·nined and a single value taken that seemed best to ·sent the conditions of concentration at that well. ·t was found that for the whole area the conductance values ranged from less than 20 to more than 1,000. For convenience of consideration, an arbitrary grouping was established involving nine ranges of concentra·ion as measured by conductance. The accepted concentration value for each well was then indicated as a part of its location symbol so that the map showed the approximate concentration of the water obtained from it.

The nine groups are listed in table 1 with the conductance limits of each group, together with the number of locations that fall into each group. It will be seen that of 411 stations sampled the waters of 150 of them had conductances of less than 50, while there were 123 stations from which the waters had conductances ranging from 50 to 100. Thus 273 out of 411 stations gave samples with conductances ranging under 100. At the other extreme there were 35 stations, including a small lake, not listed in the table, from which the conductances ranged above 400. The concentration of dissolved salts is generally less in the water from deep wells than from the shallow ones, yet 11 of the deep wells gave conductances higher than 150.

The ground waters with the lowest salinity occur on sides of the Valley. On the west side most of ·ells, both shallow and deep, north of the Rio Grande and west of range 9, fall into group 1 with conductances less than 50. On the west side, south of the river, there is a narrow band of water of low salinity mostly from deep wells extending southeast through ranges 8 and 9 to the south end of the Valley. Along the east side of the Valley there is a narrow band of ground water of low salinity extending southeastward from the southwest corner of range 11, township 44, to range 12, township 37. Between these two sides the ground water is generally more saline, though not universally so.

TABLE 1.—*Ground waters of the San Luis Valley, Colo., showing the number of locations sampled and the number of samples that fall into each of nine groups of concentration range*

Group and range of concentration as measured by conductance ($K \times 10^5$ at 25° C.)	Springs	Shallow wells	Deep wells	Total locations
1. Less than 50	7	46	97	150
2. 50 to 100	1	112	10	123
3. 100 to 150	....	47	3	50
4. 150 to 200	....	13	8	21
5. 200 to 250	....	7	2	9
6. 250 to 300	....	7	....	7
7. 300 to 350	....	10	1	11
8. 350 to 400	....	6	....	6
9. More than 400	2	32	....	34
Total	10	280	121	411

The ground waters of highest salinity occur in two areas. One of these areas extends along the trough of the Valley from north of Moffat in range 10, township 44, south to the east side of range 11 in township 38. In this area the highest salinity occurs in the vicinity of San Luis Lake, although the water of that lake was not highly saline during the period of this investigation. The other and smaller area of high salinity lies south and west of the Rio Grande in range 9, township 37, and in ranges 9 and 10, township 36. In the northern area high salinity is found in the deeper waters as well as in the subsoil waters, while in the southern area high salinity is confined to the shallow or subsoil waters.

In addition to determining the total concentration of the dissolved salts in the ground waters of the San Luis Valley, the present investigation also includes a number of detailed analyses in order to ascertain the character of the dissolved salts. Prior to the present investigation it had been known that in some of the ground waters the preponderant constituents were sodium and carbonate or bicarbonate, while in other ground waters the dominant basic constituents were calcium and magnesium. The analytical data includes on pages 198 to 219 the detailed analyses of water samples from 151 locations in the Valley, including one sample from a small saline lake (30–40–12). In respect to samples from 11 of these locations, the analyses were not sufficiently detailed to afford information as to all of the more important constituents.

The results of the more complete detailed analyses show that regardless of concentration there are at least two types of ground water that differ from each other in important particulars. The differences between representative samples of waters of the two types are shown in table 2. The first two samples listed in the table are similar in concentration and in composition to the surface waters that enter the Valley from the surrounding hills. The first of these two samples is from a deep well located on the west side of the Valley on the delta of the Rio Grande. The other sample is from the east side of the Valley on the delta of Trinchera Creek. In these two samples the dominant basic constituents are calcium and magnesium, and while the dominant acidic constituent is bicarbonate, there are present also appreciable proportions of sulphate and chloride.

TABLE 2.—*Typical ground waters of the San Luis Valley, Colo., showing the ratio of each constituent to the sum of the constituents of each group, i. e. cations and anions.*

Location of sample	Conductance $K \times 10^5$ at 25° C.	Percentage of each Constituent					
		Calcium (Ca)	Magnesium (Mg)	Sodium (Na+K)	Bicarbonate (CO_3+HCO_3)	Sulphate (SO_4)	Chloride (Cl+NO_3)
13-40-7 (11J13R1)	16.5	62	18	20	70	15	15
14-30-73 (14S14Q1)	24.7	71	18	11	88	9	3
9-40-11 (11N9D1)	182	1	2	97	97	.5	2.5
10-37-10 (14M10L1)	29.5	12	2	86	92	6	2

The second pair of samples shown in the table represent the conditions found in the "soft" ground waters of the central part of the Valley. One of these is from a deep well located in the trough of the Valley about 5 miles northwest of San Luis Lake. It has been selected as representing the rather saline yellowish or brownish water that is found under an extensive area of the central section of the Valley. Its dissolved salt is composed almost wholly of sodium carbonate or bicarbonate. Many of the waters of this type in this area contain flammable gas of the hydrocarbon type. The other sample of "soft" water is from a well located at Alamosa, south of the Rio Grande and west of the Valley trough. The ground waters represented by this sample are usually not colored, do not contain gas, and have low salinity like the inflowing surface water, but the proportions of calcium and magnesium are very low.

The inference is that the deeper waters circulating through the sediments of the central part of the Valley have been subject to base exchange reactions and possibly also to some reduction or decomposition of the sulphate constituent. The soft water from these wells has doubtless been an important factor contributing to the occurrence of extensive areas of "tight" or relatively impermeable soil that exist in the lower sections of the Valley.

The significant and characteristic difference between the two types of water shown in table 2 lies in the sodium percentage. In the first pair of samples this percentage is low, less than 30, while in the second pair it is high, more than 80. A summary of the conditions found in the San Luis Valley in respect to the sodium percentage of the ground waters is shown in table 3. The locations from which the more complete detailed analyses were made are classified into 10 groups. It will be seen that in the case of the 100 deep wells there are 44 with low sodium percentages, i. e., less than 30, while there are 30 wells with sodium percentages above 80. The waters from the shallow wells and from the springs tend to fall into these groups rather than into the intermediate position. It seems probable that in the case of the shallow wells the high sodium percentages are the result of local contamination by waste water from adjacent deep wells rather than of the natural accumulation of such water in the subsoil from irrigation with surface water.

TABLE 3.—*Ground waters of the San Luis Valley, Colo., classified as to sodium percentages*

Ranges of sodium percentages	Springs	Shallow wells	Deep wells	Total locations
Less than 10	....	1	3	4
10 to 20	....	3	22	25
20 to 30	3	6	19	28
30 to 40	2	2	12	16
40 to 50	....	1	8	9
50 to 60	1	1	1	[illegible]
60 to 70	1	8	2	[illegible]
70 to 80	....	4	3	[illegible]
80 to 90	....	2	13	[illegible]
90 to 100	2	7	17	26
Total	9	30	100	139

One notable characteristic of the ground waters of the San Luis Valley is the frequent occurrence of fluoride and the occasional occurrence of boron. Not all of the analyses included the determination of these elements and the quantities found were listed in the present report when the fluoride was not less than 1.0 p. p. m. or when the boron was not less than 0.55 p. p. m. Of the samples from 151 stations in the Valley, fluoride of 1.0 p. p. m. or more was reported for 44 and among these were 14 samples containing more than 0.55 p. p. m. of boron.

For the San Luis Valley as a whole, it may be said that the ground waters around the margins are of low salinity with low sodium percentages, being similar in character to the inflowing surface waters. In the lower sections of the Valley there are two areas in which the shallow or subsoil waters are generally rather saline. Toward the middle of the Valley the deeper water is generally "soft", i. e., has a high sodium percentage and in the area north of the eastern edge of the Rio Grande delta the deeper waters are both soft and rather saline.

PART IV
SECTION 4.—THE MIDDLE RIO GRANDE VALLEY

Surface Waters

The Middle Rio Grande Valley as here delimited includes that section of the drainage basin extending from the Colorado State line south some 230 miles to the San Marcial gaging station. In the present investigation, water samples have been obtained from 24 stations on 15 tributaries that join the main stream in this section. On the east side from Costilla Creek on the north to Galisteo Creek there are 10 small streams, while on the west side there are 5 streams, 2 of which, the Chama and the Puerco, are relatively large. Samples were obtained also from 5 stations on 4 tributary streams south of San Marcial, 2 from the west side of the river and 2 on the east side. Of these 4 streams probably only 1, the Alamosa, that discharges into Elephant Butte reservoir makes any surface contribution to the main stream.

The waters contributed from the east by the streams north of Galisteo Creek are all of low salinity with conductances ranging from 4.8 up to 72, with only one tion above 50. The sodium percentages are also none exceeding 30. For Galisteo Creek, which is y much of the time, there is only one sample. This sample, with conductance of 212, probably does not represent the normal flood discharge of the stream.

The Rio Chama, an important tributary from the west, has been sampled at six stations. Its waters are also of low salinity with conductances less than 80 and with sodium percentages less than 30. Conditions are different in Jemez Creek. This stream drains a region in which soft rocks are exposed and in which there are salt springs. Some of the flood waters from torrential rains are not highly saline but the low water discharge is strongly so, with conductances ranging well above 400. The Rio Puerco and Rio Salado that join the main stream above the San Acacia gaging station are also rather saline. In both of them the waters of the latter part of a flood may have conductances below 100, but the low-stage discharge and the first flood waters are likely to range up to 400 or more. The dissolved salts carried by these last-named streams—the Jemez, Puerco, and Salado—consist largely of sulphates of calcium, sodium and magnesium. The sodium percentages seldom range much above 50. Of the four streams south of San Marcial, the samples from only one, Tularosa Creek, had conductances ranging above No detailed analyses were made on samples these streams.

The main stream of the Rio Grande, on leaving the San Luis Valley in Colorado, enters a canyon section at 7,425 feet above sea level and emerges from that section 120 miles south, above Cochiti, at 5,230 feet elevation. From Cochiti to San Marcial, a distance of approximately 165 miles, its gradient is lower, about 4.5 feet per mile, and it meanders through a flood plain sometimes 4 or 5 miles wide. In this section the river bed is only slightly lower than the flood plain and along much of its course it has been necessary to confine the river channel by levees on one or both sides. On the land side of these levees the borrow pits have been interconnected to make intercepting drainage canals which are known as riverside drains. The irrigated land along this section of the stream lies chiefly on the flood plain and is watered by canals that head at successive diversion points. The sedimentary material of the valley fill is saturated with water and the surface of this saturated zone is seldom more than 5 or 6 feet below the ground surface and is often closer. In order to keep the subsoil water from rising so high as to cause crop injury a system of open drains has been constructed through the irrigated land. These are known as interior drains. These interior drains discharge into the river or into the Riverside drains, which in turn discharge into the river, and these waters are again diverted for irrigation farther down the stream.

In the present investigation water samples were taken from the main stream of the Rio Grande at two stations above Cochiti and at 11 points from Cochiti to San Marcial, inclusive. The conductances of these samples are reported on pages 100 to 105 of the analytical data and the results of the detailed analyses are given on pages 226 to 229. These analytical data show that there is a general increase in salinity in the down stream direction. This increase in salt concentration may be due in part to the contributions made by the Jemez, Puerco, and Salado and in part to the dissipation of water by plant use and by evaporation taking place on the irrigated lands. The analytical and discharge data do not afford an adequate basis for estimating what quantities of water and of dissolved salts enter the Middle Valley by way of the Rio Grande at Cochiti and what part enters from its tributaries between Cochiti and San Marcial, or of estimating the quantities that pass out at San Marcial. This subject will be considered in a later part of the present report.

In addition to the samples taken from stations on the main stream of the Rio Grande, the irrigation supply of the Middle Valley was sampled at 22 stations on 15 of the more important canals. Eight of the canals supply land west of the river and seven are on the east side. On six of these canals samples were taken at two or more stations to learn whether the water was appreciably different toward the lower end of the canal than near its head. The findings of this part of the investigation are that the canal water is much the same as the river water and that there is no appreciable difference between samples taken near the head of the canal and those taken lower down on the same canal. The conductances tend to range higher in the canals that take water from lower down stream than in those that take off at the upper end of the valley. There is one that is exceptional. It is Jaral lateral no. 1 (index no. 17-5-2). The water sampled from this canal showed conductances consistently higher than that of adjacent canals. For 17 consecutive samples taken from July to December 1936 the conductances ranged from 129 to 173. The water in this canal comes not from the river but from the lower Belen Riverside drain, which in turn carries the water of the Sausal interior drain.

At one of these canal stations, at the head of Arenal main canal near Albuquerque, it was deemed advisable to take samples more frequently than once a week to learn if there were differences from day to day in the salinity of the water. The samples taken at this station (p. 109 of the analytical data) are assumed to represent the water in the Rio Grande as it passes Albuquerque. The record of these 95 consecutive samples shows that in general the differences from day to day were slight. There were times however, notably early in August and again late in September, when the daily differences were large.

While the data so far available are not sufficient to justify an attempt to estimate the quantities of dissolved salts that annually move past any given point in the Middle Valley, they do appear to justify an estimate as to the concentration or conductance of the water passing certain of the control stations. The control stations selected for consideration are the following:

(1) Cochiti—the uppermost diversion point for the Middle Valley;

(2) Isleta, which is at the lower end of the Albuquerque division;

(3) San Acacia, which is at the lower end of the Belch division; and

(4) San Marcial, which is at the lower end of the entire Middle Valley.

In the upper division, between Cochiti and Isleta, two tributaries, Galisteo Creek and Jemez Creek, enter the Valley. In the next division, between Isleta and San Acacia, the Rio Puerco and Rio Salado enter. Finally all the Valley drainage is returned to the main stream above San Marcial. In arriving at a single mean value for the conductance of the water passing each station during the period of the present investigation the conductance data are taken not only for the samples collected at the station but also the samples taken from the irrigation canals that head at the station. Thus the mean for the Cochiti station is derived from samples taken at the river station and at two points on the Sili Canal and two on the Cochiti Canal. The Isleta mean includes results from the Belen and Peralta canals, and the San Acacia mean includes the data from the Socorro canal. The mean for San Marcial, not weighted for discharge, is based on 63 consecutive samples taken during the year ending October 1, 1936. The mean conductance values for the four stations are shown in table 4. It is evident from this table that there is a progressive increase in salinity at the successive stations in the down-stream direction. It is evident also that the percentages of sodium and of chloride increase progressively in the same direction.

TABLE 4.—*The mean conductance values and the sodium and chloride percentages of water passing successive control stations on the Rio Grande through the Middle Valley in New Mexico during 1936*

Station	Number of samples	Mean conductance ($K \times 10^6$ at 25° C.)	Percent	
			Sodium Na	Chloride Cl
Cochiti	83	37.9	27	7
Isleta	85	53.2	34	11
San Acacia	84	89.0	44	17
San Marcial	63	100.7	----------	----------

It has been noted above that where the elevation of the river channel is nearly as high as that of the land on either side, levees have been built to confine the stream, and that on the land side of these levees open channels, known as riverside drains, have been made. The water collected in these riverside drains is returned to the river at favorable points. This water is evidently derived in part from lateral percolation from the river channel and in part from water percolating directly from the irrigated land or discharged by the interior drains.

In the present investigation water samples were taken from a number of stations on these riverside drains. The number of such samples and the mean conductance values for the three main divisions of the valley are shown in table 5. It will be seen that these conductance values are somewhat higher for each division than the corresponding values reported for the river and irrigation-canal samples in table 4. The increased concentration for each division ranges from 26 to 39 percent. This is probably not a valid comparison, however, because there is wide variation in the salinity of the samples from the different drains. In some of them the water is very similar to that of the river, while in others the salinity is much higher. I the Belen division, for example, the lower Belen Rive side drain is much more saline than the river. Salinity ·· latively high also in the San Antonio and Limitar ide drains in the lower division. It seems prob-... that in these cases the water in the riverside drains is contaminated from the land side either by percolating subsoil water or by the discharge of interior drains.

TABLE 5.—*The mean conductance values of water samples from riverside drains in the Middle Rio Grande Valley, N. Mex., 1936*

Division	Number of samples	Mean conductance ($K \times 10^5$ at 25° C.)
Cochiti to Isleta	407	52.7
Isleta to San Acacia	333	71.1
San Acacia to San Marcial	119	110.7

The conditions of salinity found in the waters of the interior drains are extremely variable. Some of these drains evidently are cut through permeable soil areas so that they collect large quantities of water of low salinity, while others serve areas where the subsoil water is more saline. In the report of analytical data, pages 112 to 145, conductance data are reported from 76 stations on 37 named interior drains, and detailed analyses of samples from 40 of these stations are reported on pages 230 to 245. Some of these named drains are branches of others and there are in some cases ·l successive stations on the same drain.

.e more important of the interior drains are listed in table 6. This table shows also the approximate length of each drain, including branch drains, above the lowest sampling station, the approximate discharge, the mean conductance, and the character of the dissolved salts as expressed by the percentage of sodium and of chloride.

An examination of the data of table 6 shows that the water of these interior drains varies greatly in salinity. This variation is less pronounced among the drains of the upper division than among those of the middle and lower divisions. In the lower division the mean conductance of the water in one drain is 58.9, while that of another is 303. There are similar differences among the drains in respect to the sodium and chloride percentages of the water.

In order to show the comparative salinity found in the irrigation water, in the Riverside drains, and in the interior drains, their mean conductance data are assembled in table 7. It should be noted that while for the irrigation water the means are based on data from samples taken at the three diversion points and in canals heading at these points, the data for the Riverside drains include all samples taken from these ·s. In both cases the means have not been ted by the discharge. The means for the interior ...s include only samples from one station on each

TABLE 6.—*Characteristics of interior drains of the Middle Rio Grande Valley, N. Mex., 1936*

Name	Station index no.	Approximate length above station, miles	Approximate discharge c. f. s.	Mean conductance ($K \times 10^5$ at 25° C.)	Mean percent Sodium	Mean percent Chloride
Upper division:						
Santa Domingo	34-15-5	3.0	7.0	80.4	27.5	4.7
Bernalillo	14-12-3	4.5	2.0	106.7	66	34
Corrales	34-12-3	1.1	2.0	81.0	31	9
Alemeda	13-10-2	13.0	35.0	93.3	35	12
San Jose	7- 9-3	2.7	3.0	79.7	25	16
Barr	1- 8-2	4.0	10.0	117.3	43	23
Isleta	23- 8-2	24.0	51.0	80.7	36	11
Middle division:						
Otero	14- 7-2	3.0	4.0	99.2	34	15
Los Lentes	27- 7-2	2.2	4.0	116.4	40	12
San Fernandez	3- 6-2	1.2	2.0	65.8	25	14
Tome	4- 5-2	20.3	32.0	153.0	45	16
Los Chavez	8- 5-2	13.0	16.0	202	60	18
Bosque	25- 4-1	11.8	20.0	195	52	23
Las Nutrias	36- 3-1	6.0	12.0	96.7	48	15
Bernardo	10- 2-1	3.5	12.0	204.3	53	28
Lower division:						
San Acacia	11- 1-1	4.0	5.0	303	59	51
Chamisal	24- 1-1	1.5	3.0	116.3	29	43
Polvadera	1- 2-1	3.0	2.0	193.0	45	42
Lopez C	20- 3-1	5.5	15.0	76.6	33	13
Lopez B	31- 3-1	1.8	3.0	58.9	32	16
Lopez A	32- 4-1	5.4	10.0	254	71	49
Elmendorf	30- 5-1	2.0	5.0	114	47	20

drain; the one nearest the outlet, and these means have been weighted by the discharge. The data of table 7 show that while with the irrigation water and the Riverside drains there is a progressive increase in salinity in the downstream direction, this is not true with the interior drains. Reference to the data of table 6 shows that in the lower (Socorro) division the water of two drains is of remarkably low conductance. In fact, in these drains, Lopez C and Lopez B, the mean conductances are lower than the mean conductance of the irrigation water for that division. The explanation for this phenomenon is not apparent from the data at hand.

TABLE 7.—*Comparison of the mean conductance of the irrigation water with that of the Riverside drains and the interior drains in the Middle Rio Grande Valley, N. Mex., 1936*

Division	Mean conductance of samples: Irrigation	Riverside drains	Interior drains
Cochiti and Albuquerque	37.9	52.7	88.5
Belen	53.2	71.1	163.0
Socorro	89.0	110.7	155.0

Ground Waters

The area involved in the present investigation lies in the flood plain adjacent to the Rio Grande, and extends from the Angostura diversion dam at the north line of township 13 north, to a point just above San Marcial gaging station in township 6 south, a distance of approximately 120 miles. The flood plain, which includes all of the irrigated land, ranges up to 5 miles in width, but is constricted to a mile or less at several places. Two of these constrictions, the one at Isleta and the one at San Acacia, separate the valley into three natural subdivisions. Each of these divisions is known by the name of its principal town. They are in succession from north to south, Albuquerque, Belen, and Socorro.

In order to obtain information as to the elevation of the surface of the saturated zone of the subsoil in the flood plain a large number of observation wells have been established. For the most part these wells are in lines that cross the valley in an east-west direction. They are approximately a mile apart. The investigation of the conditions of salinity in the subsoil waters is based upon samples taken from certain of these wells. In general all of the wells in a selected line were sampled three times during the latter part of the summer of 1936. The conductance data for these samples are reported on pages 146 to 167 of the analytical data. Samples from one or more wells in each line, thought to be representative, were taken for detailed analyses. These results are reported on pages 246 to 255 of the analytical data.

The tables of conductance data include also the elevation of the water surface in each well at the date of sampling. These elevation data, when compared with the best obtainable data as to the elevation of the water surface in the river, in line with the wells, show that in general the subsoil water is lower than the water in the river. It is not apparent that there is any consistent relationship between the elevation of the water surface in the wells and the salinity of the water. It is to be inferred that the wells of low salinity are surrounded by permeable subsoil through which water moves freely in the direction of the valley gradient. Conversely, it is probable that the wells of high salinity are located in areas where the subsoil water does not move freely and where the topographic conditions have long favored the evaporation of water from the soil with the consequent deposition of the residual dissolved salts.

In addition to these samples of the subsoil water, a number of samples were obtained from representative wells that penetrate to the deeper underground water such as is used locally for domestic and industrial purposes. These samples were analyzed in detail with results reported on pages 256 to 261 of the analytical data.

In discussing the data obtained from these analyses of the ground waters they will be grouped according to the divisions of the valley. It was to be expected, and it was found to be a fact, that the salinity of the water obtained from these observation wells varied between wide limits. With a few exceptions the successive samples from any one well were similar but adjacent wells were often very different. The ranges in mean conductance found in the observation wells of the three divisions are as follows:

Albuquerque	From 40 to 1,790
Belen	From 60 to 5,450
Socorro	From 36 to 7,290

It will be noted that in respect to the maximum salinity found, the lowest value was in the upper division and the highest value was in the lower division. This was not true in respect to the lowest salinity. The lowest mean value was found in the Socorro division, along with the highest.

A summary of the conditions found in each of the three divisions of the Middle Valley in respect to the salinity of the ground waters is presented in table 8. The first entries in this table relate to wells sampled for conductance only. The mean conductances reported for each division of the valley show that in general there is an increase in salinity from the upper to the lower end of the valley. The second group of entries in the table relate to the samples selected for detailed analysis from among the larger number of wells sampled for conductance only. It is evident that fairly representative wells were selected because the mean conductance values for these wells, about one-fourth of the total number sampled, are very close to the mean values for the larger number. The data as to the percent sodium and percent chloride show trends in the same direction as the conductance values.

From the data reported for the deep wells it is evident first, that in general the deeper waters are somewhat less saline than the shallow or subsoil waters; yet the mean values for conductance are somewhat higher for the deep wells of each division than those reported for the inflowing surface waters (table 4). The values for the percentages of sodium and of chloride, while only slightly different from those for the shallow wells, are appreciably higher than those reported for the inflowing surface water.

TABLE 8.—*The ground waters of the Middle Rio Grande Valley, N. Mex., summarized by divisions*

	Albuquerque	Belen	Socorro
Subsoil waters (conductance only):			
Number of stations	138	156	70
Mean conductance ($K \times 10^5$ at 25° C.)	158	274	337
Detailed analyses:			
Number of stations	35	37	20
Mean conductance ($K \times 10^5$ at 25° C.)	146	276	319
Percent sodium	42	52	56
Percent chloride	13	20	24
Deep wells, detailed analyses:			
Number of stations	11	11	12
Conductance ($K \times 10^5$ at 25° C.)	73.5	157	150
Percent sodium	32	58	55
Percent chloride	11	19	20

Another comparison that may be made is that between the salinity of the water from the shallow wells and that found in the interior drains. It is to be inferred that both the wells and the drains are supplied from the same zone of subsoil water. The fact is that the mean conductance values for the wells as shown in table 8 are nearly twice as high as the corresponding mean values for the drains as shown in table 7.

This difference is probably due largely to the con- ›ns of subsoil and topography where some of the ɹs of high salinity are located. These conditions may be such as to favor the evaporation of water and at the same time to retard or even to inhibit the lateral movement of the concentrated residual water. The subsoil water that reaches the drains is more likely to do so by moving through the more permeable subsoil, while the water that saturates the less permeable subsoil may be dissipated chiefly by evaporation and thus become more concentrated with residual dissolved salts. It is to be expected, therefore, that the subsoil water that finds its way to the drains represents the water contained in the more permeable subsoil, while the wells being located at random in respect to subsoil conditions, probably give a better representation of salinity conditions in the whole mass of subsoil water.

There is one characteristic of the subsoil waters of the Middle Rio Grande Valley that calls for comment. That is the fluoride content. Samples of this water from 92 stations were analyzed for this constituent. It was reported absent for only 6 of these stations. For 39 stations its concentration was less than 1 p. p. m., while in 40 stations it ranged from 1 to 4 p. p. m., and for 7 stations it was 4 p. p. m. or more. It should be understood, of course, that these subsoil waters are probably not much used for drinking purposes. Some of the samples in which the higher fluoride concentrations were found were too saline to be acceptable for domestic use. However, there appears to be little correlation between the fluoride content and total salinity in this group of samples. The analyses of the samples from the deeper wells included the determination of fluoride for only a few stations and for these the concentrations were mostly low.

PART IV

SECTION 5.—THE ELEPHANT BUTTE PROJECT

Surface Waters

The area here designated as the Elephant Butte project includes that section of the Rio Grande Drainage Basin lying between the San Marcial gaging station on the north and the Fort Quitman gaging station on the south. Within this area the irrigated lands of the Elephant Butte project lie on the flood plains adjacent to the stream and are almost continuous from Percha Dam, located at the north line of township 17 south, in New Mexico, to the intersection of the river with the eastern boundary of El Paso County, Tex. On the south side of the river below El Paso there is an area of irrigated land in Mexico that is not included in the Elephant Butte project. There is also an area of irrigated land in Hudspeth County, Tex., east of El Paso County and above the Fort Quitman gaging station that is not included in the Elephant Butte project or in the present investigation.

The Rio Grande enters the Elephant Butte area at the northeast corner of sec. 25, T. 7 S., R. 2 W., N. Mex. P. M., where the zero of the gage at the San Marcial station is 4,455.38 feet above sea level and the water surface of the stream is 6 to 8 feet higher. It leaves the area at the Fort Quitman, Tex., gaging station, where the zero of the gage is 3,454.06 feet above sea level and the water is usually 2 feet or less above that elevation. The Fort Quitman station is approximately 180 miles south and 84 miles east of the San Marcial station, a distance by river of approximately 240 miles.

There are several small ephemeral streams that enter the Rio Grande from the west between San Marcial and Las Cruces, N. Mex. None of importance enters from the east or from either side south of Las Cruces. Local torrential rains falling in this narrow section of the basin cause temporary floods and add something to the water supply. But the major portion of the water used in the Elephant Butte area enters by way of the main stream at San Marcial.

Elephant Butte Dam, located about 38 miles below San Marcial, creates a reservoir that when full backs the water up nearly to the gaging station. Water is released from this reservoir during the irrigation season to supply the irrigated land of the Elephant Butte project and certain lands in Mexico, below El Paso.

The irrigated lands of the Elephant Butte project fall into three divisions, separated by natural constrictions of the valley. The first or uppermost of these is the Rincon division. This is irrigated by water diverted from the river at Percha Dam, located near the north line of township 17 south, about 20 miles below Elephant Butte Dam. The division extends to the south line of township 19 south. The flood plain throughout this division is narrow, seldom more than a mile wide.

The next division, the Mesilla Valley, begins at Leasburg Dam, located in sec. 10, T. 21 S., R. 1 W., and extends southward across the State line into Texas, ending at another constriction of the valley just above the El Paso (Courchesne) gaging station in sec. 9, T. 27 S., R. 4 E., a distance of nearly 60 miles. The flood plain of the Valley in this division ranges up to 4 miles in width. Its irrigation water is diverted not only from Leasburg Dam but also from Mesilla Dam, located in sec. 13, T. 24 S., R. 1 E.

The lower or El Paso Valley division occupies the flood plain on the north side of the river from the city of El Paso to a point about a mile west of the line between El Paso and Hudspeth Counties where higher land approaches close to the river channel, here th international boundary. This division is about 3. miles long and ranges up to 4 miles in width. Its irrigation water is diverted from the river at three points: (1) at International Dam just west of El Paso city limits; (2) at Riverside heading, 2 miles south of the town of Isleta; and (3) at Tornillo canal heading about a mile south of the town of Fabens.

In the Elephant Butte project there is not a definite system of riverside drains such as are found in the Middle Valley. There is, however, an extensive system of open drains in each of the divisions of the project. The water collected by these drains in each division is returned to the river above the point of diversion for the next division farther down stream.

In connection with the present investigation, the waters of the Rio Grande have been sampled at 8 successive stations below San Marcial, beginning at the outlet of Elephant Butte Dam and ending at Fort Quitman gaging station. The waters collected by the drains of the project have been sampled at 29 stations. The conductance data in respect to these samples are reported on pages 168 to 175 of the analytical data. Certain detailed analyses of samples from some of these stations are reported on pages 262 to 265.

The subject of the quality of the irrigation and drainage water of this project had been under investigatio for several years before the present investigation was begun. The results of these earlier investigations have n incorporated in the present report and will be .sidered in the discussion of it.

At the moment only scant reference will be made to the data based on samples collected from the successive stations along the main stream. These data will be discussed in a later chapter of the report. It may be noted here that the conductance results on page 169 of the analytical data show that during the late summer of 1936, the salinity of the water increased at each successive diversion point from a mean of 87.9 at Percha Dam to a mean of 398 at Fort Quitman. These values should not be taken as the best expression of conditions at these stations but they do illustrate the fact that the salinity of the river water increases as it passes through the project. The trend of the volume of discharge is shown by this same table to be in the opposite direction. The mean discharge at Percha Dam for the sampling dates was 1,739 cubic feet per second while the means for the sampling dates at Fort Quitman was only 88 cubic feet per second. These values also should not be taken as the best available. A more complete summary of the discharge and salinity conditions along this section of the stream will be given in a later chapter.

In respect to the drains of the project, data as to 'ume of discharge and salinity are available for rela- .ly long periods. As early as 1918 the Bureau of .eclamation began to take water samples from some of them and to determine the total dissolved solids by evaporating a filtered aliquot and weighing the dry residue. This program of sampling was continued through 1936. The rates of discharge and total dissolved solids for the drain as reported by the Bureau of Reclamation are given on pages 270 to 285 of the analytical data.

In order to supplement this inquiry with information as to the composition of the dissolved salts, additional samples have been taken for detailed analyses. During the period from January 1929 to July 1930, five sets of samples were taken in this inquiry. Again from April 1933 to January 1934, four sets of samples were taken. Finally, a single set of samples was taken in August 1936. The results of the detailed analyses of these 10 consecutive samples are shown on pages 286 to 295 of the analytical data.

In addition to the samples taken in 1936 for detailed analysis, consecutive samples were taken from each drain during the late summer of 1936 for conductance determination. The results are given on pages 168 to 175 of the analytical data. The means for the discharge, the total dissolved solids and the conductance ined by these three different investigations show .ly good agreement in respect to each drain where comparisons are possible. This appears to indicate that in volume and in concentration the discharge of a drain has been fairly constant, at least during recent years. This makes it possible to show in tabular form some of the characteristics of each of the drains in the project. The data presented in the following tables are from the findings on the samples taken for detailed analysis from 1929 to 1936. It should be understood that these data are not to be taken as the truest and most accurate that could be derived from all the information available. They do, however, show approximately what the conditions of discharge and salinity have been.

In the Rincon division there are four drains as shown in table 9. Each of these drains discharges into the river. Their combined length is 41.7 miles. Their mean discharge is 1.1 cfs. per mile of drain with a combined annual discharge of 36,400 acre-feet of water. In mean salinity they range from 1.05 to 1.35 tons per acre-foot, and they discharge annually about 48,000 tons of dissolved salts. Because of the relatively large volume of water carried by the river through this division of the project the effect of this return flow is not appreciable. In fact the salinity of the drainage water is very little higher than that of the river itself.

For the Mesilla Valley division of the project there are 12 drains listed in table 10. Not all of these discharge directly into the river. The Leasburg and Mesilla drains discharge into the Del Rio drain and the Nemexas and West drains discharge into Montoya. The net totals shown in the table refer to the system that returns water to the river. The combined length of the drains of this division is 210 miles, or slightly more because some of the stations are above the outlets. The volume of discharge per mile of drain ranges from 0.7 to 1.7 cfs. with a mean of 1.15 or slightly more than the mean for the Rincon division. The combined annual discharge for the drains of the division is 205,000 acre-feet of water carrying 383,000 tons of dissolved solids.

TABLE 9.—*Drains of the Rincon division, Elephant Butte project, New Mexico; length of drain; discharge of water and of dissolved solids*

Name	Length-miles	Discharge		Dissolved salts		
		Cubic feet per second per mile	Acre-feet per year	Tons per acre-foot	Tons per year	Year-tons per mile
Garfield	12.4	1.2	10,800	1.33	14,400	1,160
Hatch	10.8	1.3	10,600	1.33	14,100	1,300
Angostura	4.1	.7	2,000	1.05	2,100	510
Rincon	14.4	1.2	13,000	1.35	17,500	1,210
Total division			36,400		48,100	

By way of comparison it may be noted that the mean annual discharge at Leasburg Dam, at the head of the

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TABLE 10.—*Drains of the Mesilla Valley division, Elephant Butte project, New Mexico and Texas; length of drain; discharge of water and of dissolved solids*

Name	Length-miles	Discharges				
		Water		Dissolved salts		
		Cubic feet per second per mile	Acre-feet per year	Tons per acre-foot	Tons per year	Year-tons per mile
Selden	4.6	1.1	3,600	1.43	5,100	1,100
Leasburg	12.3	.9	8,300	1.01	8,400	700
Picacho	7.2	1.2	6,200	1.15	7,100	1,000
Mesilla	17.1	.7	8,300	1.30	10,800	600
Del Rio	73.1	1.5	77,700	1.32	102,600	1,400
Chamberino	5.3	1.0	3,700	2.13	7,900	1,500
La Mesa	21.8	1.7	27,400	1.13	31,000	1,400
East	22.9	1.0	15,900	4.06	64,600	2,800
Anthony	7.7	1.0	5,300	2.34	12,400	1,600
Nemexas	20.2	1.2	17,200	2.50	43,000	2,100
West	39.0	1.3	37,500	1.61	60,400	1,500
Montoya	67.6	1.2	65,300	2.46	152,100	2,200
Net total	210.2	....	205,000	....	383,000	....

Mesilla Valley division, is approximately 745,000 acre-feet of water carrying approximately 650,000 tons of dissolved solids, while the corresponding values at El Paso (Courchesne) in the lower end of the division are 523,000 acre-feet and 638,000 tons. Between the upper and the lower gaging station there is an annual loss of 220,000 acre-feet of water and possibly 10,000 tons of dissolved salts. If the actual diversion of water to the irrigated lands of the division were restricted to the quantity currently consumed, namely 220,000 acre-feet, this water would carry to the land annually 190,000 tons of dissolved salts none of which would be returned to the river. It seems inescapable that the annual addition of 190,000 tons of dissolved salts to the irrigated soils of the division would, in time, impair their productivity. There may be a question as to whether it is necessary to divert 200,000 acre-feet of water in addition to the 220,000 acre-feet consumed in order to carry away the residual salt and maintain a salt balance within the division. But it seems obvious that there must be diverted enough water in excess of the quantity consumed to carry away the residual salt.

Conditions in the El Paso Valley division are less simple than in the Mesilla Valley division. The latter includes all the irrigated land contiguous to and served by the irrigation and drainage systems. In the El Paso Valley division on the other hand a substantial quantity of water, possibly 100,000 acre-feet annually, is diverted across the international boundary and there are no data as to the quantity or salinity of the drainage return from that water. Then, too, the water to irrigate San Elizario Island (the island district) is diverted above Fabens. Finally, there is an area of irrigated land in Hudspeth County between the Elephant Butte project and Fort Quitman gaging station, to which water is diverted below Fabens but for which no data are available as to drainage return. Consequently the best that can be done in respect to the El Paso Valley division is report the findings as to the drains located in that division and compare these findings with the known condition at the Courchesne station above the division and at the Fort Quitman station below it, leaving out of account the conditions on the irrigated lands in Mexico and in Hudspeth County, Tex.

There are six drains that discharge into the river. The volume of discharge per mile of drain ranges from 0.5 to 1.8 cubic feet per second. The combined length of the drains as shown in table 11 is 193.4 miles and the combined annual discharge is 133,000 acre-feet, carrying 494,000 tons of dissolved salts. The mean annual discharge at Courchesne, at the head of the Valley, is approximately 523,000 acre-feet carrying 638,000 tons of salt, while at Fort Quitman the mean annual discharge is approximately 172,000 acre-feet, carrying 473,000 tons of salt. It appears from this comparison that while the annual discharge of the drains from this division is some 50,000 acre-feet less than that of the river at Fort Quitman, their annual salt burden is some 21,000 tons larger.

TABLE 11.—*Drains of the El Paso Valley division, Elephant Butte project, Texas; length of drain; discharge of water and of dissolved solids*

Name	Length (miles)	Discharges				
		Water		Dissolved salts		
		Cubic feet per second per mile	Acre-feet per year	Tons per acre-foot	Tons per year	Year-tons per mile
Above Fabens:						
Playa	23.6	1.3	22,900	2.11	48,300	2,045
Franklin	36.8	1.2	32,900	2.68	88,200	2,390
Middle	55.3	1.2	46,400	3.10	143,800	2,600
River	23.4	.9	15,400	3.83	59,000	2,520
Quadrilla	8.6	.8	5,000	1.62	8,100	944
Mesa	29.1	.5	10,600	3.21	34,000	1,170
Fabens intercepting	1.9	1.8	2,500	2.64	6,600	3,470
Net total	118.3	....	79,900	....	251,500	2,800
Tornillo and island districts:						
Fabens	10.7	1.1	8,500	2.50	21,200	1,980
Island	13.7	1.3	12,500	6.21	77,600	5,660
Border	9.3	.7	4,700	8.25	38,800	4,180
Alamo	20.6	.6	9,400	3.60	33,800	1,640
Tornillo	75.1	1.0	52,900	4.59	242,800	3,230
Net total	75.1	....	52,900	....	242,800	....
Division total	193.4	....	132,800	....	494,300	2,970

It should be emphasized that these values for discharge and salt burden should be taken as only approximations of the truth. They are presented here rather to indicate the trend of relationships than to give definite estimates. Furthermore the comparisons between the total drainage discharge and the discharge of the river at Fort Quitman are not valid because some of the drains join the river above Fabens, so that some of the water and of the salt that they discharge is diverted, just below Fabens, into the Tornillo canal, and these totals 'us include some water and salt that is counted twice.

.t now remains to consider the characteristics of the ussolved salts removed from the irrigated land of the Elephant Butte project in comparison with those of the water of the Rio Grande as it is diverted to the land for irrigation and as it is influenced by the return of the drainage water. In order to facilitate comparisons between the conditions in the several drains and in the river above and below the drains it is advantageous to show, in addition to the concentration of the dissolved solids, the proportions of each of the major salt constituents. There are six of these constituents—three cations, calcium, magnesium, and sodium, and three anions, bicarbonate, sulphate, and chloride. In computing the percentage composition of the salt constituents the sum of the cations, as milligram equivalents, is divided into the value for each cation (multiplied by 100) and the sum of the anions is similarly divided into each anion value. These percentage values are then directly comparable with each other regardless of the concentration of the solution.

The conditions reported for each of the drains listed in the following three tables are based on the findings reported in the tables of detailed analyses for these drains on pages 286 to 295 of the analytical data. The ·ean values reported have not been weighted for ·erent discharge values. The mean annual discharges .. water and of dissolved solids for each drain have similarly been computed from the arithmetical, not the weighted mean values. The percentage composition values reported for the gaging stations on the Rio Grande above and below each division are based on weighted means.

The conditions found in the drains of the Rincon division are reported in table 12. It will be noted that the values representing concentrations, i. e., conductance and total dissolved solids are higher in each drain than in the river water either above or below the division. In respect to the several salt constituents the calcium is higher in three of the drains than in the river water; the magnesium is lower in all of the drains. The values for sodium reported for the drains range above and below those of the river. The same is true for bicarbonate. The sulphate values for the drains are consistently lower while the chloride values are consistently higher than in the river.

The comparable data for the river at Elephant Butte outlet, above the Rincon division and for Leasburg Dam below it, show that while the volume of the drainage is relatively small and its salinity is not relatively , there is an appreciable increase in salinity between two river stations. This increase may be due in part to salts brought into the river by creeks or washes that enter it along this section. There is no other information as to the quantity or quality of such contributed waters.

The Mesilla Valley division is much larger in area than the Rincon division and has more drains. The conditions found in these drains are shown in table 13, together with comparable data for the river stations above and below the division.

It is evident from the data of table 13 that the aggregate discharge of the drains constitutes a large part of what passes the Courchesne station, namely 40 percent of the water and 60 percent of the dissolved solids. The mean concentration of the drainage water of the division is 1.87 tons per acre-foot and the effect of this contribution on the river has been to increase its concentration from 0.87 ton per acre-foot at Leasburg to 1.22 tons per acre-foot at Courchesne.

The data as to percentage composition show that there are pronounced differences among the drains not only in concentration but also in the composition of their dissolved solids. The range in concentration is from 1.01 tons per acre-foot for Leasburg drain up to 4.06 tons per acre-foot for east drain. There are certain trends of change in composition that occur with the increase in concentration, namely, as the concentration goes up the percentages of sodium and of chloride also rise but the percentages of the other four constituents tend to decline.

The drains of the El Paso Valley division fall into two groups, those that discharge into the river above Fabens and those that contribute to the Tornillo drain and return to the river at the lower end of the project. The data for each of these drains in respect to discharge, concentration, and percentage composition are given in table 14. In general the drain waters of the El Paso Valley division are more concentrated than those of the Mesilla Valley and Rincon divisions but they differ among themselves both in concentration and in composition. The drains above Fabens range in concentration from 1.62 tons per acre-foot in Quadrilla drain to 3.83 tons per acre-foot in River drain. The mean concentration of the net total drainage discharge from this area is 3.15 tons per acre-foot.

The drains of the Island and Tornillo districts all discharge through Tornillo drain. The contributing drains range in mean concentration from 2.50 tons per acre-foot for Fabens drain up to 8.25 tons per acre-foot for Border drain with a mean concentration for the entire discharge of 4.59 tons per acre-foot. In percentage composition these drain waters are also somewhat variable but they are all high in sodium and particularly in chloride and low in bicarbonate.

In respect to the quantities of water and of dissolved solids discharged by the drains and those carried by the

TABLE 12.—*The drains of the Rincon division, Elephant Butte project, New Mexico; characteristics of their discharge as compared with that of the river above and below the division, 1930–36*

	Mean annual discharge		Mean concentrations		Constituent percentages					
	Water (acre-feet)	Total dissolved solids (tons)	Conductance $K \times 10^6$ at 25° C.	Total dissolved solids (tons per acre-foot)	Ca	Mg	Na	HCO_3	SO_4	Cl
Elephant Butte Dam	766, 130	619, 909	86	0. 81	41	15	44	32	51	17
Garfield	10, 800	14, 400	140	1. 33	43	13	44	36	40	24
Hatch	10, 600	14, 100	137	1. 33	49	13	38	31. 5	44	24. 5
Angostura	2, 000	2, 100	109	1. 05	48	13	39	36	41	23
Rincon	13, 000	17, 500	142	1. 35	41	12	47	26. 5	45. 5	28
Total	36, 400	48, 100		1. 32						
Leasburg Dam	744, 982	647, 408	91	. 87	41	14	45	31	49	20

TABLE 13.—*The drains of the Mesilla Valley division, Elephant Butte project, New Mexico and Texas; characteristics of their discharge as compared with that of the river above and below the division, 1930–36*

	Mean annual discharge		Mean concentrations		Constituent percentages					
	Water (acre-feet)	Total dissolved solids (tons)	Conductance $K \times 10^6$ at 25° C.	Total dissolved solids (tons per acre-foot)	Ca	Mg	Na	HCO_3	SO_4	Cl
Leasburg Dam	744, 982	647, 406	91	0. 87	41	14	45	31	49	20
Selden	3, 600	5, 100	159	1. 43	36	12	52	26	35. 5	38. 5
Leasburg	8, 300	8, 400	108	1. 01	44. 5	13. 5	42	37	41	22
Picacho	6, 200	7, 100	120	1. 15	44	15	41	33	42	25
Mesilla	8, 300	10, 800	137	1. 30	40	13. 5	45. 5	34	43	23
Del Rio	77, 700	102, 600	133	1. 26	42	12	46	32	40	28
Chamberino	3, 700	7, 900	230	2. 13	33	12	55	23	36	41
La Mesa	27, 400	31, 000	121	1. 13	41	12	47	34	40	26
East	15, 900	64, 600	442	4. 06	17	10	73	15	32	53
Anthony	5, 300	12, 400	264	2. 34	25	13	62	23	32	45
Nemexas	17, 200	43, 000	280	2. 50	26	10	64	21	35	44
West	37, 500	60, 400	175	1. 61	29	12	59	27	41	32
Montoya	65, 300	152, 100	261	2. 33	25	10	65	20	36	4
Net totals	205, 000	383, 000		1. 87						
El Paso (Courchesne)	522, 758	637, 968	127	1. 22	35	12	53	26	43	31

river at the Courchesne and Fort Quitman stations, comparisons are not valid because of the facts that some of the water passing Courchesne is diverted to lands in Mexico and that the irrigated lands along the river in Hudspeth County, Tex., may use some water from the river and may contribute some salt to it above Fort Quitman. However, it is to be noted that the volume of the drainage discharge from the two districts of the El Paso Valley division equals 78 percent of the discharge at Fort Quitman while the salt tonnage from the drains is 5 percent greater than that carried by the river past Fort Quitman.

The conditions in respect to the surface waters of the Elephant Butte project may be summarized briefly. The river brings into the area annually from Elephant Butte Reservoir about 766,000 acre-feet of water carrying about 620,000 tons of dissolved solids. It takes away from the area, past Fort Quitman, about 172,000 acre-feet of water carrying about 473,000 tons of dissolved solids. Between these two stations on the river the irrigation and drainage of the contiguous agricultural lands result not only in changing the concentration of the dissolved solids of the stream waters, but they change also and appreciably the composition of those dissolved solids. The change of concentration is upward at each successive station along the stream and this is accompanied by higher concentrations in the drain waters and in the subsoil waters as sampled from observation wells. The changes in composition are in the direction of higher percentages of sodium and of chloride with lower percentages of the other four major constituents.

Ground Water

While the salinity conditions of the ground waters of this area as represented by the water collected by the open drains has been under investigation for several years, there appear to be no data from observation wells prior to 1936. Beginning in August of that year 77 wells were established and the water surface elevations were recorded and samples were taken for conductance determinations until the end of November. Of these 77 wells, 4 were located in the Rincon division, 18 in the Mesilla Valley division, and 55 in the El Paso Valley division.

From some of these wells as many as nine successive samples were taken for conductance measurements but from many others only three samplse were taken

TABLE 14.—*The drains of the El Paso Valley division, Elephant Butte project, Texas; characteristics of their discharge as compared with that of the river above and below the division, 1930–36*

	Mean annual discharge		Mean concentrations		Constituent percentages					
	Water acre-feet	Total dissolved solids (tons)	Conductance $K \times 10^5$ at 25° C.	Total dissolved solids (tons per acre-foot)	Ca	Mg	Na	HCO_3	SO_4	Cl
El Paso (Courchesne)	532,758	637,968	127	1.22	35	12	53	26	43	31
Above Fabens:										
Playa	22,900	48,300	234	2.11	31	13	56	20	29	51
Franklin	32,900	88,200	300	2.68	29	13	58	17	28	55
Middle	46,400	143,800	353	3.10	30	10	60	14	29	57
River	15,400	59,000	419	3.83	32	10	58	13	27	60
Quadrilla	5,000	8,100	180	1.62	28	11	61	23	42	35
Mesa	10,600	34,000	351	3.21	27	10	63	16	36	48
Fabens, intercepting	2,500	6,600	289	2.64	36	13	51	17	34	49
Net total	79,900	251,500		3.15						
Island and Tornillo:										
Fabens	8,500	21,200	299	2.50	36	12	52	16	30	54
Island	12,500	77,600	720	6.21	31	8	61	7	17	76
Border	4,700	38,800	945	8.25	27	7	66	5	19	76
Alamo	9,400	33,800	409	3.60	30	11	59	12	30	58
Tornillo	52,900	242,800	517	4.59	32	9	59	9	22	69
Net total	52,900	242,800		4.59						
Division total	132,800	494,300		3.72						
Fort Quitman	172,373	473,129	296	2.75	26	11	63	12	29	59

With very few exceptions, the conductance values of these successive samples are in close agreement so that the mean values for each well are believed to be good. During the same period of time that the wells were under observation, samples were taken from the drains that serve the same areas. In general the conductance values of these successive samples of drain water are in good agreement, so that it seems warranted to consider together the mean salinity of the drains and the mean salinity of the water from wells as representing the ground waters of each area.

In the uppermost or Rincon division of the project there are four drains and four wells. Two of these wells are contiguous to the uppermost or Garfield drain. The ground waters of this division appear to be of low salinity. The mean conductance values for the drains range from 130 to 152, with a mean for the four of 145. The corresponding values for the wells range from 190 to 218, with a mean of 200. The mean conductance of the irrigation water used in this division was about 90.

Of the 18 wells in the Mesilla Valley division, 2 at the lower end of the division are so situated as not to be comparable with the contiguous drain. The mean conductance values of the remaining 16 may be so compared and this is done in table 15. It will be noted that in the seven comparisons the mean values for the wells are higher than in the contiguous drains in five cases and lower in two. The unweighted means are 206 for the drains and 237 for the wells. The evidence from these observation wells, confirmed by that of the drains, is that in the Mesilla Valley division the subsoil water is not very saline except in two areas, one along the east side of the valley above Anthony and the other along the middle of the valley, west of the river, below Anthony. Of the two wells not listed in the table, one is located just north of Montoya drain syphon, and the other just north of the gaging station of Montoya drain. The first has a mean conductance of 342 and the other is very saline with a mean conductance of 2,574.

TABLE 15.—*Mean conductance values of the wells of the Mesilla Valley division and of contiguous drains*

Drain	Length (miles)	Mean conductance	Number of contiguous wells	Range of conductance	Mean conductance
Del Rio	73.[illegible]	143	2	153–206	180
Picacho	7.2	130	1		228
La Mesa	21.8	125	1		146
Chamberino	8.3	221	1		201
East	22.9	374	7	184–446	301
West Drain	39	184	2	125–255	190
Nemexas	20.2	267	2	400–425	412
Mean		206			237

The El Paso Valley division, lying along the river southeast of El Paso, comprises three districts. Midway down the valley the river leaves its old channel, the international boundary, and crosses to the northeastern side near the town of Fabens, thence to turn south again and reenter its old channel at a point about 2 miles southeast of the town of Tornillo. The uppermost district (above Fabens) lies between the river and the higher, unirrigated land to the northeast. The island district is the area, opposite Fabens, between the present river channel and its old channel. The Tornillo district lies below Fabens, between the river and the mesa. Of the 55 wells in the El Paso Valley division, 11 are located in the district above Fabens, 7 are in the island district, and 37 are in the Tornillo district.

TABLE 16.—*Mean conductance values of the wells of the El Paso Valley division and of contiguous drains*

Drains	Length	Mean conductance	Contiguous wells		
			Number	Range of conductance	Mean conductance
Above Fabens:					
Mesa	29.1	426	5	235–1499	750
Middle	55.3	381	5	163–1023	640
River	23.4	537	1	----------	724
Means	--------	448	11	----------	705
Island district: Island	33.7	559	7	325–2583	854
Tornillo district:					
Alamo Alto	20.6	395	17	213–1301	503
Tornillo	--------	--------	20	202–1674	528
Total Tornillo, including island	75.1	497	44	----------	570

A summary of the conditions of ground-water salinity as found in the El Paso Valley division is shown in table 16. In the district above Fabens the mean conductance of 11 wells is 705, while that of the 3 drains that serve the district is, for the same period, 448. In the island district the mean of 7 wells is 854, while that of the 3 drains is 559. In the Tornillo district the Tornillo drain, that serves the area between the Tornillo canal and the river, carries the discharge of the 3 drains of the island district as well as the water it collects in the Tornillo district. In the area between the Tornillo canal and the mesa served by the Alamo drain there are 17 wells with a mean conductance of 503, while the mean conductance of the Alamo drain for the same period is 395. For the combined island and Tornillo districts served by the Tornillo drain, there are 44 wells. The mean conductance of these 44 wells is 570, while that of the Tornillo drain is 497.

The following is a summary of salinity conditions found in the ground waters of the three major divisions of the Elephant Butte project in the summer of 1936.

	Mean conductance values of	
Rincon division	4 drains, 145	4 wells, 200.
Mesilla Valley division	7 drains, 206	16 wells, 237.
El Paso Valley division:		
Above Fabens	3 drains, 448	11 wells, 705.
Below Fabens	3 drains, 497	44 wells, 570.

It is obvious that these data are not adequate to serve as a basis for a convincing picture of the ground water conditions of the Elephant Butte project. The observation wells are too few in number and they give samples only from the upper surface of what may be assumed to be a deep body of water contained in the sediments of the valley fill. The data show that there are wide differences in salinity between wells that are not far apart. Had the wells been located in different positions from those selected for the present inquiry, different mean values might have been obtained. Furthermore, in the absence of information as to the conditions of salinity in the deeper waters of the valley sediments, there exists the possibility that there is little relationship between the subsoil water sampled from the observation wells and that collected by the drains. It seems probable, in fact, that much of the subsoil water that finds its way into the drains represents deeper subsoil water entering them from below as a result of hydrostatic conditions in the system consequent on percolation from irrigation canals. It is not necessarily to be inferred that the water appearing in these open drains comes chiefly by way of lateral flow along the surface of the saturated zone of the subsoil. Waters percolating downward from irrigation canals or through the readily permeable areas of irrigated lands may displace the subsoil water locally and the consequent hydrostatic readjustments may take place through deep permeable aquifers to the drains rather than through the lateral movement of the surface horizon of the subsoil water.

The findings of other investigations [1] show that there is in fact very little lateral translocation of water in the surface of the saturated zone of the subsoil, even when the elevations of that water surface show appreciable gradients. Closely adjacent wells that have been under observation for 10 years or more, and in which the seasonal vertical movement may be 3 feet or more, continue to show wide differences in salinity.

The presentation here of data concerning the salinity of water in observation wells and in contiguous open drains should not be taken as warranting the inference that there is thought to take place normally a lateral movement to the drains of the water represented by the wells. The purpose of presenting the data in summary form is to show what conditions of salinity were found to exist in the area.

Samples were taken for detailed analysis from 23 of the observation wells in the Elephant Butte project. The results are given on pages 266 to 269 of the analytical data. Summarized briefly, these analyses show that in respect to the percentages of sodium and chloride there is a progressive increase in the downstream direction. The mean percentages for the wells of the three major divisions are as follows:

Division	Number of wells	Percentages of—	
		Sodium	Chloride
Rincon	4	46.5	28.0
Mesilla Valley	8	55.6	29.0
El Paso Valley	11	67.3	52.5

[1] Scofield, C. S. The Movement of Water in Irrigated Soils, Jour. Agr. Research 27: 617–694, illus., and Subsoil Waters of Newlands (Nev.) Field Station. Tech. Bull. No. 533, U. S. Dept. Agr. 1936.

PART IV
ECTION 6.—THE WATERS OF THE RIO GRANDE ABOVE FORT QUITMAN, TEX.

The Gaging Stations

In the preceding chapters of this report consideration has been given to conditions of salinity found in the surface and ground waters of the three major divisions of the Rio Grande Drainage Basin above Fort Quitman, Tex. It now remains to discuss the conditions found at the several control or gaging stations along the main stream. There are nine such stations for which data are available in respect to the volume of discharge and the quality of the water. Two of these are in Colorado. The uppermost station, near Del Norte, is located above the points of diversion for San Luis Valley. The next, the State Line station, is located near Lobatos and below the tributary streams and drains of the San Luis Valley.

Below the Lobatos station the river enters a canyon section in northern New Mexico, in which it receives the flow of several tributaries, chief of which is Rio Chama, from the west. Toward the lower end of this canyon section is the third gaging station at Otowi Bridge. After leaving the canyon section, the river emerges into a section of lower gradient with alluvial lands on either side. This is the Middle Valley which extends to the San Marcial gaging station, located just above Elephant Butte Reservoir. In the Middle Valley some tributaries join the main stream; chiefly Jemez Creek and Rio Puerco and Rio Salado. The drains serving the irrigated lands of the Middle Valley also discharge into the main stream above San Marcial.

Elephant Butte Reservoir collects the flow of the main stream passing San Marcial and receives also some water from small local streams. Water from the reservoir is released chiefly during the irrigation season from April to September each year. There is a sampling station at the outlet of the reservoir. Leasburg Dam, the next sampling station is located below the Rincon division of Elephant Butte project and above the Mesilla Valley division. Courchesne station is below the Mesilla Valley division and above the points of diversion to lands in Mexico and to the El Paso Valley division of the Elephant Butte project. There are no important tributaries reaching the river in the Mesilla Valley division but drains that serve the irrigated land discharge into the river above the Courchesne station.

About midway down the El Paso Valley division is located the Tornillo-Fabens station. Topographic conditions in the El Paso Valley are such that most of the drains serving the irrigated land above Fabens discharge into the river above that station and at that station water is diverted from the river into Tornillo canal to serve lands below Fabens. The Fort Quitman station, the last one of this series, is located about 35 miles below the lower end of Elephant Butte project. In the section between the Courchesne and Fort Quitman stations no important tributaries join the main stream, but the drains that serve the contiguous irrigated land discharge into the stream above Fort Quitman.

Sampling and Analyses

The conditions at each of these gaging stations, in respect to the volume of discharge and quality of water, vary from day to day and from year to year. At most of them, observations as to the volume of discharge have been made and recorded for many years past. It is only recently that systematic observations have been made concerning the quality of the water by collecting and analyzing samples. Such data as are available in respect to the samples collected at these stations are reported in the analytical data, pages 10 to 54. For the Del Norte station, data on quality are available only for 1936. For the Lobatos and Otowi Bridge stations the record covers the 3 years, 1934 to 1936.

For the San Marcial station the record is much longer. During the period from May 1905 to April 1907, samples were taken about twice a week at this station and their partial analyses, together with the volume of discharge, are reported in Water Supply Paper 274, published by the United States Geological Survey. These data have not been incorporated in the present report. During the period from April 1920 to June 1932 the river was again sampled at this station and the total dissolved solids were determined. These data, together with the record of the discharge at the time of sampling, are reported in the analytical data, pages 13 and 14. From June 1932 to December 1936 samples were taken approximately once a week and the detailed analyses of these are also reported in the analytical data.

At the outlet of Elephant Butte Reservoir occasional samples were taken from 1920 to 1930 for the determination of total dissolved solids. In 1931 and 1932 samples were taken at this station about once a month for detailed analyses. Since June 1933 samples have been taken more frequently. For purposes of comparison, samples have been taken also from the surface of the reservoir above the dam.

The record of quality for the Leasburg Dam station includes the total dissolved solids for occasional samples taken from 1920 to 1930 and the detailed analyses of weekly samples or of monthly composites of weekly samples taken since 1931.

At the Courchesne station, near El Paso, Tex., a series of samples was taken and analyzed, like those at San Marcial, during 1905 to 1907, also reported in Water Supply Paper No. 274, but not here incorporated. From June 1918 to January 1930 occasional samples were taken for the determination of total dissolved solids and these results, together with results of the detailed analyses of weekly samples or of monthly composites are reported in the analytical data.

The record for the Fabens-Tornillo station includes the data as to the total dissolved solids found in samples taken during the period from 1918 to 1930 and the detailed analyses of weekly samples or monthly composites since January 1930. Finally the record for Fort Quitman includes the total dissolved solids on occasional samples or of monthly composites since January 1930.

The summarized findings, here presented, as to salinity conditions along the main stream are based on 1 year's record at Del Norte, 3 years' at Lobatos and Otowi Bridge, 4 years' record at San Marcial, and 6 years' records at the five stations from Elephant Butte outlet to Fort Quitman. No attempt is here made to interpret the findings of the earlier reports of analyses for the stations having older records.

Before proceeding to discuss the findings based on the data here presented, it seems proper to consider the validity and the significance of the data. It seems unnecessary to labor the point that on such a stream as the Rio Grande the conditions of discharge and of the quality of the water passing a gaging station are extremely variable. Appreciable changes may occur within an hour and great changes may occur from day to day. Such changes are less pronounced at some seasons of the year than at others but they are continual and characteristic.

The customary procedure of sampling for investigating the quality of the water is to take a sample from time to time, such as once a day, once a week, or once a month, using reasonable care that the sample represents the discharge at the time. The volume of discharge at the time of sampling is estimated or measured and recorded on the sample label, along with the date and the name of the collector. These individual samples may be analyzed separately or they may be assembled into composites representing some period of time, such as a month. In making up such composite samples for analysis, the procedure here followed is to take from each individual sample a quantity proportional to the volume of discharge each sample represents.

In any event, whether the individual samples analyzed separately or proportionately compo before analysis, the results of an analysis are evaluated or weighted by the discharge values that each represents, when it is desired to estimate the quantities of dissolved solids or of any constituents passing the station during any period of time, such as a year. This procedure rests on the assumption that a sample taken at any given time truly represents the water passing the station during the time-period allocated to that sample. As a matter of fact, it is well known that at several of these gaging stations on the Rio Grande the changes that occur from day to day or even from hour to hour in volume of discharge and in quality of the water are such as to invalidate the assumption of uniformity during the time-period involved in the present sampling program. Fortunately, the resulting errors do not run in one direction and in time they tend to cancel each other. But it should be kept in mind in considering the quantitative data here presented as to the salt burden of the stream, that these computed values can be at best only approximations of the truth.

It is believed that the results reported for the individual analysis are valid and acceptable. Their validity may be and has been tested in a variety of ways. The sources of error mentioned above are inherent ir system of periodical sampling rather than in the me of analysis. One of the ways of testing the validity of the analyses is to compare the results obtained from any sample or any group of samples in respect to similar or related characteristics of the water. For example, one of the more important characteristics of water is the quantity of dissolved solids it contains; in other words, its concentration. By the methods of analysis used in the present investigation we obtain three independent measurements of concentration:

(1) An aliquot of the sample, carefully filtered, is evaporated, the residue is dried and weighed. The result, computed as total dissolved solids (t. d. s.), is reported as tons per acre-foot of water.

(2) The specific electrical conductance of the sample is determined by measuring the electrical resistance of a known volume at known temperature. The result is reported as conductance ($K \times 10^6$ at 25° C.).

(3) Each of the six or eight more important constituents of the dissolved salts is separately measured and reported in terms of milligram equivalents per liter. The sum of these milligram equivalents is also a measure of concentration. It does not include all the dissolved material (e. g. silica) but is nevertheless an acceptable relative measure of concentration.

In the course of reporting water analyses these three criteria of concentration are compared as a means of guarding against errors. Long experience has shown that in a series of samples from any one source

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ratios to each other are remarkably constant. These ratios differ somewhat among themselves with samples f--m different sources having different compositions, to be expected.

Computing the Data

In the matter of weighting the results of invididual analyses in respect to the discharge volumes they represent, more than one procedure is possible. According to the sampling program followed in the present investigation, at least two methods of weighting analytical results have been used. The earlier method adopted and still in use in respect to certain of the stations is as follows: The individual samples received from a station are separately analyzed. All of the analyses for each month are then taken as being representative of the total discharge for that station for that month and the arithmetical mean for each characteristic or constituent is computed. Subsequently, when the discharge data for that station (in acre-feet per month) become available the mean values for the month's analyses are multiplied by that discharge. By the other method, the samples from each station for each month are made into a composite for one analysis. Each sample contributes to this composite a quantity that is proportional to the discharge (in cubic feet per second) that was reported with it. Th- data from this single analysis are subsequently lied by the reported discharge for that station in .e-feet per month.

Neither of these methods is wholly satisfactory or free from error. Neither takes adequately into account the differences in volume of discharge or of salinity that regularly occur at these river stations. Attention is here called to the obvious and admitted faults in the methods of computation used in the present report in order to avoid the implication that the findings here presented are regarded as definitive and the most accurate that could be obtained. They represent merely one interpretation of the detailed analytical data. Other and more refined methods of computation might yield results that would be nearer the truth.

The objective of the present discussion of the analytical data concerning the regimen of the Rio Grande is to show what the conditions are at each of the nine control or gaging stations described above. A summary will be given of the findings for each station for each year of record, together with a summary for each station for the whole period of record. Comparisons will then be made between pairs of stations as a means of showing the effects of conditions between them, and as showing the trend of changes that occur from the upper to the lower stations.

use of the fact that only 1 year's record, 1936, is ble for the uppermost station, near Del Norte, Colo., a summary of that year's record is shown in table 17, and for comparison data are given for the same year for the Lobatos station, located below the San Luis Valley. The table shows first the volume of water, in acre-feet, passing each station during the year as reported by the State Engineer of Colorado. The next entry reports the total dissolved solids, in tons, passing each station during the year as computed from the analysis of one composite sample from each station for each month. These composite samples were made up at the laboratory from four or five individual samples with each of which was reported the estimated discharge, in cubic feet per second, at the time of sampling. The determined concentration of total dissolved solids, as tons per acre-foot, was then multiplied by the discharge, in acre-feet, subsequently reported for each month, and the sum of these products is reported as the second entry in the table. The third entry is the mean concentration as tons per acre-foot, obtained by dividing the value for discharge, in acre-feet, into the value for tons of total dissolved solids.

The values given for conductance were obtained by multiplying the conductance determined for each individual sample by the discharge value reported with that sample, adding these products together for the whole year and dividing that sum by the sum of the individual discharge values. The method of obtaining the third concentration value, i. e., the sum of the milligram equivalents, will be described later.

The next seven entries in the table give the values for the tonnage of each of seven constituents of the dissolved solids. These values are obtained by the following method: The value for the discharge, in acre-feet, for each month is multiplied by the value reported, as milligram equivalents, for the constituent as obtained by the analysis of the composite sample for that month, and this product is then multiplied by a factor to convert it into tons. The sum of these tonnages for each month is reported as the tonnage for the year.

The mean composition for the station is then computed by dividing the value for the annual discharge, in acre-feet, into the value for the annual tonnage of each constituent and then dividing this quotient by the factor that was used for computing the tonnage of each constituent. The sum of the milligram equivalent values for the mean composition is then taken as the third measure of concentration referred to above.

The percentage composition reported by the last six entries in the table is obtained by dividing the value for the sum of the cations into the value for each cation and the value for the sum of the anions into the value for each anion. In computing the percentage composition when potassium is reported, its value is added to the value for sodium. Similarly, when the nitrate ion is reported, its value is added to that for chloride before dividing by the sum of the anions.

TABLE 17.—*The Rio Grande above and below San Luis Valley, Colo.; discharge conditions at two control stations; data for 1936*

Item	Del Norte station	Lobatos (State line) station
Discharge:		
Water (acre-feet)	472,300	280,950
Dissolved solids (tons)	51,976	74,495
Concentrations:		
Tons per acre-foot	0.11	0.265
Conductance	8.46	26.51
Sum (milliequivalents)	2.27	5.71
Constituents (tons):		
Calcium (Ca)	7,203	10,601
Magnesium (Mg)	2,074	2,698
Sodium (Na)	4,408	8,039
Bicarbonate (HCO_3)	13,715	18,006
Sulphate (SO_4)	9,731	18,268
Chloride (Cl)	2,818	3,881
Nitrate (NO_3)	197	27
Composition (milligram equivalents):		
Ca	.56	1.39
Mg	.27	.58
Na	.30	.91
Sum (cations)	1.13	2.88
HCO_3	.70	1.54
SO_4	.32	1.00
Cl	.12	.29
NO_3	T.	T.
Sum (anions)	1.14	2.83
Percentage:		
Ca	50	48
Mg	24	20
Na	26	32
HCO_3	61	55
SO_4	28	35
Cl	11	10

The Stream Above San Marcial

With this explanation of the methods used in computing the data shown in the following tables, the conditions found at the Del Norte and Lobatos stations for 1936 may be compared. It may be recalled that below the Del Norte station water is diverted from the Rio Grande to irrigate land in San Luis Valley. Drainage water from the irrigated land is returned to the river above the Lobatos station and several tributary streams also join the river above the latter station. The table shows that the total volume of water passing the Lobatos station was 191,350 acre-feet less than that passing the Del Norte station. The volume at Lobatos was approximately 60 percent of that at Del Norte. The total dissolved solids passing Lobatos was greater than the quantity passing Del Norte by 22,521 tons for the year, or 45 percent.

The changes occurring between Del Norte and Lobatos, i. e., the loss of water and the gain of dissolved solids, are reflected in the differences of concentration shown for the two stations. The concentration at Lobatos, as shown by the total dissolved solids and the sum of the milligram equivalents, is approximately 2.5 times that at Del Norte. As measured by conductance, the difference is greater; about 3.1 times that at Del Norte. The discrepancy between the conductance criterion and the other two is owing, in part at least, to the different methods used in computing these weighted mean concentration values.

The notable fact about the river as sampled at the two stations is that its water contains very little dissolved material in comparison with the water farther down the stream. Even though the concentration of the water at the Lobatos station is 2.5 to 3 times as high as at Del Norte, it is still not very saline.

The data for the percentage composition shown in the last six entries of table 17 show the nature of the changes in composition that occur between the two stations. These values show that the water passing the Lobatos station contains relatively less calcium, magnesium, and bicarbonate than the waters passing Del Norte, and relatively more sodium and sulphate. There is only a slight difference in respect to the chloride percentage.

The conditions at the Lobatos station for 1 year, 1936, were shown in table 17. The conditions at that station for the past 3 years, 1934–36, are summarized in table 18. This record shows that the annual volume of discharge varied widely, from 99,000 acre-feet in 1934 to 360,000 acre-feet in 1935. The range in the salt tonnage carried is not quite so great and, consequently, the concentration was higher in the year of low discharge. The character of the salts, as shown by the percentage composition, differed very little from year to year.

TABLE 18.—*Lobatos (State line) gaging station, Colorado, showing the quantities of water, of dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1934 to 1936.*

Item	1934	1935	1936	Mean
Discharge:				
Water (acre-feet)	98,910	360,340	280,950	246,733
Dissolved solids (tons)	36,001	89,162	74,495	66,553
Concentrations:				
Tons per acre-foot	0.364	0.247	0.265	0.27
Conductance	37.4	26.4	26.5	27.9
Sum (milliequivalents)	8.69	5.26	5.71	5.84
Constituents (tons):				
Calcium (Ca)	5,214	12,164	10,601	9,326
Magnesium (Mg)	1,266	3,168	2,698	2,377
Sodium (Na)	4,655	9,991	8,039	7,562
Bicarbonate (HCO_3)	8,967	21,809	18,006	16,261
Sulphate (SO_4)	10,941	19,834	18,268	16,314
Chloride (Cl)	1,918	5,063	3,881	3,621
Nitrate (NO_3)	----	807	27	167
Composition (milligram equivalents):				
Ca	2.16	1.24	1.39	1.39
Mg	.77	.53	.58	.58
Na	1.50	.89	.91	.98
Sum (cations)	4.43	2.66	2.88	2.95
HCO_3	2.18	1.46	1.54	1.58
SO_4	1.68	.84	1.00	1.01
Cl	.40	.29	.29	.30
NO_3	----	.01	T	----
Sum (anions)	4.26	2.60	2.83	2.89
Percentage:				
Calcium	49	47	48	47
Magnesium	17	20	20	20
Sodium	34	33	32	33
Bicarbonate	51	50	55	55
Sulphate	39	33	35	35
Chloride	10	11	10	[illegible]

The next station down stream from Lobatos is at vi Bridge, near San Ildefonso, N. Mex. In the on section between these two stations the river receives contributions from both sides, the most important one being Rio Chama, from the west. There are no important diversions between the two stations. The record of the Otowi Bridge station (table 19), like that of the Lobatos station, shows that 1934 was a dry year. The differences at Otowi Bridge were less than at Lobatos and this is true also as regards the discharge for 1935 and 1936. At Otowi Bridge these 2 years were very similar.

Comparison of the 3-year means for Lobatos and Otowi Bridge shows that between the two stations the river gained annually 604,000 acre-feet of water and 226,000 tons of dissolved solids. From this it may be inferred that water contributed between the two stations had a concentration equivalent to 0.37 ton per acre-foot, or slightly higher than that of the water passing the Lobatos station.

The record for the San Marcial station, as shown in table 20, covers a 4-year period, including the dry year, 1934. Conditions at San Marcial are such that this record is not very satisfactory. The station is located below the junction of Rio Puerco and Rio Salado which drain the uplands west of the Rio Grande. This area subject to local, torrential, summer rains which may brief floods in these streams. These flood waters often highly saline, at least in the first part of a flood or in the first flood after a long dry season, and as they pass the San Marcial station they cause abrupt changes in the regimen of the stream at that point. Because of these abrupt changes, both in the volume and salinity of the water, it is suspected that the periodical samples taken at the San Marcial station may not afford a basis for dependable estimates of the salt burden of the stream at that point.

Between Otowi Bridge and San Marcial the Rio Grande passes through the Middle Rio Grande Valley with its extensive irrigated area. Jemez Creek, Rio Puerco, and Rio Salado join the river from the west, bringing in rather saline waters. The 3-year records for the two stations show that notwithstanding the tributary contributions, the annual volume of water passing San Marcial is 137,000 acre-feet less than passes Otowi Bridge. The annual salt burden of the stream at San Marcial is nearly 300,000 tons greater than at the upper station. From the data now available it is not practicable to estimate how much of this increased salt burden is derived from the tributary streams and how much comes from the drainage of the irrigated land contiguous to the main stream.

mparison of the mean percentage composition of alts passing Otowi Bridge and San Marcial shows that at the lower stations the proportions of calcium, magnesium, and bicarbonate are lower while the proportions of sodium, sulphate, and chloride are higher.

By way of a summary of conditions found at the three stations above Elephant Butte Reservoir for the 3-year period ending with 1936, the mean values for each sta-

Table 19.—*Otowi Bridge gaging station, New Mexico, showing the quantities of water, of total dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1934–36*

Item	1934	1935	1936	Mean
Discharge:				
Water (acre-feet)	380,430	1,100,740	1,071,520	850,890
Dissolved solids (tons)	151,861	374,751	351,692	292,768
Concentrations:				
Tons per acre-foot	0.40	0.34	0.33	0.34
Conductance	39.3	30.4	30.5	31.8
Sum (milliequivalents)	9.14	7.55	7.49	7.76
Constituents (tons):				
Calcium (Ca)	23,361	66,119	63,899	51,126
Magnesium (Mg)	5,489	10,319	12,220	9,343
Sodium (Na)	17,122	33,263	30,188	26,857
Bicarbonate (HCO_3)	42,575	106,022	94,126	80,908
Sulphate (SO_4)	36,496	88,360	89,807	71,554
Chloride (Cl)	7,297	12,868	15,488	11,884
Nitrate (NO_3)	----------	1,376	899	1,137
Composition (milligram equivalents):				
Ca	2.26	2.21	2.19	2.21
Mg	.87	.57	.69	.66
Na	1.44	.97	.90	1.01
Sum (cations)	4.57	3.75	3.78	3.88
HCO_3	2.70	2.32	2.12	2.29
SO_4	1.47	1.23	1.28	1.29
Cl	.40	.24	.30	.29
NO_3	----------	.01	.01	.01
Sum (anions)	4.57	3.80	3.71	3.88
Percentage:				
Calcium	49	59	58	57
Magnesium	19	15	18	17
Sodium	32	26	24	26
Bicarbonate	59	61	57	59
Sulphate	32	32	35	33
Chloride	9	7	8	8

Table 20.—*San Marcial gaging station, New Mexico, showing the quantities of water, of total dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1933–36*

Item	1933	1934	1935	1936	Mean
Discharge:					
Water (acre-feet)	716,564	244,399	1,029,500	867,500	713,800
Dissolved solids (tons)	746,567	269,211	851,265	653,332	591,269
Concentrations:					
Tons per acre-foot	[illegible].04	[illegible]0	[illegible].33	0.75	[illegible].33
Conductance	117.3	131.1	104.3	79.4	97.2
Sum (milliequivalents)	23.60	24.52	18.35	17.31	18.63
Constituents (tons):					
Calcium (Ca)	92,698	32,366	113,018	88,692	78,025
Magnesium (Mg)	20,668	6,490	23,838	18,243	16,190
Sodium (Na)	117,952	43,881	119,081	98,176	87,046
Bicarbonate (HCO_3)	93,697	34,222	130,189	106,707	90,373
Sulphate (SO_4)	304,381	104,180	306,842	232,748	214,590
Chloride (Cl)	76,148	28,153	77,907	65,974	57,375
Nitrate (NO_3)	----------	----------	2,144	768	1,456
Composition (milligram equivalents):					
Ca	4.76	4.87	4.04	3.76	4.02
Mg	1.75	1.61	1.40	1.27	1.37
Na	5.26	5.74	3.70	3.62	3.90
Sum (cations)	11.77	12.22	9.14	8.65	9.29
HCO_3	3.15	3.38	3.05	2.98	3.05
SO_4	6.51	6.53	4.57	4.11	4.61
Cl	2.17	2.39	1.57	1.58	1.66
NO_3	----------	----------	----------	.01	.02
Sum (anions)	11.83	12.30	9.19	8.66	9.34
Percentage:					
Calcium	40	40	44	43	43
Magnesium	15	13	15	15	15
Sodium	45	47	41	42	42
Bicarbonate	27	27	33	34	33
Sulphate	55	53	50	48	49
Chloride	18	20	17	18	18

TABLE 21.—*The Rio Grande above Elephant Butte Reservoir in Colorado and New Mexico, discharge conditions at 3 control stations, means for 1934 to 1936*

Item	Lobatos (State line)	Otowi Bridge	San Marcial
Discharge:			
Water (acre-feet)	246, 733	850, 890	713, 800
Dissolved solids (tons)	66, 553	292, 766	591, 264
Concentrations:			
Tons per acre-foot	0. 27	0. 344	0. 83
Conductance	27. 9	31. 8	97. 2
Sum (milliequivalents)	5. 84	7. 76	18. 63
Constituents (tons):			
Calcium (Ca)	9, 326	51, 126	88, 025
Magnesium (Mg)	2, 377	9, 343	16, 190
Sodium (Na)	7, 562	26, 857	87, 046
Bicarbonate (HCO_3)	16, 261	80, 906	90, 373
Sulphate (SO_4)	16, 314	71, 554	214, 590
Chloride (Cl)	3, 621	11, 884	57, 375
Nitrate (NO_3)	167	1, 137	1, 456

tion as to discharge, concentration, and tonnage of each salt constituent are brought together in table 21. It may be noted that between Otowi Bridge and San Marcial the concentration of the water increases by 2.4 to 3 times. In respect to certain constituents the tonnage increase is much greater than that. For example, the chloride tonnage at Otowi Bridge is 3.3 times that at Lobatos, while at San Marcial it is nearly 5 times as high as at Otowi Bridge.

The Stream Below San Marcial

Elephant Butte Reservoir constitutes a definite break in the continuity of the regimen of the Rio Grande. It is a storage and equalizing reservoir in which water is held from year to year in varying quantities. Consequently, the data as to the annual volumes of discharge at stations above and below the reservoir are unrelated unless the volume of water in the reservoir is taken into account. It does not seem pertinent to the present inquiry to attempt to correlate the conditions found at stations immediately above and below the reservoir. Consequently the following discussion starts with the consideration of findings at the station just below Elephant Butte Dam and follows downstream to the station near Fort Quitman, Tex.

In the early stages of the inquiry here reported it was assumed that the water held in Elephant Butte Reservoir would be thoroughly mixed and of uniform composition. Consequently it was thought to be adequate to take a sample of the water at the outlet once a month or even less frequently. This assumption proved to be unwarranted. It was found, as a matter of fact, that the quality of the water released from the reservoir may change suddenly and profoundly. Subsequent investigations have shown that the water of the reservoir is not ordinarily a homogeneous mixture. It is probably very seldom in that condition.

This is not an appropriate place to discuss in detail the phenomena that occur in the reservoir. The facts essential to such a discussion are not yet available. It is known, however, that at certain times turbid and saline flood waters enter the reservoir at its upper end and pass along the floor of the reservoir to emerge or 3 days later through the outlet gates at the dam. It is known also that at other times flood waters, also turbid but of low salinity, enter the reservoir at its upper end and, after dropping their suspended silt, spread out over the surface of the reservoir, and, with comparatively little blending, reach the dam at the lower end. Such mixture as does occur in the reservoir appears to be dependent chiefly on differences of temperature between the surface and the deeper water. When the surface water gets colder than the deeper water, as during the autumn and winter, it sinks to the bottom, replacing the warmer water.

These conditions in the reservoir have been the cause of some anomalous findings in respect to the salt burden of the water released from it. The details of these findings are reported in the analytical data, pages 20 to 25, and are summarized by years in table 22. The data of this table show that, except for 1935, the quantity of water released from the reservoir each year has been less variable than the quantities passing the up-river stations. The drought of 1934 diminished the inflow for that year and caused a diminished outflow during the following year.

TABLE 22.—*Elephant Butte Dam outlet, New Mexico, showing the quantities of water, of dissolved solids, and of each of the more important salt constituents released from the reservoir during each calendar year, 1931–36*

Item	1931	1932	1933	1934	1935	1936	Mean
Discharge:							
Water (acre-feet)	751, 000	832, 000	826, 520	803, 710	636, 454	747, 120	766, 131
Dissolved solids (tons)	617, 195	658, 385	610, 297	659, 453	583, 935	589, 690	619, 909
Concentrations:							
Tons per acre-foot	0. 82	0. 79	0. 74	0. 82	0. 92	0. 79	0. 81
Conductance	82. 6	83. 4	73. 0	88. 8	100. 3	86. 3	87. 0
Sum (milliequivalents)	19. 15	18. 20	16. 37	18. 71	20. 11	17. 87	18. 32
Constituents (tons):							
Calcium (Ca)	80, 863	80, 790	81, 133	82, 861	67, 745	76, 273	78, 277
Magnesium (Mg)	14, 597	19, 655	17, 765	18, 359	15, 480	15, 857	16, 952
Sodium (Na)	102, 551	106, 963	85, 023	103, 640	90, 611	90, 780	96, 561
Bicarbonate (HCO_3)	98, 791	96, 632	125, 237	88, 275	75, 363	82, 343	94, 440
Sulphate (SO_4)	237, 559	262, 331	174, 124	273, 386	228, 802	232, 184	234, 731
Chloride (Cl)	58, 797	58, 647	51, 403	60, 675	55, 521	55, 419	56, 744
Nitrate (NO_3)	------	------	------	------	586	112	349
Composition (milligram equivalents:							
Ca	3. 96	3. 57	3. 61	3. 79	3. 91	3. 75	3. 76
Mg	1. 18	1. 43	1. 30	1. 38	1. 47	1. 28	1. 34
Na	4. 37	4. 11	3. 29	4. 12	4. 55	3. 88	4. 03
Sum (cations)	9. 51	9. 11	8. 20	9. 29	9. 93	8. 91	9. 13
HCO_3	3. 17	2. 80	3. 65	2. 65	2. 85	2. 66	2. 97
SO_4	4. 85	4. 83	3. 23	5. 21	5. 51	4. 76	4. 69
Cl	1. 62	1. 46	1. 29	1. 56	1. 81	1. 54	1. 53
NO_3	------	------	------	------	. 01	------	------
Sum (anions)	9. 64	9. 09	8. 17	9. 42	10. 18	8. 96	9. 19
Percentage:							
Calcium	42	39	44	41	39	42	41
Magnesium	12	16	16	15	15	14	15
Sodium	46	45	40	44	46	44	44
Bicarbonate	33	31	44	28	28	30	32
Sulphate	50	53	40	55	54	53	51
Chloride	17	16	16	17	18	17	17

The data as to mean annual concentration show variations from year to year that are not closely correlated with the discharge values or with each other. There are inconsistencies also in the data for the annual ˙ ˙nages of the several constituents of the dissolved ˡs and consequently in values for composition. ..ese inconsistencies are believed to be due in part at least to inadequacies in the sampling program. They may be due in part also to phenomena of decomposition that occurred in some of the samples between the time they were collected and the time when they were analyzed. Such decomposition is known to occur in samples containing silt, rich in organic matter.

Notwithstanding the admitted anomalies and discrepancies in these data, they may be accepted, with some reservations, as reflecting conditions at the outlet of Elephant Butte Reservoir and they may serve also as a basis of comparison with conditions found at the gaging stations farther down the stream, as summarized in the following tables.

The data of table 23, summarizing the conditions found at Leasburg Dam, seem to require less in the way of explanation and apology than has been given for the data for the Elephant Butte station. The data for the two stations should be much alike because conditions along the stream between them are not such as to have much influence for change. No important tributaries join the stream in this section and the area of contiguous irrigated land is small. Here, as at Elephant Butte, the annual volume of discharge is ˈvely constant and the annual mean concentration .e water ranges between narrow limits. There are some anomalies in the table, as for example the low value for the tonnage of sodium in 1933 as compared with the values for other years. The value for chloride in 1932 seems high as does also that for bicarbonate in 1933. No explanation is offered for these apparent discrepancies. They may be due in part to errors of sampling or of analysis or it may be that things were that way.

The summarized data for the 6-year period for the two stations show that there has been about 20,000 acre-feet less water passing Leasburg annually than was released from the reservoir, and that this water carried annually about 27,000 tons more dissolved solids. Its concentration was in consequence slightly higher. The differences in composition of the salt were slight but indicate some increase in the proportion of chloride at the expense of the sulphate and bicarbonate constituents.

The conditions at the Courchesne gaging station near El Paso, Tex., are summarized in table 24. Between Leasburg Dam and this station the river serves a large area of irrigated land but receives no tributaries of consequence. It appears that this irrigated land acts i· ·me measure as an equalizing reservoir in respect ˌ monthly discharges throughout the year. At this station also the mean annual concentration of the water ranges between rather narrow limits. A fact

TABLE 23.—*Leasburg Dam, N. Mex., showing the quantities of water, of total dissolved solids, and of each of the more important salt constituents passing the dam during each calendar year, 1931–36*

Item	1931	1932	1933	1934	1935	1936	Mean
Discharge:							
Water (acre-feet)	738, 000	814, 000	824, 000	768, 230	632, 400	693, 260	744, 982
Dissolved solids (tons)	642, 700	679, 283	651, 547	700, 381	614, 411	596, 114	647, 406
Concentrations:							
Tons per acre-foot	0. 87	0. 83	0. 79	0. 91	0. 97	0. 86	0. 87
Conductance	88. 8	92. 2	80. 0	93. 4	102. 9	91. 5	91. 00
Sum (milliequivalents)	20. 50	20. 97	17. 73	20. 17	21. 61	19. 23	19. 97
Constituents (tons):							
Calcium (Ca)	82, 718	88, 785	83, 205	86, 115	73, 732	76, 306	81, 810
Magnesium (Mg)	16, 121	20, 305	19, 840	18, 064	17, 439	15, 488	17, 876
Sodium and potassium (Na+K)	111, 142	126, 036	95, 015	106, 338	94, 317	91, 116	103, 994
Bicarbonate (HCO_3)	100, 504	107, 034	111. 634	94, 649	79, 871	80, 975	95, 778
Sulphate (SO_4)	240, 618	257, 187	212, 800	267, 787	234, 825	220, 720	238, 989
Chloride (Cl)	70, 552	97, 857	65, 873	70, 002	65, 522	64, 645	72, 392
Nitrate (NO_3)	-------	-------	-------	-------	1, 103	1, 475	1, 289
Composition (milligram equivalents):							
Ca	4. 12	4. 01	3. 71	4. 12	4. 29	4. 05	4. 04
Mg	1. 32	1. 51	1. 46	1. 42	1. 67	1. 35	1. 45
Na	4. 81	4. 95	3. 67	4. 43	4. 77	4. 20	4. 46
Sum (cations)	10. 25	10. 47	8. 84	9. 97	10. 73	9. 60	9. 95
HCO_3	3. 28	3. 17	3. 27	2. 97	3. 04	2. 82	3. 10
SO_4	4. 99	4. 84	3. 96	5. 34	5. 69	4. 88	4. 91
Cl	1. 98	2. 49	1. 66	1. 89	2. 15	1. 93	2. 01
Sum (anions)	10. 25	10. 50	8. 89	10. 20	10. 88	9. 63	10. 02
Percentage:							
Calcium	40	39	42	41	40	42	41
Magnesium	13	14	16	14	16	14	14
Sodium	47	47	42	45	44	44	45
HCO_3	32	30	37	30	28	29	31
SO_4	49	46	44	51	52	51	49
Cl	19	24	19	19	20	20	20

TABLE 24.—*El Paso (Courchesne) gaging station, Texas showing the quantities of water of total dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1931–36*

Item	1931	1932	1933	1934	1935	1936	Mean
Discharge:							
Water (acre-feet)	518, 000	567, 240	609, 180	508, 480	259, 910	473, 740	522, 758
Dissolved solids (tons)	671, 350	681, 324	701, 233	643, 792	569, 738	560, 323	637, 968
Concentrations:							
Tons per acre-foot	1. 30	1. 20	1. 15	1. 27	1. 24	1. 18	1. 22
Conductance	131. 1	132. 0	111. 7	137. 8	122. 8	129. 9	127. 2
Sum (milliequivalents)	30. 82	31. 92	26. 21	28. 25	27. 91	27. 28	28. 71
Constituents (tons):							
Calcium (Ca)	75, 198	78, 533	74, 480	68, 818	60, 919	63, 782	70, 288
Magnesium (Mg)	13, 871	19, 304	17, 847	15, 063	13, 880	13, 302	15, 346
Sodium and potassium (Na+K)	137, 448	155, 431	129, 932	116, 830	103, 051	103, 389	124, 297
Bicarbonate (HCO_3)	84, 933	92, 705	96, 874	75, 901	68, 195	69, 835	81, 407
Sulphate (SO_4)	224, 280	241, 432	209, 347	207, 838	189, 608	187, 849	210, 060
Chloride (Cl)	120, 062	149, 256	118, 709	105, 424	91, 728	91, 117	112, 716
Nitrate (NO_3)	-------	-------	-------	-------	1, 186	2, 136	1, 661
Composition (milligram equivalents):							
Ca	5. 34	5. 09	4. 49	4. 98	4. 87	4. 95	4. 95
Mg	1. 62	2. 06	1. 77	1. 79	1. 83	1. 70	1. 79
Na	8. 48	8. 76	6. 82	7. 33	7. 16	6. 98	7. 59
Sum (cations)	15. 44	15. 91	13. 08	14. 10	13. 86	13. 63	14. 33
HCO_3	3. 95	3. 94	3. 83	3. 60	3. 57	3. 55	3. 74
SO_4	6. 63	6. 52	5. 26	6. 26	6. 22	6. 07	6. 18
Cl	4. 80	5. 45	4. 04	4. 29	4. 13	3. 98	4. 46
NO_3	-------	-------	-------	-------	0. 03	0. 05	-------
Sum (anions)	15. 38	16. 01	13. 13	14. 15	14. 05	13. 65	14. 38
Percentage:							
Calcium	35	32	34	35	35	37	35
Magnesium	10	13	14	12	13	13	12
Sodium	55	55	53	53	53	51	53
Bicarbonate	26	26	29	25	25	26	26
Sulphate	43	41	40	44	45	44	43
Chloride	31	34	31	31	30	30	31

TABLE 25.—*Fabens-Tornillo gaging station, Texas, showing the quantities of water, of dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1931–36*

Item	1931	1932	1933	1934	1935	1936	Mean
Discharge:							
Water (acre-feet)	280,000	291.606	328,610	222,519	195,886	224.420	257,123
Dissolved solids (tons)	571,950	544,431	585,991	446,045	394,519	433,149	496,014
Concentrations:							
Tons per acre-foot	2.04	1.87	1.78	2.00	2.02	1.93	1.93
Conductance	209.2	198.7	185.1	221.9	232.1	245.2	212.0
Sum (milliequivalents)	49.66	46.04	40.90	46.20	46.07	44.17	45.51
Constituents (tons):							
Calcium (Ca)	53,033	53,618	56,130	43,517	38,369	42,139	47,801
Magnesium (Mg)	12,095	13,392	14,090	9,687	8,898	10,212	11,396
Sodium (Na)	127,731	122,957	118,250	91,039	79,823	87,021	104,420
Bicrabonate (HCO_3)	53,907	54,068	60,110	40,395	34,572	38,149	46,867
Sulphate (SO_4)	149,223	154,763	156,958	124,146	105,826	120,986	135,317
Chloride (Cl)	158,354	146.700	139,670	111,276	99,354	105,306	126,776
Nitrate (NO_3)	------	------	------	------	649	729	689
Composition (milligram equivalents):							
Ca	7.96	6.76	6.28	7.19	7.21	6.90	7.05
Mg	2.61	2.78	2.59	2.64	2.75	2.75	2.69
Na	14.58	13.48	11.50	13.08	13.00	12.40	13.01
Sum (cations)	25.15	23.02	20.37	22.91	22.96	22.05	22.75
HCO_3	4.64	4.47	4.41	4.38	4.26	4.10	4.38
SO_4	8.16	8.13	7.32	8.55	8.29	8.26	8.12
Cl	11.71	10.42	8.80	10.36	10.52	9.72	10.26
NO_3	------	------	------	------	.04	.04	------
Sum (anions)	24.51	23.02	20.53	23.29	23.11	22.12	22.76
Percentage:							
Calcium	32	29	31	31	31	32	31
Magnesium	10	12	13	12	12	12	12
Sodium	58	59	56	57	57	56	57
Bicarbonate	19	19	21	19	18	19	19
Sulphate	33	36	36	37	36	37	36
Chloride	48	45	43	44	46	44	45

TABLE 26.—*Fort Quitman gaging station, Texas showing the quantities of water, of total dissolved solids, and of each of the more important salt constituents passing the station during each calendar year, 1931–36*

Item	1931	1932	1933	1934	1935	1936	Mean
Discharge:							
Water (acre-feet)	212,000	211,120	213,790	102,360	145,380	149.500	172,373
Dissolved solids (tons)	635,530	573,821	582,122	312,596	309,207	425.500	473.120
Concentrations:							
Tons per acre-foot	3.00	[illegible]	2.72	3.05	2.13	2.34	2.75
Conductance	307.1	306.8	268.2	341.3	283.8	332.0	295.7
Sum (milliequivalents)	74.20	70.17	62.63	69.02	48.96	66.27	65.81
Constituents (tons):							
Calcium (Ca)	60,272	50,993	49,933	26,769	27,871	38,837	40,779
Magnesium (Mg)	11,993	13,114	12,258	6,941	6,437	9,267	10,002
Sodium and potassium (Na+K)	165,647	149.907	128 402	66.596	66.699	92.547	111,633
Bicarbonate (HCO_3)	37,356	36,343	35,860	17,005	19,707	24,859	28,522
Sulphate (SO_4)	137,882	134.098	129.601	68,515	74,118	99,322	107,256
Chloride (Cl)	234,084	213,541	186,231	100,137	94,627	136,926	160,924
Nitrate (NO_3)	------	------	------	------	460	762	611
Composition (milligram equivalents):							
Ca	8.72	8.89	8.59	9.61	7.05	9.54	8.70
Mg	3.42	3.76	3.47	4.10	2.68	3.75	3.51
Na	24.98	22.70	19.20	20.80	14.67	19.78	20.70
Sum (cations)	37.12	35.34	31.26	34.51	24.40	33.07	32.91
HCO_3	4.25	4.15	4.04	4.00	3.27	4.01	3.99
SO_4	9.96	9.73	9.29	10.25	7.81	10.17	9.53
Cl	22.87	20.95	18.04	20.26	13.48	18.96	19.34
NO_3	------	------	------	------	------	.06	.04
Sum (anions)	37.08	34.83	31.37	34.51	24.56	33.20	32.90
Percentage:							
Calcium	24	25	28	28	29	29	26
Magnesium	9	11	11	12	11	11	11
Sodium	67	64	61	60	60	60	63
Bicarbonate	11	12	13	11	13	12	12
Sulphate	27	28	30	30	32	31	29
Chloride	62	60	57	59	55	57	59

not shown in this summary table is that the concentration of the water passing the Courchesne station is much higher during the winter months than during the summer. This is doubtless due to the higher proportion of drainage water in the stream during the months when the gates at Elephant Butte Dam are closed.

Table 25 gives the mean annual data for the stations located at the head of the Tornillo canal, near Fabens, Tex., and at Tornillo Bridge, near Tornillo, Tex. The water samples have been taken at the head of the Tornillo canal and the discharge reported represents the discharge as measured into the canal, together with that of the river at Tornillo Bridge. The quality of the water sampled at this station is influenced by the drainage water returned to the stream above the sampling point. But not all of the drainage from land served by irrigation water diverted above Fabens gets back to the river above that point. For example, some of the water diverted from the river at El Paso into the Franklin canal is taken from that canal through the Island Feeder to supply land in the upper part of San Elizario Island. The drainage from that area is returned to the river below the Fabens-Tornillo station. At this station as at Courchesne the annual mean concentrations of the water fluctuates within a narrow range but monthly means, not shown in this summary table have a much wider range of fluctuation; the lower values occurring during the summer months.

The final table of this group, 26, shows the summary of conditions found at the Fort Quitman station. This station is located about 35 miles below the Elephant Butte project and all of the drainage from the lands of that project, as well as drainage from other irrigated land contiguous to the river, returns to the river above the station. The annual volume of discharge at Fort Quitman varies between wider limits than that at the stations between it and the reservoir and the concentration also is more variable. There is an inverse correlation between volume of discharge and concentration but it is not very close.

It remains now to review and discuss the conditions of discharge and salinity as found, for the 6-year period, at each of the five stations in the Elephant Butte project and to show the trends from station to station. Before proceeding to discuss the more important phase of this subject it seems proper to call attention to the conditions in respect to the seasonal volume of discharge of water at the several gaging stations. This may be considered in two ways, one relating to the characteristic monthly discharge and the other to the variations in annual discharge during the 6-year period ending with 1936.

It may be noted again that the purpose of Elephant Butte Reservoir is to regulate the supply of the Rio Grande so as best to serve the irrigation requirements of the land below it. Consequently, water is released from the reservoir only as it is required for irrigation use. In table 27 is shown for the year 1936 the percentage of the total annual discharge that passed each ·ion in each month.

..E 27.—*The monthly discharges of water at 5 stations of Elephant Butte project, expressed as percentages of the total annual discharge for 1936*

Month	Elephant Butte	Leasburg Dam	El Paso (Courchesne)	Fabens-Tornillo	Fort Quitman
January	0.1	0.5	1.8	4.1	7.6
February	2.4	1.9	2.3	4.1	5.3
March	7.8	7.3	6.2	6.0	3.8
April	14.2	13.5	10.7	7.0	3.1
May	13.4	13.0	13.2	9.0	5.2
June	16.4	15.2	13.3	9.2	5.3
July	17.9	17.7	16.2	11.4	4.4
August	17.4	17.7	16.8	14.0	7.4
September	8.2	9.1	10.6	17.8	25.0
October	.8	1.8	3.8	6.7	13.5
November	.8	1.3	2.6	6.3	9.2
December	.6	1.0	2.5	4.4	10.2
The year (acre-feet)	747,120	693,260	473,740	224,420	149,590

It will be seen that at the outlet of Elephant Butte Reservoir the monthly discharge was above 10 percent from April to August, inclusive, and that it was below 1 percent from October to January. The regimen was much the same at Leasburg Dam as at the reservoir outlet, for obvious reasons. At Courchesne the period during which the monthly discharge was above 10 percent extended from April to September, inclusive, and maximum percentage occurred in August, rather than in July, as at the reservoir. The lowest percentage was ·'·· in January, but it was 18 times as high as the per- ·ge for that month at the reservoir. At Fabens . monthly discharge did not reach 10 percent of the total until July and reached its peak in September. At Fort Quitman the period of highest discharge extended from September to December. It is probable that the high percentages reported for Fabens and Fort Quitman for September 1936 may have been caused in part by the run-off of local rains. However, the evidence seems convincing that the irrigated land in each division of the project acts as a reservoir to equalize the discharge of the stream and to delay its peak at the lower stations.

The other aspect of the discharge regimen of the stream has to do with interannual variations at the several stations. This may be illustrated by the data of table 28. In this table the total annual discharge at each station is referenced to the mean annual discharge for that station for the 6-year period ending with 1936. It will be seen that the narrowest range of these percentages occurred at the reservoir outlet. This is to be expected. The greater significance of the table seems to be that the effects of the drought of 1934, with its consequent depletion of the reserve supply in the reservoir, were more pronounced and protracted at the lower stations of the project. This condition of affairs probably has an important bearing on the salinity ·itions within the project.

order to illustrate concisely the conditions of ·inity within the project, attention may now be called to the data assembled in table 29. This table comprises the mean values for the 6-year period ending in 1936, in respect to the quantities of water and of dissolved solids passing each station, the concentration of the water, and the tonnage of each of the major constituents of the dissolved solids. The table shows that as the river flows from Elephant Butte Reservoir to Fort Quitman it loses water progressively. It loses, in fact, about 600,000 acre-feet annually. This water is presumably dissipated by evaporation and by transpiration from plants. The river apparently loses some dissolved solids also. The quantity lost between the reservoir and Fort Quitman has been about 150,000 tons annually. As a result of these respective losses the concentration of the water at Fort Quitman is approximately 3.5 times greater than at the reservoir.

TABLE 28.—*The annual discharge of water at the five stations of Elephant Butte project, expressed as percentages of the mean annual discharge for the 6-year period 1931–36*

Year	Elephant Butte	Leasburg Dam	El Paso (Courchesne)	Fabens-Tornillo	Fort Quitman
1931	98.0	99.0	99.1	108.9	123.0
1932	108.6	109.3	108.5	113.5	122.5
1933	107.9	110.6	116.5	127.8	124.1
1934	104.9	103.1	97.3	86.5	59.3
1935	83.1	84.9	88.0	76.0	84.3
1936	97.5	93.1	90.6	87.3	86.8

TABLE 29.—*The Rio Grande in the Elephant Butte project, New Mexico and Texas; discharge conditions at five control stations; means for 1931–36*

Item	Elephant Butte Outlet	Leasburg Dam	El Paso (Courchesne) station	Fabens-Tornillo station	Fort Quitman station
Discharge:					
Water (acre-feet)	766,131	744,082	522,758	257,123	172,373
Dissolved solids (tons)	619,909	647,406	637,965	496,014	473,129
Concentrations:					
Tons per acre-foot	0.809	0.87	1.22	1.93	2.75
Conductance	87.1	91.0	127.2	212.0	295.7
Sum (milliequivalents)	18.32	19.97	28.71	45.51	65.81
Constituents (tons):					
Calcium (Ca)	78,277	81,810	70,288	47,801	40,779
Magnesium (Mg)	16,952	17,876	15,546	11,396	10,002
Sodium (Na)	96,561	103,994	124,297	104,420	111,633
Bicarbonate (HCO_3)	94,440	95,778	81,407	46,876	28,522
Sulphate (SO_4)	234,731	238,969	210,060	135,317	107,256
Chloride (Cl)	56,744	72,392	112,716	120,776	160,924
Nitrate (NO_3)	349	1,289	1,661	689	611

It will be seen that the concentration increases progressively but not at a uniform rate for the three major divisions, and the loss of dissolved solids does not occur uniformly throughout the length of the project. Indeed, there is shown to be a gain in the total salt burden of the stream, as between the reservoir outlet and the Courchesne station, of nearly 28,000 tons annually. The losses of dissolved solids occur below that point; the indicated losses between Courchesne and Fort Quitman being approximately 165,000 tons annually. It is obviously not to be inferred that all of the dissolved solids shown to be lost from the stream between these two points are deposited in the soils of the El Paso Valley division. The data available do not appear to warrant definite quantitive conclusions as to where these dissolved solids are deposited. But painstaking consideration of the available data and reviewing of the computations by which the summaries of table 29 have been obtained leads to the belief here stated, namely, that there is a very substantial quantity of soluble solids deposited annually somewhere along the Rio Grande between El Paso and Fort Quitman.

In view of this finding that there is a substantial loss of soluble solids from the Rio Grande as it flows through Elephant Butte project, it is pertinent to consider how this loss is allocated among the major constituents of these soluble solids. The data bearing on this question are also presented in table 29. In respect to the six major constituents and the total dissolved solids, expressing the quantities annually passing Fort Quitman as percentages of the quantities released from Elephant Butte Reservoir, we have the following:

Constituent:	Percentage
Calcium	52.1
Magnesium	59.0
Sodium	115.6
Bicarbonate	30.2
Sulphate	45.7
Chloride	283.6
Total dissolved solids	76.3

It is manifest that there are great differences among these several constituents in respect to their transport along this section of the river. Referenced to the quantities released from the reservoir, there is a range from an apparent loss of 70 percent for the bicarbonate to an apparent gain of 183 percent for the chloride. Of the six constituents listed, four show losses and two show gains.

It was noted above that in respect to the total dissolved solids there was no loss but apparently a small gain occurring between Elephant Butte and Courchesne (El Paso). An inspection of table 29 shows that between the same points there are slight losses of calcium and magnesium, somewhat greater losses of bicarbonate and sulphate, and substantial gains of sodium and chloride. Between El Paso and Fort Quitman there are substantial losses of all constituents except chloride. These differences among the constituents in transport behavior are reflected, of course, in the percentage composition of the constituents as reported for these several stations in tables 22 to 26.

The question naturally arises as to the processes by which these changes in salt composition come about. If we had to consider only the relative quantities of total dissolved solids as between Elephant Butte and Fort Quitman, it could be assumed that a certain portion of the quantity passing the upper station was deposited in the soil somewhere between the two stations. In other words, that during the period of record there had been an adverse "salt balance" in the soil of the area of 146,000 tons per year. Or, to localize more definitely as between Courchesne and Fort Quitman, it might be said that there had been deposited in the soil annually 165,000 tons of dissolved solids or during the last 6 years a total of 990,000 tons.

If we turn now to the evidence furnished by the data as to the several constituents, it becomes evident that the situation is not quite so simple as that. We have to deal with the fact that during the same period the quantity of the chloride constituent passing Fort Quitman has exceeded the quantity released from the reservoir by 104,000 tons annually, or 624,000 tons for the 6-year period of record. Conversely, to consider one other constituent, sulphate, the data indicate that the quantity passing Fort Quitman was less than the quantity released from the reservoir by 127,000 tons annually or 765,000 tons for the 6-year period. These facts do not fit into the simple theory of salt deposition in the soil.

We might attempt to explain the losses of tonnage for such constituents as calcium, bicarbonate, and sulphate by assuming that as a result of solution concentration in the soil these constituents were precipitated out of solution because they unite to form salts of low solubility. But no such line of reasoning may be invoked to explain the increase in the tonnage of chloride. Nor is this increase of chloride tonnage to be explained as coming into the area through tributary streams, because there are no streams of importance to bring it in.

We are thus forced to the conclusion that the increase in chloride tonnage passing Fort Quitman has originated within the area between that station and the reservoir. This conclusion, if it is warranted, has implications of profound significance. The most acceptable among the several theories that have been examined to explain these facts is one that may be designated the theory of displacement.

It was pointed out above that in respect to the seasonal inflow and outflow of water, each division of Elephant Butte Project seems to function as an equalizing reservoir. It is here suggested that this reservoir effect is indicated also in respect to inflow and outflow of the salt constituents. It is accepted as a fact that the valley through which the Rio Grande flows is a deep trough filled with sediments and that these sediments are saturated with water almost to the ground surface. Thus each division is thought of as a reservoir filled almost to the surface with ground water.

According to this theory of displacement it may be assumed that a substantial proportion of the water diverted from the stream and not dissipated by evaporation percolates through the subsoil to join the ground water, and that instead of moving thence laterally ··ng the surface of the ground water to the drains, it ·es the ground water in the vicinity of the drains to ·· into them as the result of hydrostatic pressures transmitted from the areas of freest percolation. Thus the inflowing river water, distributed through the irrigation system, replaces in part the ground water hitherto present in the subsoil and causes a corresponding quantity of ground water to pass out through the drains.

This theory seems not unreasonable and appears adequate to explain the known facts. Its validity, however, depends upon the existence of conditions not demonstrated by the present investigation. For example, the theory requires that the ground water hitherto present and assumed to be displaced by the surplus irrigation or percolating water shall contain very large quantities of chloride. It is necessary to explain the origin annually of 104,000 tons of chloride from within the area in question. The present investigation did not include an exploration of the deeper ground water in the sediments of the El Paso Valley. If subsequent investigation should show that these valley sediments do contain a large body of ground water with high chloride concentrations the theory of displacement would gain plausibility. On the other hand, if that condition could not be demonstrated the theory would be less acceptable.

·e agricultural implications of the conditions here ·ussed merit consideration. If we could leave the main body of ground water out of account and assume that the surplus irrigation water percolating through the soil moved laterally to the drains, we might assume that the increase in chloride between the reservoir and Fort Quitman represented the removal of chloride from the soil. The annual removal of 104,000 tons of chloride from the root zone of 150,000 acres of irrigated land might be accepted as appreciable progress in reclamation or salinity removal, even if at the same time it was admitted that in respect to the total dissolved solids there was an adverse salt balance of large proportions. It could be suggested that the loss of total tonnage between the reservoir and Fort Quitman was to be explained as consequent upon the precipitation in the soil, in a harmless state, of the salts of low solubility.

It must be admitted, however, that such facts as are available do not appear adequately to support the view that the changes in chloride concentration of the water that occur between the reservoir and Fort Quitman are consequent upon phenomena that occur within the root zone of the soil and above the surface of the subsoil water. Were the theater of such changes as are indicated limited to the soil of the root zone, it seems inevitable that the evidence of their effect would be more apparent than is the case.

If we consider now the transport behavior of the sodium constituent we find that it does not follow that of either the chloride or the sulphate. There is an appreciable gain of sodium between the reservoir and Courchesne and only a slight loss between Courchesne and Fort Quitman. It is known that the cation constituents of these salts participate in reactions of base exchange in the soil. It seems highly probable that it is as a result of such reactions that the transport behavior of sodium differs so greatly from that of chloride, its natural associate. While no evidence is here presented to support the view, it seems probable that under existing conditions in the Elephant Butte project base exchange reactions are taking place on a large scale and that sodium is being absorbed by the soil of the root zone in place of calcium and magnesium.

In summarizing and reviewing these data concerning the concentration and composition of the dissolved solids carried by the Rio Grande through the Elephant Butte project the aim has been to show what the conditions are in the river itself. In presenting these findings it is hardly possible to avoid inferences or implications in respect to conditions in the irrigated areas served by the stream. Indeed, there has been no conscious attempt to do so. However, the investigations covered by this report have been limited to the quality of the surface and ground waters of the drainage basin. The aim has been to assemble, present, and interpret the available facts pertinent to this subject. What these facts may imply in respect to the problems of agricultural production on these irrigated lands is unquestionably a subject of importance but it is another subject.

PART IV

SECTION 7.—SALT CONCENTRATION AND SERVICE EQUIVALENC

In the preceding chapter it has been shown that as the Rio Grande flows southward from its source in the mountains of Colorado, its water becomes progressively more saline until it passes out of the area at Fort Quitman, Tex. Throughout its course, water is diverted from the stream for irrigation. It is accepted as a fact that when irrigation water is applied to the land some of the water, usually the major portion of it, is evaporated from the soil or transpired by plants. The remaining surplus, if any, passes away either by downward percolation, or by moving laterally, escapes as subsoil drainage. Because of the losses by evaporation and transpiration, the residual water becomes more concentrated with the residual soluble material. Thus the soil solution in irrigated land is normally more concentrated than the solution with which the soil is irrigated.

Another accepted fact is that as the soil solution becomes increasingly charged with soluble material it becomes less suitable as a source of water supply for plants. It is probably not true that there is some "critical concentration" below which plants do well and above which they fail. There are, doubtless, optimum concentrations in respect to each constituent of the soil solution but these optimum concentrations are very low as compared to the concentrations which cause visible symptoms of plant injury or a serious impairment of growth. It seems unquestionable that when the salinity of the soil solution reaches concentration ranges that cause obvious plant injury conditions are far beyond any theoretical optimum and remedial measures are indicated.

In dealing with the subject of irrigation salinity, it should be kept in mind that the sphere of interest lies in the soil solution rather than in the irrigation water. It is easier to obtain samples of irrigation water than of the soil solution, consequently we know more about conditions in the former. We know also that the soil solution is always more concentrated than the irrigation water, but how much more so depends upon what proportion of the water applied to the soil surface ultimately percolates through the root zone and escapes below. As the proportion of the volume of root zone percolation to the volume of water applied increases, the difference between the concentration of the soil solution and that of the irrigation water diminishes. Consequently, because it is manifestly desirable to avoid injurious concentration of salinity in the soil solution, it follows that with more saline irrigation water it is necessary to apply larger quantities to the soil than would be necessary if the water were less saline.

These premises lead naturally to the question: What increase in application is required for a given increase in the salinity of the irrigation water in order that a given concentration of the soil solution should not be exceeded? The essential elements involved in this question may be defined and evaluated for any given situation and brought into an equation that illustrates the theoretical relationships.[1] There are at least 4 essential elements to be considered in this problem. These may be enumerated and described as follows:

(1) Consumptive use, i. e., the quantity of water, in depth per unit area required to support crop growth and meet evaporation losses. This may be designated as D_c.

(2) Irrigation requirement, i. e., the quantity of water, in depth per unit area required, not only for consumptive use, but also to provide sufficient percolation through the root zone to keep the concentration of the soil solution below a given maximum. This may be designated as D_a.

(3) Concentration of the irrigation water either in respect to total dissolved solids or in respect to any constituent regarde as potentially most likely to cause trouble. This may be designated as C_a.

(4) Concentration of the soil solution in the root zone, measured by the same standards or as to the same constituent as used for the irrigation water. This may be designated as C_r.

Whence the equation:

$$D_a=\left(\frac{2C_r-C_a}{2C_r-2C_a}\right)\times D_c.$$

To illustrate the application of this equation to a given area or situation, values may be assigned to three of the elements and values derived for the other one as follows: Let it be assumed that the consumptive use (D_c) for the situation is 2.00-acre feet per annum, and that the permissible limit of concentration of the soil solution (C_r) as measured by conductance is 400; then by means of the equation we may derive the irrigation requirement (D_a) for a series of values for various concentration of irrigation water (C_a).

With C_a as below (Conductance)	D_a becomes (Acre-feet per annum)
87	2. 28
91	2. 29
127	2. 47
212	3. 13

[1] I am indebted to Mr. Raymond A. Hill for developing this equation which illustrates concisely my views as to these relationships.

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It may be observed that the values selected for C_a in the above list correspond with the mean conductance ·es of table 29 for 4 stations on the Rio Grande in Elephant Butte project. These values as well as the assumption of 2.00 acre-feet for consumptive use (D_c) and the conductance value of 400 as the permissible limit of concentration of the soil solution (C_r) are used merely tor purposes of illustrating the use of the service equivalence equation. It is not intended to imply that 2.00 acre-feet of water per acre is the requirement for consumptive use on the Elephant Butte project or that a conductance of 400 is the limit of concentration permissible for the soil solution of that area. The correct value to adopt for "consumptive use" in that area must be ascertained by appropriate inquiry and the value for the permissible limit of concentration of the soil solution (C_r) must be ascertained locally in the same way.

PART IV

SECTION 8.—THE SODIUM CONSTITUENT OF IRRIGATION WATER

In the tables of this report showing the detailed analyses of water the value of the sodium constituent has been reported not only in terms of milligram equivalents per liter but also as a percentage of the sum of the cations. The reason for including the second value is that the effect of sodium on the physical properties of the soil is believed to be related not to its absolute concentration in the solution but rather to its relative or proportional concentration.

It has been abundantly shown that the effect of sodium in solutions in contact with the soil is deleterious to the physical properties of the soil. This is brought about through reactions of base exchange by which sodium from the solution tends to replace calcium that is combined with the soil, the calcium in turn passing into solution. Such exchange reactions are well known and are extensively utilized in the zeolitic process of water softening.

The deleterious effects of sodium combined with the soil are manifested by dispersion of the soil particles, and by impairing the permeability of the soil to the absorption of water or the movement of water through it. Soils containing much combined sodium are also more difficult to work into good tilth than the same soils containing less combined sodium.

The extent to which sodium in the soil solution replaces calcium from the soil is influenced more by its relative concentration to calcium than by its absolute concentration. Therefore, it is believed that sodium percentage is a better expression of relative values between different waters than sodium concentration.

In the present state of our knowledge we do not feel warranted in setting a definite limit as the permissible sodium percentage of irrigation water. There is substantial agreement among those who have investigated the subject that, other things being equal, the lower the sodium percentage the better the quality of the water. It is also generally agreed that the same sodium percentage is likely to prove less harmful in waters of low total concentration than in waters of higher total concentration. Finally, it is generally agreed that sodium in irrigation water serves no useful purpose and that its presence in any concentration is to be regretted.

In view of these considerations, it may be observed that in respect to the criterion of sodium percentage the concept of service equivalence does not apply. The injurious effects of high sodium percentages are not to be minimized by applying larger quantities of water. It is possible, however, to offset these injurious effects either by adding a calcium salt such as gypsum to the irrigation water or by applying gypsum to the irrigated soil. To achieve the objective of service equivalence it might be necessary to introduce into the equation a cost factor by which to compensate for differences in sodium percentage between two water supplies.

PART V
WATER IMPORTATION AND STORAGE

Report of the United States Bureau of Reclamation[1]

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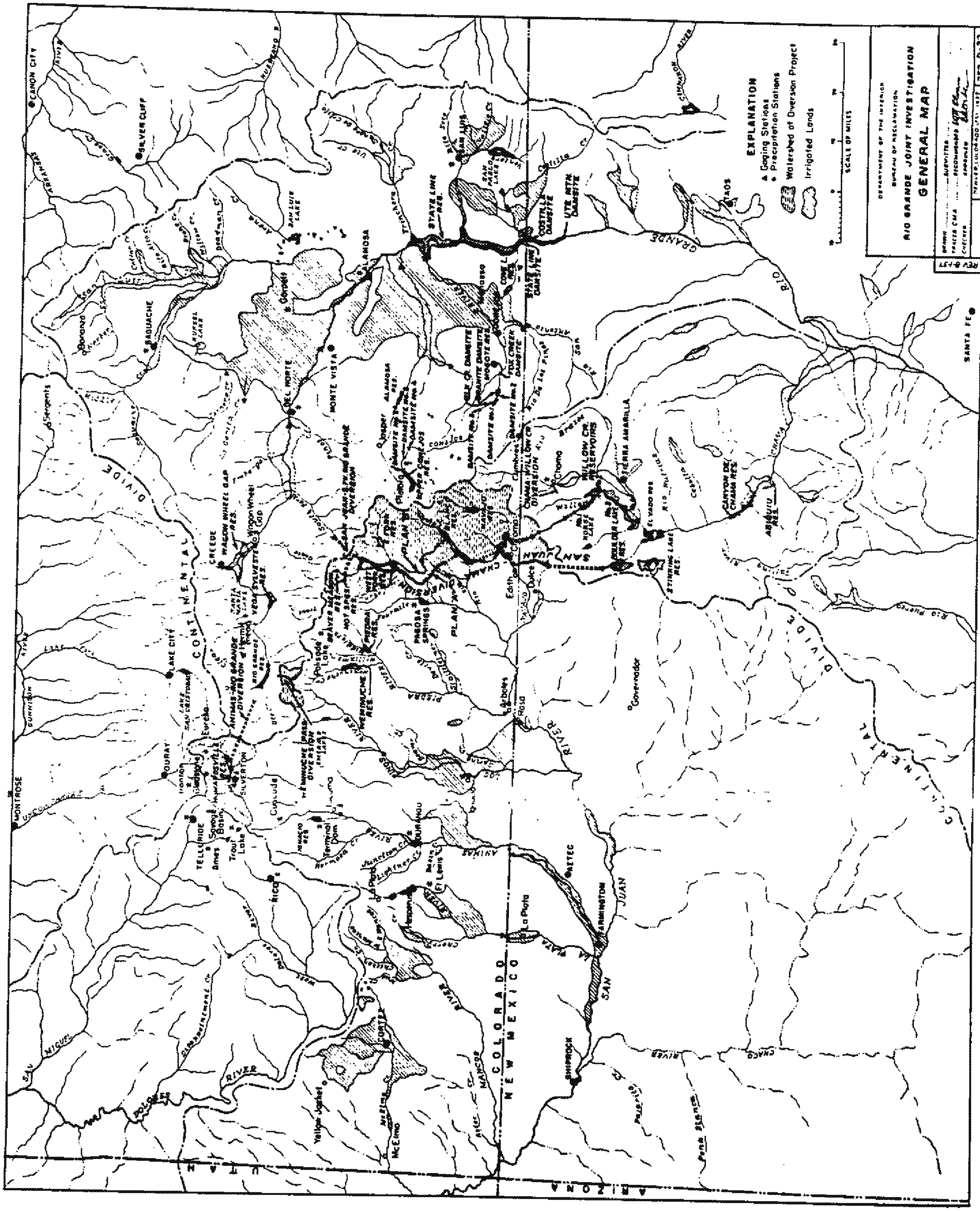
[1] By W. G. Sloan, engineer.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PART V

SECTION 1.—INTRODUCTION AND SUMMARY

Summary

New Mexico Investigations

San Juan-Chama transmountain diversion.—A mean annual yield (1924–35, inclusive) of 350,000 acre-feet can be diverted to the Chama River from a watershed area of 506 square miles above an elevation of 7,600 feet on the San Juan River and its tributaries.

Two plans have been considered, designated as plan A and plan B.

The estimated costs are as follows:

Plan A, $20,881,000; cost per acre-foot, $59.66.

Plan B, $17,500,000; cost per acre-foot, $50.00.

Terminal storage of 300,000 acre-feet to insure delivery to the Rio Grande of 350,000 acre-feet every year from 1911 to 1935, inclusive, without shortage, will cost for plan A an additional $1,350,000, and for plan B $2,500,000.

If San Juan and Chama River waters are regulated for power purposes only, a total head of 1,032 feet can be utilized and 250,000,000 kilowatt-hours of firm power, with large blocks of secondary power, developed annually, by the construction of four reservoirs on Willow Creek, two on the Chama, and utilizing the existing El Vado Reservoir, to provide a total storage capacity of 1,067,000 acre-feet.

Regulation of San Juan and Chama Rivers waters for power only, together with Rio Grande waters, would have produced a sufficient supply at Otowi for all irrigation requirements of the Middle Rio Grande conservancy district (1911–35, inclusive) except for a minor shortage in 1934.

Existing developments in the San Juan Basin as far down as Shiprock, N. Mex., will not be impaired by this diversion. Preliminary investigations indicate possible future extensions of areas to be served by the San Juan, totaling 30,000 acres, which will require 50,000 acre-feet of storage. A reservoir of 96,000 acre-feet capacity can be built on Weminuche Creek, a tributary of the Piedra, for $2,136,133, or $22.25 per acre-foot.

State-line reservoir.—Three possible dam sites were studied for this reservoir, all of which are geologically unfavorable for securing a tight reservoir but favorable for construction of a concrete dam. Ute Mountain site was finally selected as having better qualifications for an all-purpose reservoir. It is estimated to cost $2,600,750 for 452,000 acre-feet of capacity at elevation 7,500, or $5.75 per acre-foot.

Colorado Investigations

Animas-Rio Grande transmountain diversion.—A mean (1924–35) annual yield of 130,700 acre-feet can be diverted to the Rio Grande above the Rio Grande Reservoir for a total estimated cost of $10,432,500, or $79 per acre-foot, from a watershed area of 129 square miles above elevation 9,800 on the Animas River near Silverton.

The diversion system as planned comprises a reservoir of 54,000 acre-feet capacity at Howardsville, a tunnel through the Continental Divide 13 miles long, and a collection system 13.65 miles long, almost wholly of tunnel or concrete-lined conduit.

Existing and feasible developments on the Animas River below the diversion would have experienced no shortages of water in any month of any year since 1911, had the diversion been operating.

Weminuche Pass transmountain diversion.—An estimated mean annual yield (1924–35) of 20,455 acre-feet can be diverted through Weminuche Pass into the Rio Grande Reservoir for a total cost of $264,500, or about $13 per acre-foot, from a watershed of 24 square miles above an elevation of 10,500 feet on the headwaters of Pine River.

This mean yield is after allowance has been made for no diversions in 1925, 1931, and 1934, due to interference with storage development now authorized for construction on the Pine River project and after prior transmountain diversion rights of 4,000 acre-feet have been deducted.

San Juan-South Fork Rio Grande transmountain diversion.—A mean annual yield (1924–36) of 53,000 acre-feet can be diverted to the South Fork of the Rio Grande for an estimated total cost of $5,290,300, or about $98 per acre-foot, from a watershed area of 44.7 square miles on the headwaters of the San Juan River above an elevation of 9,050.

The diversion system consists of a feeder canal 2.6 miles long from the West Fork of the San Juan River to Beaver Creek, a tunnel 3.2 miles long from Beaver Creek to a junction with a 1-mile tunnel from Wolf Creek, and a tunnel 6.7 miles long from the junction to the South Fork of the Rio Grande. The total length of tunnels is 10.9 miles. Sites for regulating reservoirs have been located above this diversion, but from present data their inclusion in the project would increase the water yield but little and the project cost much more.

No existing rights on the San Juan below the diver-·ion would be impaired, but the supply available for San Juan-Chama diversion would be depleted by . amount diverted to the Rio Grande.

Conejos River storage.—Reconnaissance of the entire watershed resulted in the selection of four reservoir sites for intensive study, with results as follows:

No. 1 site.—Poor foundation conditions necessitate extreme conservatism in dam design. Estimated cost for a reservoir of 100,000 acre-feet is $3,700,000 or $37 per acre-foot.

Granite site offers more favorable foundation conditions but requires a high dam. Estimated cost for 100,000 acre-feet is $3,655,000 or $36.55 per acre-foot.

No. 6 site.—Favorable foundation and reservoir conditions permit construction for 32,000 acre-feet at total estimated cost of $608,400 or $19.01 per acre-foot.

Mogote.—An inland reservoir requiring a 5-mile feeder canal. Only fair geological conditions. For a capacity of 30,000 acre-feet the total estimated cost, including feed canal, is $746,100 or $24.87 per acre-foot.

Wagon Wheel Gap dam and reservoir.—A concrete arch dam at this site, to store 1,000,000 acre-feet of water, is estimated to cost $11,400,000, exclusive of railroad relocation and power installation. Potential power production at the dam will average 132,000,000 kilowatt-hours annually, all of which will be secondary ·er. Geologic conditions are favorable.

·ega Sylvester reservoir.—Foundation conditions are unattractive. Tentative designs and estimates for 240,000 acre-feet capacity show an estimated cost of $4,825,900.

Foreword

The Rio Grande rises in Colorado, flows across the entire State of New Mexico, then from El Paso to the Gulf of Mexico it becomes the international boundary between Mexico and the United States, and the southwestern border of Texas.

Irrigation developments in the San Luis Valley of Colorado consume all of the flow of the river and its tributaries except for the flood peaks and small winter flows. In northern New Mexico the stream is augmented by numerous partially used mountain tributaries, reaching a maximum flow in White Rocks Canyon opposite Santa Fe. The stream then enters the Middle Rio Grande Valley which ends at Elephant Butte Reservoir. Stream flow diminishes through Middle Rio Grande Valley despite flash floods contributed by numerous tributaries.

Waters are released from Elephant Butte Reservoir only as required for irrigation of the valley down to F··t Quitman, including a supply of 60,000 acre-feet ·ally for Mexican use by the terms of a treaty. The reservoir has not spilled since 1924 and was almost empty in 1935.

Below Fort Quitman, Tex., irrigation is largely confined to an area just above Brownsville, and mainly dependent on inflow below Fort Quitman.

Above Fort Quitman (according to the 1929 United States census), approximately 1,000,000 irrigated acres are dependent upon the river and its tributaries for their supply, about one-half of which are in Colorado, about 40 percent in New Mexico, and the balance in Texas.

Limited water supplies have, for many years, been the cause of many local and interstate controversies, extended litigation, arrested development, and unstable economic conditions.

A compact, ratified by the three States and the Federal Government in 1929, was in the main intended to arrest development pending further efforts to arrive at a permanent compact. This compact provided that not later than June 1, 1935, or such later date as might be agreed upon by the signatory States, a commission of four members, three appointed by the Governors of the respective States and one a representative of the President, shall equitably apportion the waters of the Rio Grande on the basis of conditions obtaining on the river and within the Rio Grande Basin at the time of the signing of the compact.

Experience gained by the Commission has increasingly demonstrated the need for a comprehensive study of the entire watershed and possible future developments within it, to assist them in making their decision. No methods of financing or conducting such a study were provided in the compact.

Creation of the National Resources Committee by Presidential order in 1934 brought into existence a central coordinating agency with power and authority to undertake just such investigation. The Compact Commission and the Resources Committee at once began negotiations for cooperation in the study. As a result, arrangements were finally perfected for participation of five agencies of the Federal Government with funds provided in part by the National Resources Committee, the cooperating agencies, and the interested States, all to be under the direction of the National Resources Committee. Each cooperating agency was assigned some portion of the investigations.

This report sets forth the accomplishment up to August 1, 1937, of that part of the Rio Grande joint investigation assigned to the Bureau of Reclamation.

Authorization and Cost

That part of the Rio Grande joint investigations undertaken by the Bureau of Reclamation, has been carried out under the terms of an agreement entered into on February 28, 1936, between the National Resources Committee and the Bureau of Reclamation, which reads as follows:

In order to prepare a report on the Upper Rio Grande as contemplated in the request of the Rio Grande Compact Commission and in the allotment of funds to the National Resources Committee by the Public Works Administration, warrant no. 222, January 13, 1936, it is hereby agreed that:

(1) The Bureau of Reclamation will make such surveys and investigations (*a*) of reservoirs and dam sites in the basin of the Rio Grande, with designs and estimated costs of necessary dams and related structures; (*b*) of the possibilities of transmountain diversion of water from San Juan River and tributaries to the basin of the Rio Grande, including storage and the design and estimates of costs of all necessary conduits and works; and (*c*) of the possibilities and cost of hydroelectric developments in the basin of the Rio Grande, including its economic feasibility and the possible markets for and income from the electric power to be generated, as contemplated in work sheets filed with the National Resources Committee, which are subject to such modifications as may be mutually agreed upon between the Bureau of Reclamation and the National Resources Committee.

(2) To meet the cost of the work outlined in paragraph (1) above, including payment for salaries, expenses, subsistence, equipment, compilation of data, preparation of reports, supplies, and other purposes:

(*a*) *Contribution by Bureau of Reclamation.*—The Bureau of Reclamation agrees to make available from the funds allocated to the Bureau by the Emergency Administration of Public Works for the purposes herein set forth the sum of $30,000.

(*b*) *Contribution by National Resources Committee.*—The National Resources Committee agrees upon execution of this memorandum of agreement to advance to the Bureau of Reclamation from the funds made available to it by the Emergency Administration of Public Works for the purposes herein set forth the sum of $60,000 in accordance with section 601 of the act of June 30, 1932 (47 Stat. 417).

(*c*) *Reserved funds.*—It is understood that, in addition to the immediate allotment provided for in subparagraph (*b*) above, the National Resources Committee expects to develop a reserve fund from contributions to the project by other agencies or out of funds made available to it by the Emergency Administration of Public Works, such sums to be allotted by the National Resources Committee for the purposes of this investigation, if and as available, to meet expenses in connection therewith among the various agencies party to the Rio Grande joint investigations.

(3) *Reports.*—The Bureau of Reclamation agrees to finish the compilation of data and the preparation of necessary maps, diagrams, and specifications, and to file 100 copies of a complete report thereon with the National Resources Committee not later than January 1, 1937, or by such other date as may be mutually agreed upon between the parties hereto.

(4) *Reversion of funds.*—In the event of funds becoming available from other sources to the Bureau of Reclamation for any or either of the purposes set forth herein, or in the event the total sum made available to the Bureau by the National Resources Committee under this memorandum of agreement is not wholly expended, it is understood that such amounts as may be mutually agreed upon between the Bureau and the National Resources Committee shall revert to the reserve fund described in paragraph (2) (*c*) above.

A short time after the above agreement had been signed, the Committee made the following allotments and priorities:

New Mexico investigations:	
1. San Juan-Chama diversion	$35, 000
2. State Line Reservoir	15, 0
3. Willow Creek or other terminal reservoir	5, C
Total	55, 000
Colorado investigations:	
1. Wagon Wheel Gap Reservoir	10, 000
2. Conejos River Reservoir	9, 000
3. Vega Sylvester Reservoir	3, 000
4. San Juan-South Fork (Rio Grande) diversion	8, 000
5. Animas-Rio Grande diversion	14, 000
6. Navajo-Conejos diversion	1, 000
Total	45, 000

No part of the reserve fund set up in the agreement became available to the Bureau of Reclamation.

In October 1936, an additional sum of $50,000 was made available for continuation of the work, from other P. W. A. funds.

Situations developing in the course of the work made allotment shifts desirable. All deviations were fully discussed with the various interests and approved by them before authorized by the Committee or its representatives.

Unsatisfactory foundation conditions disclosed at the dam site proposed on the Conejos River made it advisable to give consideration to several additional dam sites. Diversion of Pine River waters through Weminuche Pass was suggested, and this feature w added to the investigation. A paper study of th proposed Navajo-Conejos diversion quickly proved that plan to be infeasible. Several alternative surveys on the San Juan-Chama diversion were found advisable. Additional dam sites for the State Line Reservoir were investigated. Preliminary studies of power possibilities at Wagon Wheel Gap Dam and on Willow Creek and the Chama River were made.

Expenditures as of July 1, 1937:	
Surveys—general	$6, 147. 39
Wagon Wheel Gap Dam	13, 193. 66
Conejos River Dams	19, 973. 67
Vega Sylvester Dam	5, 523. 80
San Juan-South Fork Rio Grande diversion	3, 689. 65
Animas-Rio Grande diversion	5, 436. 97
San Juan-Conejos diversion	236. 22
State Line Dam and reservoir	20, 394. 05
Willow Creek Dam	290. 38
San Juan-Chama diversion [1]	47, 323. 12
Total	122, 208. 91
Plant and equipment	11, 187. 80
Total	133, 396. 71

[1] Includes $2,800 expended for studies on utilization of San Juan River below Pagosa Springs in Colorado and New Mexico.

The item of plant and equipment represents ledger values of engineering, prospecting, and transportatior equipment, the remaining value of which will be credite to the project as it is transferred to other work.

Estimated costs upon completion of the authorized program, with credit allowances for returned equipment, distribution of general costs, compare with the net .ments as follows:

	Expenditure
Utilization of San Juan River waters within its basin in Colorado and New Mexico	$9,000
New Mexico:	
San Juan-Chama diversion	52,000
State Line Reservoir	21,000
Willow Creek Reservoir	1,000
Subtotal	74,000
Colorado:	
Wagon Wheel Gap Dam	16,000
Conejos River Reservoirs	23,000
Vega Sylvester Dam	7,000
San Juan-South Fork (Rio Grande) diversion	5,000
Animas-Rio Grande diversion	5,700
San Juan-Conejos diversion	300
Subtotal	57,000
Grand total	140,000

Conduct of Work

Initial surveys, dam site exploration, and geological examinations were begun at Wagon Wheel Gap and Vega Sylvester dam sites late in April 1936. On May 1, 1936, two surveying crews were started on the San Juan-Chama diversion. Thereafter, from four to six crews were employed continuously until July 1, 1937, ɔt for a 6-weeks lay-off in February and March , due to extreme bad winter weather. Diamond drill rigs were moved on to the Wagon Wheel site in July 1936, and after completing the work at that site and Vega Sylvester, started work on the Conejos River site. The rigs were released to Western Slope surveys during the latter part of September and returned to drill at the State Line site on December 1. Additional drilling on Mogote Reservoir, Conejos River, and State Line sites, was continued until April 15, 1937. A churn drill rig started work on the Conejos site in July 1936, and finished at the upper West Fork site in October of that year.

Test pit crews were working at Vega Sylvester site in April, Conejos site in June, and on the four sites on the San Juan River until late in November 1936, when they moved to the Mogote site. Thereafter, they worked on the State Line and Stinking Lake sites until February 1, when this part of the work was discontinued.

Four-man plane-table survey parties, consisting of the instrumentman, a recorder, and two rodmen, were used on all reservoir and dam topography. Transit parties comprised a transitman, a flagman, two chainmen, and an axman. Only one transit party was used on canal location, while on strip topography, and on reservoir surveys, there were at times five plane-parties at work.

.h diamond drill was worked two shifts, the crews comprising a driller and two helpers on each shift. The churn drill was worked two shifts part of the time, but only one shift for the remainder. One driller and one helper comprised the crew for each shift.

Surveying crews and geologists used five station wagons and three sedans; the diamond drill crews had a 1½-ton truck and a pick-up available. Occasionally an additional truck was hired for transporting material and equipment for the test pit and churn drill crews. Pack outfits were utilized for the Animas-Rio Grande and Weminuche Pass surveys.

A summary of the work accomplished by the surveying crews is as follows:

Summary of surveys:
- Dam-site topography, 5-foot contours: Scale, 50 feet to 1 inch. 27 sites surveyed.
- Reservoir topography, 5-foot contours:
  - Scale, 1,000 feet to 1 inch, 5 covering 27,579 acres.
  - Scale, 200 feet to 1 inch, 5 covering 3,965 acres.
- Canal fly line (transit and stadia or plane table), 234 miles.
- Canal location, transit and chain, 150 miles.
- Strip topography for canals and roads, 5-foot contours. Scale 200 feet to 1 inch, 104 miles.
- Tunnel triangulation, approximately, 25 miles.
- Reservoir triangulation, approximately, 25 miles.
- Levels, approximately, 350 miles.

All water supply studies were made in the Denver office with the assistance of some of the field men brought in after field work was shut down.

Canal estimates and designs were made by the Canal Section under the direction of H. R. McBirney of the Denver office.

Dam estimates and designs were made in the Denver office by the Dams Section under the direction of W. E. Blomgren. Vega Sylvester dam designs and estimates were made under the direction of F. F. Smith.

A subforeman handled all of the test pit crews, working on as many as three dam sites at one time. All pits were cribbed with timber framing. Two 4-horsepower gasoline single-drum hoists were used for hoisting. Percolation tests were carried out at most of the pits using a 3-inch centrifugal pump direct connected to a 6-horsepower gasoline engine.

One 75-pound sample of material from each 5 feet of pit was taken. These samples, together with all cores secured by the diamond drill rigs, are stored in the warehouse of the Farmers Union Ditch Co. near Del Norte.

Expenditures on dam-site explorations have amounted to about 28 percent of the total amount spent on the investigation. The exploration work accomplished may be summarized as follows:

Type of work	Number of holes	Number of sites	Total footage	Average depth of hole	Average field cost per foot
Diamond drilling	31	11	5,070	164	$4.49
Churn drilling	7	4	913	130	4.69
Test pits	39	9	1,114	29	10.80
All types	77		7,097	85	5.48

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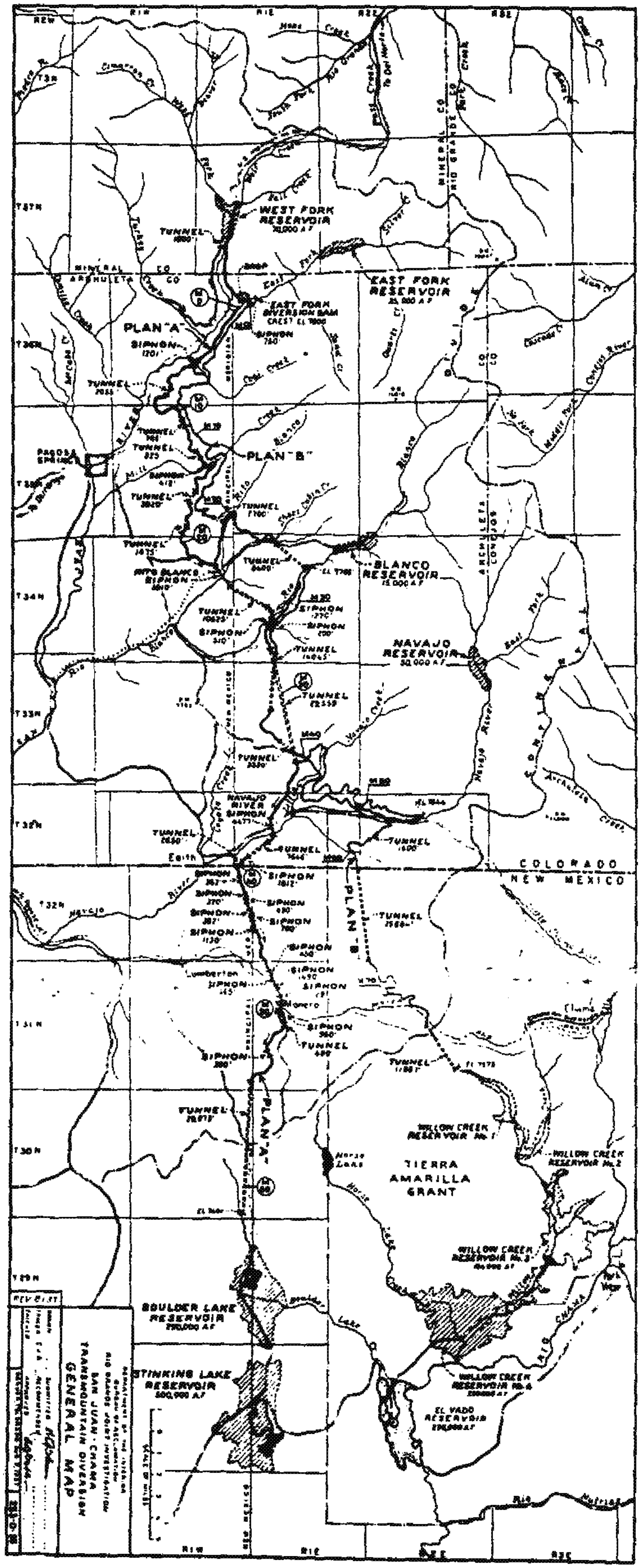
WEST FORK RESERVOIR
EAST FORK RESERVOIR
PLAN "A"
PLAN "B"
BLANCO RESERVOIR
NAVAJO RESERVOIR
COLORADO
NEW MEXICO
TIERRA AMARILLA GRANT
BOULDER LAKE RESERVOIR
STINKING LAKE RESERVOIR
EL VADO RESERVOIR
SAN JUAN - CHAMA TRANSMOUNTAIN DIVERSION
GENERAL MAP

FIGURE 100

PART V

SECTION 2.—NEW MEXICO INVESTIGATIONS

San Juan-Chama Transmountain Diversion

General Description

Figure 100 is a general map showing the various features of the plan herein outlined for the diversion of San Juan River water to the basin of the Chama River, a tributary of the Rio Grande.

Early Surveys

In 1933, a reconnaissance survey was made for the San Juan-Chama diversion. This line was run at an elevation of about 8,000 feet, beginning at the East Fork of the San Juan River to the Navajo River, where it dropped to elevation 7,800, thence across the Continental Divide about 12 miles west of Chama, discharging into Willow Creek, a tributary of the Chama River on the south side of the Divide. Surveys of a part of the reservoir sites on the West Fork, East Fork, Blanco, and Navajo, adopted for the present plan, were also made. The diversion point of the canal was so high that waters of the West Fork of the Juan could not be utilized except with a pumping of about 200 feet.

Two plans have been considered in some detail in the 1936–37 surveys, herein designated as plans A and B.

Plan A

Surveys of 1936 began with retracement of the line originally proposed, except for the last 6 miles in the East Fork Basin. A reconnaissance for a line at a lower elevation was started at the same time which soon disclosed possibilities justifying a survey along this route which developed into plan A. Although plan A was found to be higher in first cost than the 1933 line, the additional water secured more than offsets the difference in cost. Topography was then taken on the line for plan A with 5-foot contours covering a strip reaching 25 feet above and 50 feet below the tentative line elevations. This survey was started on July 20 and completed by October 23. The preliminary lines were run with horizontal control by transit and chain, which control was transferred to planetable sheets and used by the topographic parties. Vertical control was based on United States Geological Survey benchmarks with elevations taken from published bulletins. Between New Mexico and Colorado, a discrepancy of from 5 to 7 feet was found in the United s Geological Survey elevations. The original n at Monero was carried throughout the surveys.

In locating lines A and B, special consideration was given to lines that would offer low maintenance risks, avoid questionable side slopes, and give the shortest possible routes. Many cases of alternative routes were met. At important cross-drainages it was always necessary to make a decision between a route up one side and back the other, or to go straight across with a long siphon. Sometimes both lines were surveyed and the final location selected on the basis of lowest cost. In general, though, when time did not permit a detailed study of the alternatives, the decision was in favor of a route which appeared to offer the least hazards in operation, even though the cost might be considerably greater.

Plan A involves the diversion of Turkey Creek (a tributary of the San Juan River) into a reservoir of 70,000 acre-feet capacity on the West Fork of the San Juan River about 14 miles north of Pagosa Springs, Colo. From the bottom of this reservoir a diversion canal of 300-second-foot capacity carries Turkey Creek and West Fork waters to a 70-foot drop into East Fork about 1 mile above its confluence with the West Fork. About 6 miles upstream a reservoir of 35,000 acre-feet capacity is planned to regulate the flow of the East Fork.

A diversion dam a short distance below the canal drop into the East Fork diverts into a canal of 500 second-foot capacity which lies just above the 7,500 contour east of the San Juan River. Coal Creek, Mill Creek, Rito Blanco, and the Blanco River are diverted into the main canal by short feeder canals. Five and a half miles above the Blanco River crossing, a reservoir of 15,000 acre-foot capacity is planned to regulate the flood flows of that river. From the Blanco River to the Little Navajo River the canal capacity is increased to 700 second-foot and is almost entirely in tunnel. At the lower portal of the tunnel on the Little Navajo River the canal is joined by a diversion canal from the Navajo and Little Navajo Rivers and its capacity is again increased to 800 second-feet.

After passing a few miles along the westerly side of the Little Navajo River, the main Navajo River is crossed with a siphon almost a mile long under 350 feet maximum head. At the end of the siphon the canal enters a succession of tunnels and siphons on the south side of the Navajo River to a point about 1½ miles east of Edith and almost on the Colorado-New Mexico boundary line. Continuing almost due south the canal traverses several deep cross drainage streams, crosses Amargo Creek and the Denver & Rio Grande Western Railroad (narrow gage) near Monero, N. Mex., and finally enters a 6-mile tunnel under the Continental Divide beneath Hillcrest on the Jicarilla Indian Reservation. From the lower portal of this tunnel at an elevation of 7,400 feet the water flows in a natural stream bed to Boulder Lake.

Plan B

Following completion of the plans and estimates for plan A, consideration was given to the possibilities of a less costly route, as a result of which plan B was surveyed, and estimates prepared, although not with the same detail as plan A.

Plan B starts with the same reservoir on the West Fork of the San Juan River, except that the outlet is 82 feet higher, with an increase in dead storage of 10,000 acre-feet. The reservoir was not enlarged to offset this increase in dead storage. Turkey Creek diversion is common to both plans. The East Fork of San Juan River is crossed with a 700-foot siphon at the lower end of which East Fork waters are received from a short diversion canal, thus saving an additional 70 feet in elevation over the A line. Line B is on a slightly lighter gradient to conserve head for the purpose of shortening the tunnels. Lines A and B are closely parallel from the East Fork of San Juan River to Little Navajo River, with a difference in elevation increasing from 140 to 160 feet. The feed canals used in plan A from Coal Creek, Mill Creek, Rito Blanco, and Rio Blanco, are eliminated as the line at this higher elevation permits crossing these streams at grade. At Little Navajo River, line B deflects to the east to cross Navajo River on grade and then passes southward to cross the Continental Divide immediately west of Chama and very close to the crossing of the Divide by the Denver & Rio Grande Western Railroad Co. Between the Navajo River and Chama summit a long tunnel is required to penetrate a high mesa around which no practical route could be found. While line B intercepts slightly less drainage area than line A, no difference has been made in the canal capacity as the difference in run-off would be negligible. One advantage of plan B over plan A is the higher level for delivery of waters into the Chama River watershed, plan B making such delivery at elevation 7,575 and plan A at elevation 7,401, a difference of 174 feet in favor of plan B, which will be useful in power production. Furthermore, plan B entails lesser length of costly structures as indicated by the following comparison.

Greater accessibility along the entire route of plan B also offers distinct advantages. The new highway now being built between Chama and Pagosa Springs will be within 1 mile of the entire route between the Blanco River and Chama Summit.

The four reservoirs, viz, West Fork, East Fork, Blanco, and Navajo, are common to both plans.

	Plan A	Plan B
	Miles	*Miles*
Earth canal	35.07	55.29
Combination section	8.08	13.41
Siphons	4.04	.17
Tunnels	17.03	12.85
Bench flume	.46	0
Total	64.68	81.72
Subsidiary feed canals	26.51	9.33
Total	91.19	91.05

Design and Estimate Data

Earth canal is proposed for cross slopes up to 20° with the horizontal and combination concrete-lined sections for heavier slopes. Bench flumes with vertical side walls are proposed for sidehill location in rock. Tunnel sections are of horseshoe shape and concrete lined throughout. Tunnel estimates are based on providing steel rib and timber lagging supports for their entire length as they are thought to be located in shale and loose material. Sandstone may be encountered in some places, in which case supports probably would not be needed and construction costs lessened.

Canal excavation is divided into two classes: Class 1 being earth and loose rock requiring no blasting; and class 2 being rock and shale requiring blasting.

Figure 101 shows typical sections for the component parts of the canal system. The only railroad service into the territory is over the narrow-gage line of the Denver & Rio Grande Western Railroad Co. from Alamosa to Durango. The A line crosses this railroad at Monero at canal milepost 50, and B line about 12 miles east of Monero. Shipping points will be either Monero, Lumberton, or Chama, in New Mexico. The route of the A canal is never more than 3 miles from improved roads. Above Pagosa Springs, the canal line parallels an oiled highway. From Pagosa Springs to Navajo River the highway is either graveled or will be within a few months. Below Navajo River, the dirt roads that must be used with plan A often become impassable with mud. South Fork, Colo., on the Creede branch of the Denver & Rio Grande Western Railroad Co. from Alamosa, is the nearest (29.5 miles) shipping point for the north end of the work with an excellent highway between.

Estimates—Plan B

Time did not permit line B to be surveyed in the same detail as line A. The cost for much of line B was based on the cost per foot of comparable sections of line A, using equal unit costs and suitably revised quantities. The estimate for line B is as follows:

TABLE 1.—*San Juan-Chama transmountain Diversion, plan A, quantities and unit costs*

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
MAIN CANAL								
Excavation:								
Canal:								
Common	3,963,520	Cubic yard					$0.15	$594,528
Rock	937,210	Cubic yard					.75	702,910
Structure:								
Common	4,645	Cubic yard					.75	3,484
Rock	3,505	Cubic yard					3.00	10,515
Tunnel—9.5-foot diameter, 925 to 3,820 feet long, all classes	35,100	Cubic yards					8.00	280,800
Tunnel:								
9.5-foot diameter, 10,625 feet long, all classes	40,590	Cubic yard					9.00	365,310
11.0-foot diameter, 29,350 feet long, all classes	151,150	Cubic yard					11.00	1,662,650
11.5-foot diameter, 400 to 7,646 feet long, all classes	60,220	Cubic yard					7.50	451,650
Tunnel, 11.5-foot diameter, 29,873 feet long, all classes	168,185	Cubic yard					11.00	1,850,035
Trimming foundations	129,560	Square yard					.45	58,303
Backfill	37,030	Cubic yard					.25	9,258
Puddling backfill	4,820	Cubic yard					.50	2,411
Concrete:								
Canal lining	107	Cubic yard					15.75	1,685
Combination section	22,224	Cubic yard					17.25	383,363
Bench flume	2,120	Cubic yard					18.75	39,750
Structure	1,350	Cubic yard					21.75	29,362
Monolithic siphon barrels	12,419	Cubic yard					21.75	270,114
Siphon piers and anchors	4,844	Cubic yard					19.75	95,669
Tunnel lining:								
9.5-foot diameter	18,423	Cubic yard					13.75	253,316
11.0-foot diameter	37,862	Cubic yard					17.25	653,120
11.5-foot diameter	15,188	Cubic yard					13.75	208,835
11.5-foot diameter	42,420	Cubic yard					17.25	731,745
Steel:								
Reinforcement:								
Siphons, structures	5,491,400	Pound					.055	302,029
Piers and anchors	451,800	Pound					.06	27,108
Ribs	5,030,250	Pound					.08	402,42
Gates	5,000	Pound					.15	750
Hoists	1,500	Pound					.30	450
Welded pipe	10,375,650	Pound					.09	933,809
Tunnel drains	9,185	Linear foot					1.50	13,777
Do	66,580	Linear foot					2.50	166,450
Timber	4,000.1	M board measure					80.00	320,008
Riprap	125	Cubic yard					1.50	188
Right-of-way	794	Acre					20.00	15,880
[illegible]ing	465	Acre					25.00	11,625
[illegible]rossings		8					200.00	1,600
[illegible]		25					250.00	6,250
[illegible]		4					300.00	1,200
Do		20					400.00	8,000
Farm turnouts		28					250.00	7,000
Do		15					325.00	4,875
Highway crossings		1					3,000.00	3,000
Do		3					2,000.00	6,000
Drainage inlets		22					160.00	3,520
Do		15					200.00	3,000
Do		65					225.00	14,625
Do		60					275.00	16,500
Diversion of East Fork, San Juan								300
Property damage	[1]							2,500
								10,932,177
FEEDER CANALS								
Diversions:								
Diversion and care of creeks	[1]	6						4,900
Structure excavation:								
Common	800	Cubic yard					.75	600
Rock	750	Cubic yard					3.00	2,250
Backfill	650	Cubic yard					.25	160
Puddling backfill	650	Cubic yard					.50	325
Structure concrete	905	Cubic yard					21.75	19,686
Riprap	405	Cubic yard					1.50	609
Reinforcement steel	72,400	Pound					.055	3,982
Gates	23,000	Pound					.15	3,450
Hoists	7,600	Pound					.30	2,280
Excavation:								
Canal:								
Common	680,800	Cubic yard					.15	102,120
Rock	175,250	Cubic yard					.75	131,437
Tunnel, 6.5-foot diameter, 1,800 feet long, all classes	3,200	Cubic yard					15.00	48,000
Trimming foundations	65,300	Square yard					.45	29,385
Concrete:								
Combination section	13,090	Cubic yard					17.25	225,803
Structure	40	Cubic yard					21.75	870
Tunnel lining, 6.5-foot diameter	790	Cubic yard					23.00	18,170
Steel:								
Reinforcement	1,260,000	Pound					.055	69,300
Ribs	27,800	Pound					.08	2,224
Tunnel drains	1,800	Linear foot					1.50	2,700
Timber	24.9	M board measure					80.00	1,992
Right-of-way	335	Acre					20.00	6,700
Clearing	290	Acre					25.00	7,250
Farm crossings		13					150.00	1,950
Do		12					200.00	2,400
Farm turnouts		2					200.00	400
Do		10					250.00	2,500

[1] Lump sum.

TABLE I.—*San Juan-Chama transmountain Diversion, plan A, quantities and unit costs*—Continued

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
FEEDER CANALS—continued								
Highway crossings		1					$2,500.00	$2,500
Drainage inlets		34					160.00	5,440
Do		79					225.00	17,775
								717,156
Subtotal								11,649,335
Contingencies, 15 percent								1,747,400
Total estimated field cost								13,396,735
Investigations and surveys								50,000
Engineering and inspection, 6 percent								803,804
Superintendence and accounts, 1½ percent								200,951
General expense, 2½ percent								334,918
Total estimated cost								14,786,408

Main canal	West Fork, San Juan River to East Fork, San Juan River, length in feet	Capacity, 300 second-feet, cost
Earth canal	15,500	$57,195
Combination section	2,000	27,620
Siphons	700	42,000
Subtotal	18,200	126,815

Main canal	East Fork, San Juan River to Rio Blanco	Capacity, 500 second-feet
Earth canal	118,600	$722,274
Combination section	41,800	819,280
Siphons	0	0
Tunnels	11,100	783,660
Subtotal	171,500	2,325,214

Main canal	Rio Blanco to Navajo River, length in feet	Capacity, 700 second-feet, cost
Earth canal	97,840	$435,388
Combination section	18,000	474,120
Siphons	200	12,162
Tunnels	17,375	1,937,312
Subtotal	133,415	2,858,982

Main canal	Navajo River to Willow Creek	Capacity, 800 second-feet
Earth canal	60,000	$465,600
Combination section	9,000	300,600
Siphons	0	0
Tunnels	39,370	4,783,455
Bench flume	0	0
Subtotal	108,370	5,549,655

Subsidiary diversions

Turkey Creek Canal (same as for plan A)	$370,241
East Fork	126,500

Subsidiary diversions—Continued

Coal Creek, Mill Creek, and Rito Blanco	7,590
Little Navajo River	12,650
Navajo River	20,240
Subtotal	539,751

Summary of costs—Plan B

Main canal		$10,860,666
Subsidiary diversions		539,751
Reservoirs:		
West Fork	$2,069,588	
East Fork	1,449,306	
Blanco	1,060,494	
Navajo	1,515,138	
		6,094,526
Grand total		17,494,943
Cost per acre-foot of annual yield (350,000 acre feet)		50

Water Supply

The general map, figure 90, shows drainage lines and the location of all run-off and rainfall stations at which any records at all have been secured. A list of gaging and rainfall stations and a diagram showing the length of record secured at each of them is given in figure 102. United States Geological Survey quadrangle sheets are available for the entire watershed in Colorado, but in New Mexico no reliable topographic maps are in existence. These records comprise all of the basic data from which the available run-off in the San Juan Basin must be estimated. The dearth of run-off and rainfall records in the areas affected by the transmountain diversions necessitated developing methods of estimating the same from available records. Figure 102 shows that for the 10-year period of 1916–25 there are more

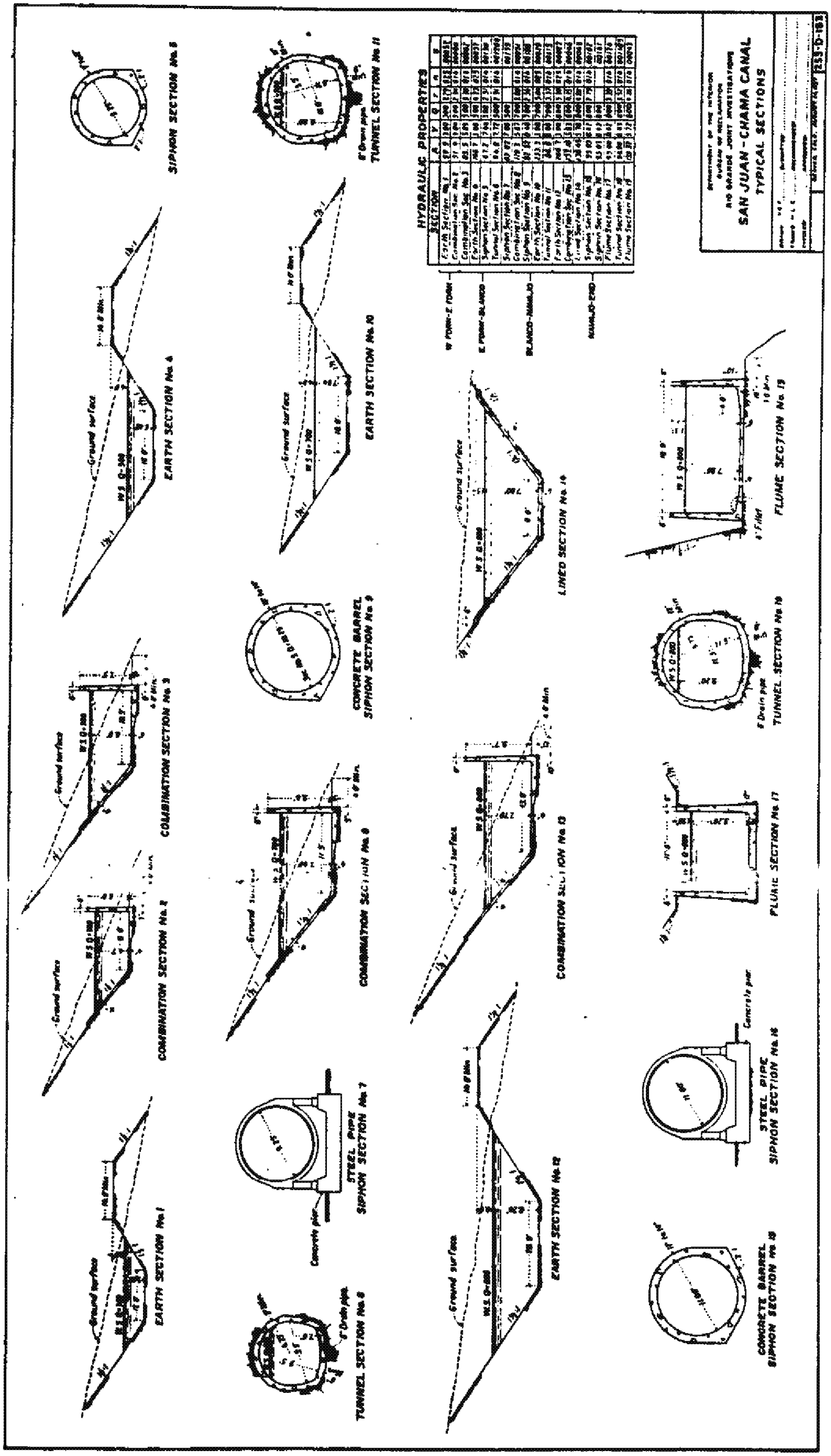
SAN JUAN-CHAMA CANAL
TYPICAL SECTIONS
HYDRAULIC PROPERTIES
EARTH SECTION No. 1
COMBINATION SECTION No. 2
COMBINATION SECTION No. 3
EARTH SECTION No. 4
SIPHON SECTION No. 5
TUNNEL SECTION No. 6
STEEL PIPE SIPHON SECTION No. 7
COMBINATION SECTION No. 8
CONCRETE BARREL SIPHON SECTION No. 9
EARTH SECTION No. 10
TUNNEL SECTION No. 11
EARTH SECTION No. 12
COMBINATION SECTION No. 13
LINED SECTION No. 14
CONCRETE BARREL SIPHON SECTION No. 15
STEEL PIPE SIPHON SECTION No. 16
FLUME SECTION No. 17
TUNNEL SECTION No. 18
FLUME SECTION No. 19
Ground surface
Concrete pier

FIGURE 101

complete concurrent data than for any other period. This cycle was therefore selected as a base for making all other determinations.

Two methods have been tried, described herein as the rainfall-altitude and run-off altitude methods, respectively.

Rainfall-altitude method.—The procedure adopted in using this method is as follows:

(*a*) Determine mean run-off at each gaging station for the period 1916–25 in acre-feet per square mile of tributary watershed area.

(*b*) Calculate mean rainfall for each station within or adjacent to the drainage area above the run-off station.

(*c*) Plot mean rainfall for each rainfall station against its altitude and draw a curve through the points which averages them as near as possible. Mean rainfall at any elevation can then be taken from the curve.

(*d*) From topographic maps determine the area of the watershed between each 500-foot contour.

(*e*) Multiply each area between 500-foot contours by the mean rainfall (taken from the curve) for the average elevation of that band. The sum of these products divided by the total area gives the mean rainfall for the watershed.

(*f*) Rainfall less run-off gives the "consumptive use" or the residue of rainfall after it has been subjected to evaporation and transporation losses except for underground waters leaving or entering the basin.

Run-off for each 500-foot band can then be computed by assuming "consumptive use" to be constant for all elevations and subtracting this constant from rainfall in each case.

Run-off for individual years can be determined by the same procedure but the method does not lend itself readily to determination of monthly stream discharges. This procedure was carried out for both the Animas River above Tacoma and the San Juan River above Arboles, with fairly satisfactory results when the 10-year mean was used but when an effort was made to break it down to individual years, the rainfall points on the diagram were so badly scattered that it was difficult to draw a curve which would justify confidence in the results.

Run-off altitude method.—The same period, 1916–25 was used for determining means. Procedure was then as follows:

(*a*) Mean unit run-off in acre-feet per square mile was determined for three stations on the San Juan River, the Navajo River at Edith, three stations on the Animas River, and the Pine River at Bayfield (in part derived from Ignacio).

(*b*) Watershed areas above each gaging station were divided into bands of 500 feet difference in elevation in

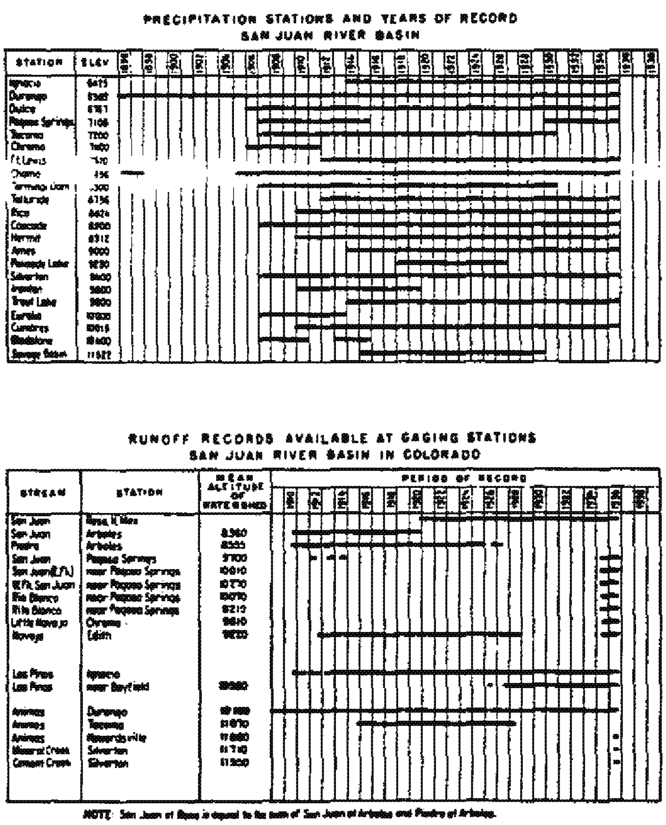

Figure 102

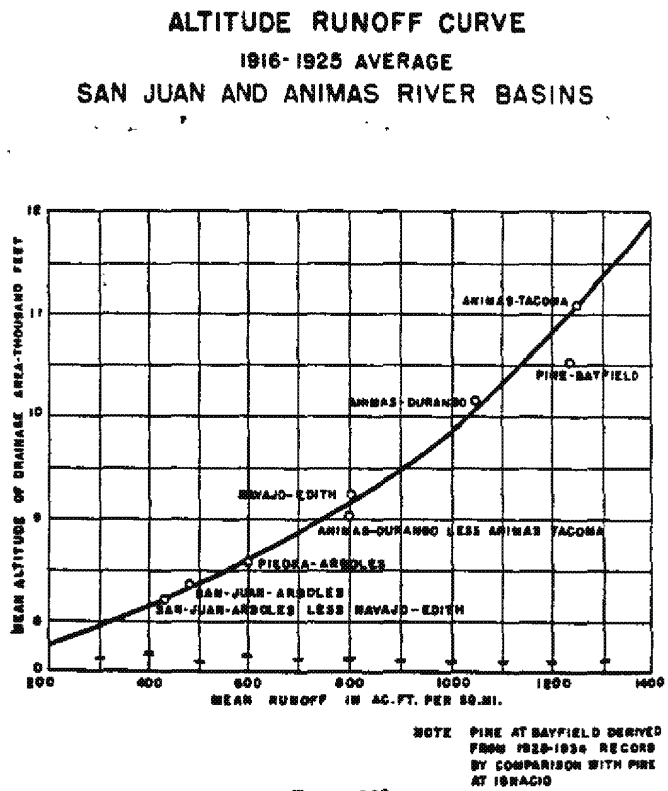

Figure 103

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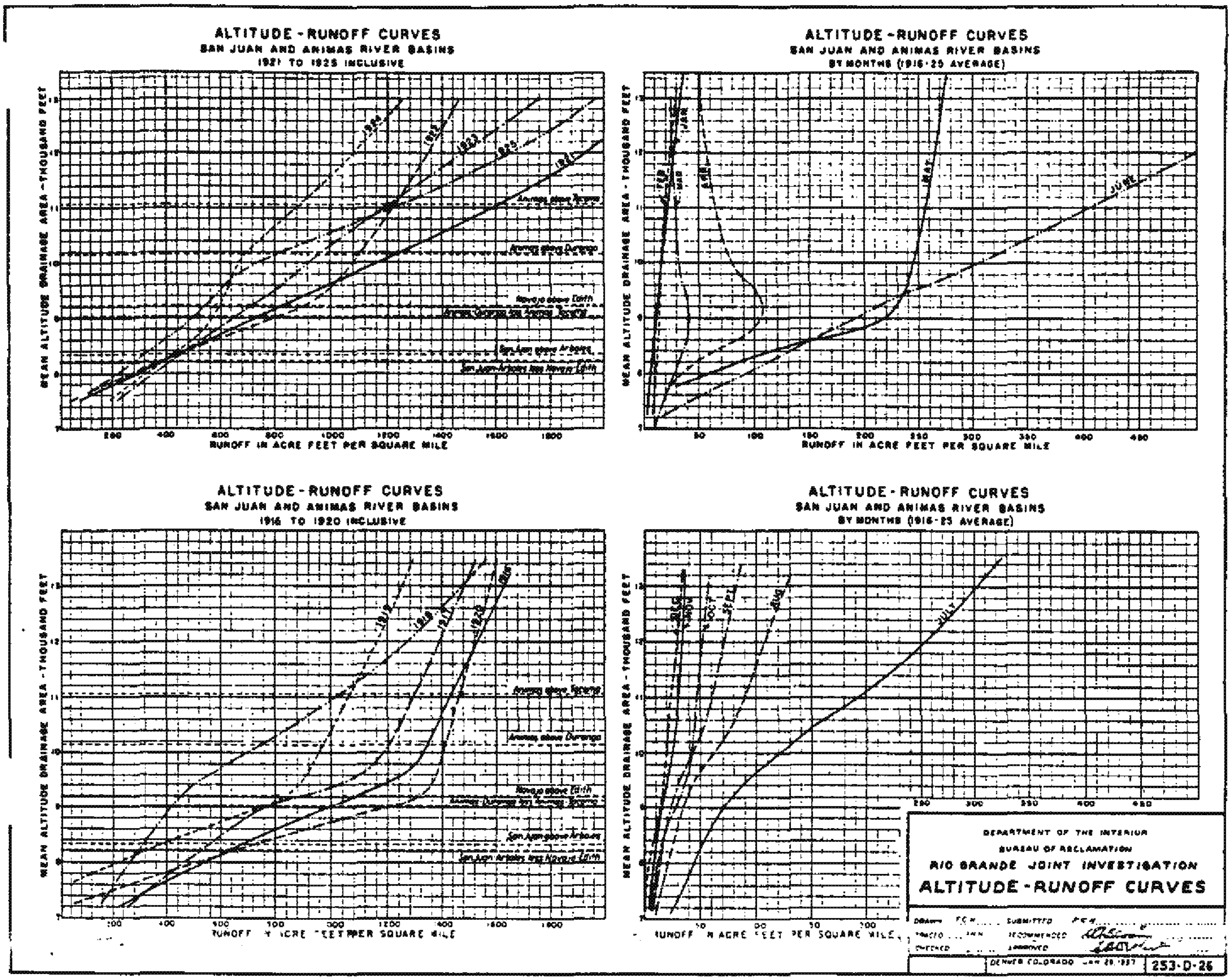

FIGURE 104

the manner heretofore described for determining mean rainfall.

(*c*) Unit run-off for each gaging station was then plotted against mean altitude and a curve drawn through the points.

The resulting curve is shown in figure 103. The points are well scattered from low to high elevations and departures from the mean are small. The greatest departure is for the Pine River at Bayfield and this influence was recognized by modification of the curve when used for the Pine or the San Juan Rivers.

By this method two run-off records on the same watershed enable three points to be calculated for the curve; one for the area above the higher station, another for the entire area above the lower station, and the third for the area between.

The same procedure was followed in determining run-off for any watershed for individual years and even for individual months for any particular year. In practically all cases, the points were so near the mean curve drawn through them that the results appear to be as reliable as can be obtained with so little record data available. Details of the application of this method to each of the watersheds studied in the investigation are given in the report on each feature.

Extensions of run-off estimates from 1926 to date, where necessary, were made by correlating the short-term record at the station in question with that of a station with a long-time record in periods of concurrent record. It is recognized that the resulting discharges are to a large degree estimates and it is hoped that arrangements can be made to establish and continuously operate gaging stations found to be desirable in connection with projects deemed likely to be constructed.

The total area contributing to the diversion is 506.24 square miles with a mean altitude of 9,688 feet. From figure 103 mean run-off at this altitude is found to be

SAN JUAN - CHAMA TRANSMOUNTAIN DIVERSION - OPERATION DIAGRAM

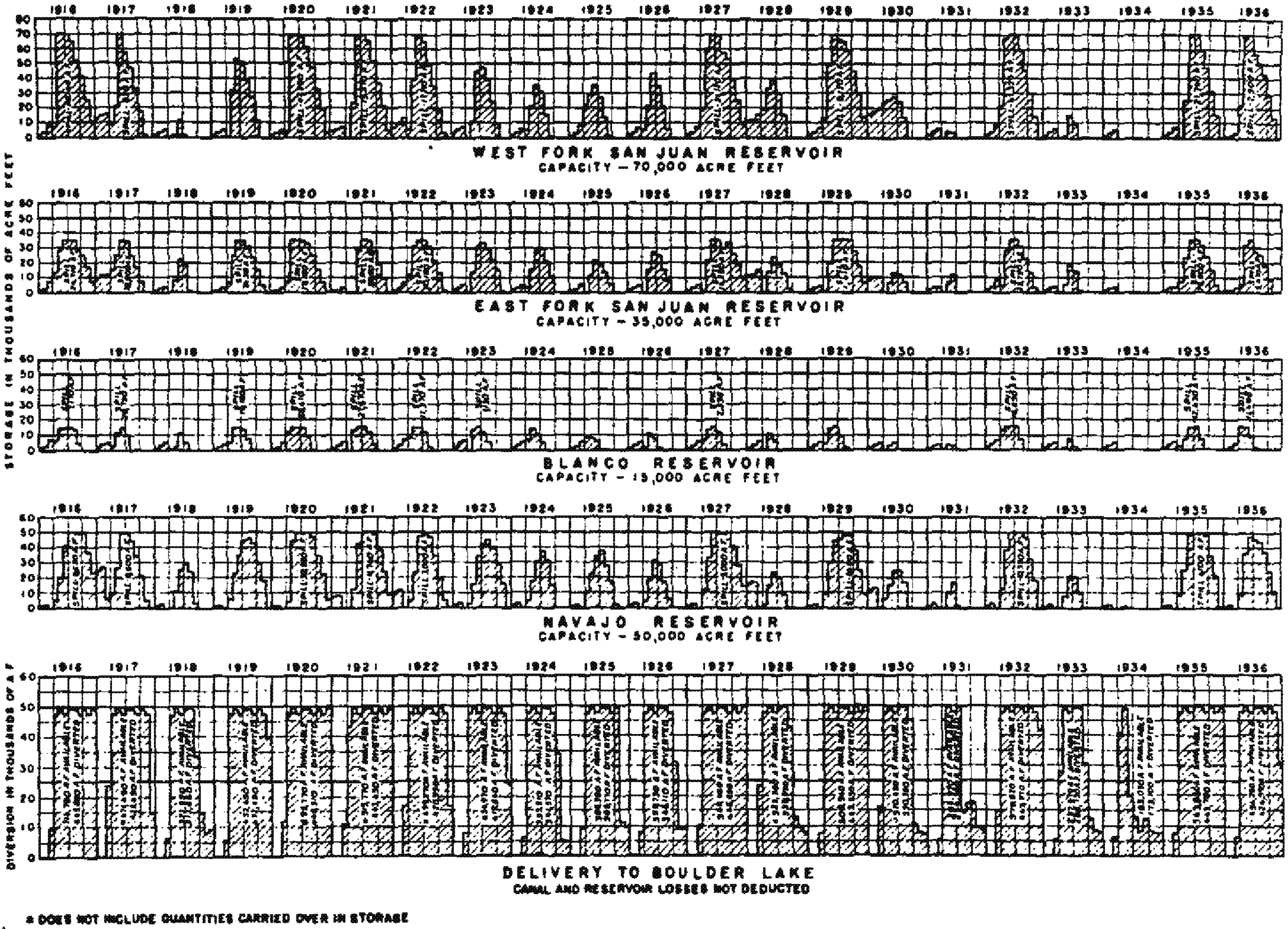

FIGURE 105

970 acre-feet per square mile, or a total of 486,200 acre-feet.

Operating studies of capacities for reservoirs and canals made it necessary to determine the monthly discharges in any year. The altitude-run-off method was found to be admirably adapted thereto, the curves for which are also shown in figure 104. Total average annual run-off for 1916–25 estimated from the altitude run-off curves compare as follows:

	Acre-feet
Mean annual discharge from fig. 103	486, 200
Mean of individual annual discharges for entire area, fig. 104	479, 920
Mean of sum of monthly discharges for entire area from fig. 104	469, 620
Mean of annual discharge of constituent watersheds from fig. 104	478, 650
Average	478, 598

The only long-term record on San Juan River is that at Rosa, N. Mex., which is below all streams proposed to be diverted and also below the mouth of the Piedra River. Monthly discharge for the years 1926 to 1936, inclusive, were estimated with correlation curves based on concurrent records of monthly discharges during the years 1916–26 for each of the watershed areas tributary to the canal and the reservoirs. The area of each of the watersheds as compared to the area above Rosa is so small, however, and Rosa is so remote from the areas considered, that the results can only be considered approximations, although the best that can be secured with the available data.

Required canal and reservoir capacities were determined by trial operations. Small diversion canals were designed for a capacity 50 percent in excess of the mean daily discharge for the maximum mean month during the period 1916–25. Reservoir capacities were sometimes fixed by the physical limitations at the dam site and in other cases by the capacity necessary for the adopted operating schedule. A number of possible combinations of canal and reservoir capacities were studied with the one here presented found to be the most practical of any tried. Below the Navajo River canals were considered to be in operation each month except January and February. All other canals --e assumed to be incapable of operation in the months 'anuary, February, and March. Necessarily, capac-, cannot practicably be provided to capture all water available in high years, but the amounts escaping are not excessive. The operations are graphically presented on figure 105.

The 1916–36 mean of divertible supply is 380,860 acre-feet with no allowances for losses in transit or from the reservoirs. The reservoirs are full for about 2 months out of the year. The maximum total area of the reservoirs, excepting Boulder Lake, is 1,850 acres. With an estimated evaporation rate of 2 feet in depth per year (new losses in excess of existing uses on the same areas), the loss would be 3,700 acre-feet per annum. Seepage losses from the reservoirs would probably be recovered in every case except for the West Fork Reservoir as the canal diversions are so far downstream from the dams. The total length of unlined canal is about 52 miles. Canal losses would be offset in part by contributions from areas in New Mexico tributary to the main canal not included in the estimates of water supply. A 5-percent net loss through seepage should probably be anticipated, or a total of 20,000 acre-feet per annum.

Local Requirements in the San Juan Basin

The San Juan River at Shiprock, N. Mex., has a drainage area of 12,738 square miles and a mean discharge of 2,500,000 acre-feet per annum. Land classification studies being made as a part of the Colorado Basin investigation under section 15 of the Boulder Canyon Act show that within this area there was irrigated in 1933 a total of 104,743 acres of land, of which 32,228 acres were in New Mexico, and 72,515 acres in Colorado. Irrigation on the San Juan River and its tributaries above the San Juan-Chama diversion is practically nonexistent. Below the diversion and down to Arboles, a total of 2,245 acres is irrigated from the San Juan River and its tributaries. Below Arboles there are but 8,162 acres being served from the San Juan River. The balance is irrigated from tributaries. Bahmeier found an additional area of 2,567 acres of arable land above Arboles, all of class II character. Not over 360 acres of this area can probably be feasibly irrigated. With enough water left to supply 2,600 acres, the balance can be diverted without injury to existing irrigation projects. Waters rising below the diversion line, together with losses from the canal will hold necessary bypasses to negligible amounts for these lands.

TABLE 2.—*Water supply—San Juan-Chama transmountain diversion* [1]

[All quantities in thousands of acre-feet]

Year	Unregulated supply			Inflow to reservoirs					Releases from reservoirs					Spill from reservoirs					Gross delivery to Boulder Lake	Total waste [5]	Maximum storage			
				San Juan					San Juan					San Juan							San Juan			
	Total [2]	Diverted	Waste [3]	West fork [4]	East fork	Blanco	Navajo	Total	West fork	East fork	Blanco	Navajo	Total	West fork	East fork	Blanco	Navajo	Total			West fork	East fork	Blanco	Navajo
1916	190.14	159.61	30.53	189.12	76.34	85.39	75.12	524.64	120.72	44.03	78.22	43.30	286.27	58.16	24.71	7.17	8.63	98.67	445.88	105.43	70.00	35.00	15.00	50.00
1917	170.51	140.53	29.98	104.38	59.07	73.13	64.40	300.98	113.80	47.77	44.40	78.99	284.96	.82	18.90	28.73	8.60	57.05	425.49	74.49	70.00	35.00	15.00	50.00
1918	92.20	83.01	9.19	83.28	51.33	47.41	48.63	230.65	83.28	51.33	47.41	48.63	230.65	0	0	0	0	0	313.66	0	10.76	21.82	10.76	29.58
1919	149.46	137.85	11.51	112.68	62.22	68.16	59.93	302.99	112.68	57.50	64.39	59.93	294.50	0	4.72	3.77	0	8.49	432.45	9.80	53.30	35.00	15.00	44.63
1920	238.32	185.68	52.64	163.94	94.57	104.68	94.26	457.45	113.79	55.22	36.27	57.35	262.63	47.28	39.35	68.41	30.88	185.92	446.31	216.42	70.00	35.00	15.00	50.00
1921	146.88	136.08	10.80	139.19	74.46	78.50	76.74	368.89	123.88	70.51	50.83	62.15	307.37	13.37	3.95	27.67	11.74	56.73	443.45	58.87	70.00	35.00	15.00	50.00
1922	165.19	124.56	40.63	124.87	68.33	75.00	65.88	334.08	112.47	48.14	63.63	71.75	295.99	17.21	20.19	11.37	3.00	51.77	420.55	81.15	70.00	35.00	15.00	50.00
1923	141.07	126.87	14.20	112.98	58.20	63.01	59.71	293.90	112.98	58.20	61.88	59.71	292.77	0	0	1.13	0	1.13	419.64	1.13	47.39	32.21	15.00	44.26
1924	124.78	111.14	13.64	84.24	47.22	51.16	47.81	230.43	84.24	47.22	51.16	47.81	230.43	0	0	0	0	0	341.57	0	35.45	29.49	13.40	37.79
1925	108.39	97.57	10.82	100.08	56.28	57.04	58.80	272.20	100.08	56.28	57.04	58.80	272.20	0	0	0	0	0	369.77	0	34.46	21.47	8.33	37.26
1926	118.75	107.13	11.62	92.26	47.72	51.90	49.10	240.98	92.26	47.72	51.90	49.10	240.98	0	0	0	0	0	348.11	0	44.35	27.50	10.14	30.60
1927	192.07	153.42	38.65	140.81	76.68	83.00	76.90	377.39	101.23	53.10	80.65	58.25	293.23	31.12	14.25	2.35	5.00	52.72	446.65	77.75	70.00	35.00	15.00	50.00
1928	111.23	96.16	15.07	80.97	43.16	45.70	42.50	212.33	89.43	52.49	45.70	56.15	243.77	0	0	0	0	0	339.93	0	38.75	23.15	10.35	23.15
1929	168.61	145.77	22.84	129.42	68.51	74.10	68.30	340.33	106.93	60.15	74.10	56.60	297.78	9.12	1.41	0	2.40	12.93	443.55	24.85	70.00	35.00	14.15	50.00
1930	97.15	87.45	9.70	83.60	42.18	45.80	41.70	213.28	96.97	49.18	45.80	51.00	242.90	0	0	0	0	0	330.35	0	26.93	12.53	4.30	23.85
1931	83.63	75.24	8.39	66.72	36.82	40.60	35.20	179.34	66.72	36.82	40.60	35.20	179.34	0	0	0	0	0	254.58	0	5.43	10.57	2.80	16.50
1932	184.60	142.12	42.48	143.28	80.04	86.70	85.10	395.22	102.06	56.29	69.85	73.65	301.85	41.32	23.75	16.85	10.35	92.27	443.97	114.36	70.00	35.00	15.00	50.00
1933	90.07	81.33	8.74	83.04	40.76	44.00	39.60	207.40	83.04	40.76	44.00	39.60	207.40	0	0	0	0	0	288.73	0	14.77	18.14	7.40	21.30
1934	64.95	55.00	9.95	39.50	26.50	28.10	24.00	118.10	39.50	26.50	28.10	24.00	118.10	0	0	0	0	0	173.10	0	5.91	2.89	3.50	2.40
1935	162.63	130.70	31.93	143.10	77.55	82.20	77.40	380.25	121.36	48.65	69.77	73.30	313.08	21.74	28.90	12.43	4.10	67.17	443.78	88.72	70.00	35.00	15.30	50.00
1936	118.78	108.53	10.25	127.10	66.66	68.72	73.00	335.48	124.60	61.19	57.23	73.00	316.02	2.50	5.47	11.49	0	19.40	424.55	19.46	70.00	35.00	15.00	47.48
Mean annual diversion																			380.86					

[1] No reservoir or canal losses subtracted in this table.
[2] Supply from tributaries unregulated by reservoirs including Turkey Creek for January, February, and March, when canal is not operated.
[3] Includes waste during months canals not in operation and undivertible peak flows.
[4] Includes flow from Turkey Creek, April-December, inclusive.
[5] Reservoir spill plus undivertible peak flows only.

The mean annual net delivery of regulated water to the Chama River above El Vado Reservoir is then 'nated at 350,000 acre feet.

The Piedra, Pine, Florida, and Animas Rivers enter the main San Juan River below Arboles and adequately supply the 8,162 acres now irrigated.

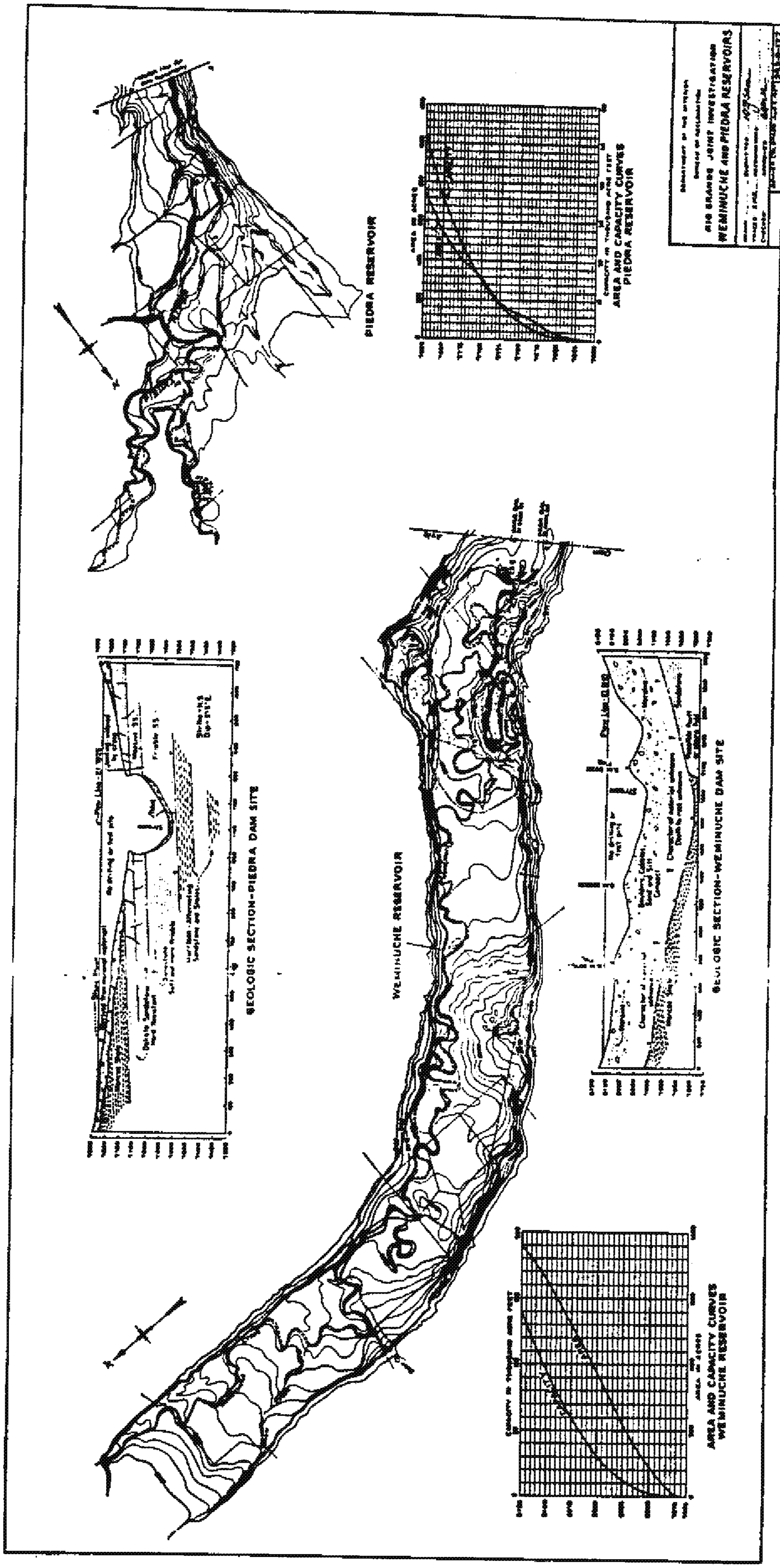
WEMINUCHE AND PIEDRA RESERVOIRS
PIEDRA RESERVOIR
AREA AND CAPACITY CURVES
PIEDRA RESERVOIR
GEOLOGIC SECTION-PIEDRA DAM SITE
WEMINUCHE RESERVOIR
GEOLOGIC SECTION-WEMINUCHE DAM SITE
AREA AND CAPACITY CURVES
WEMINUCHE RESERVOIR

FIGURE 106

The Vallecito Reservoir with a capacity of 124,000 acre-feet soon to be constructed on Pine River will 'uce flood flows of the San Juan River but return ; from the project may actually increase some of the late season discharges at the mouth of the Pine River and on the San Juan River below.

While the extent of future development on the lower San Juan is not definitely known, it is, nevertheless, certain that some storage for regulation of the flood flows will be needed to enable complete irrigation development. The Arboles site on the San Juan just below the mouth of the Piedra River has been surveyed but not explored. Geologists report a poor quality of sandstones and shales in the abutments with little possibility of satisfactory foundation at reasonable depth. The site was originally contemplated for a reservoir of 1,500,000 acre-feet capacity. A considerable part thereof would need to be set aside for silt.

During the summer of 1937, two dam and reservoir sites were surveyed on the Piedra River and its tributary, Weminuche Creek, the results of which are shown on figure 106. The reservoir on the Piedra River would have a capacity of 52,000 acre feet with a dam 245 feet high. It will obviously have a high cost per acre-foot of capacity. On Weminuche Creek, a capacity of 140,285 acre-feet can be secured with a dam 160 feet in height but estimates of run-off available 'he site indicate that no more than 96,000 acre-feet ıpacity is justified. The estimated cost of a dam and reservoir for this capacity is $2,140,000, or $22.25 per acre foot, including the diversion of Williams Creek into Weminuche Creek, the latter diversion being necessary to justify the capacity of 96,000 acre-feet.

The following are estimates of the mean annual flow of Weminuche Creek, Williams Creek and the Piedra River above the proposed dam sites for the period 1916 to 1925, inclusive.

	Acre-feet
Weminuche Creek at proposed reservoir	41, 850
Williams Creek above diversion to Weminuche Creek	40, 600
Piedra River above proposed reservoir	88, 830

Over 50 percent of the present irrigation development on the lower San Juan River is served by canals diverting from the Animas River itself or from the San Juan River below the mouth of the Animas River.

Incomplete surveys within the San Juan River Basin under the provisions of the Boulder Canyon Project Act, indicate a probable increase of about 30,000 acres in the irrigated area in the future, in addition to completion of development under existing ditches, south of San Juan River, mainly below Farmington. A storage capacity of as much as 50,000 acre-feet may be needed for this area, and can be secured within the Piedra 'shed. Possibly an equal area may be developed the lower portion of the Animas River and westward along the north side of San Juan River. This area can best be served by storage on Animas River with the Animas reservoir site at Durango, often mentioned in such connection. Utilization of the upper San Juan River waters for any purpose would have no bearing on Animas River plans. Florida River lands expect to secure some water from Vallecito reservoir and must in any event look to Florida River for any additional supplies needed.

It is concluded, therefore, that diversion of San Juan River waters to the Chama River would not injure the future development of the San Juan Basin although with more extensive development than now anticipated it may become proper for the diversion project to assist in storage development for San Juan Basin use, to offset diversion of waters which could be locally used. No interference seems possible under present conditions.

West Fork Reservoir

The dam site is located on the West Fork of the San Juan River about 4 miles above its junction with the East Fork in section 29, T. 37 N., R. 1 E., of Mineral County, Colo. and about 12 miles northeast of Pagosa Springs. An alternative dam site 3 miles downstream, known as the Lower West Fork site, was investigated but found less desirable by cost and elevation.

A storage capacity of 70,000 acre-feet is required for regulation of the West Fork waters.

Summary of estimate data:

Storage capacity	70,000 acre feet.
Spillway capacity	13,000 second feet.
Regulated outlet capacity	300 second feet.
Elevation—top of dam	7,888.
Normal and maximum water-surface elevation.	7,880.
Height of dam above stream	160 feet.
Total estimated cost—dam and reservoir.	$2,069,588.
Preliminary estimate	Table 3.
Reservoir topography and geologic section.	Fig. 107.
General plan and sections	Fig. 108.

The reservoir area at elevation 7,880 covers 1,100 acres of privately owned lands. No clearing will be required. The nearest shipping point is South Fork, on the Creede branch of the Denver & Rio Grande Western Railroad 29.5 miles away.

West Fork Reservoir geology.—Almost the entire watershed is of igneous flow rock containing little soluble material. The basin is a normal erosional valley carved through these flow rocks (andesite) into underlying shales and sandstones. None of the bedrocks are exposed in the valley floor nor will the flow lines contact any of the igneous rocks. The beds lie approximately horizontal. There are signs of faulting but it is believed that no recent movements have occurred.

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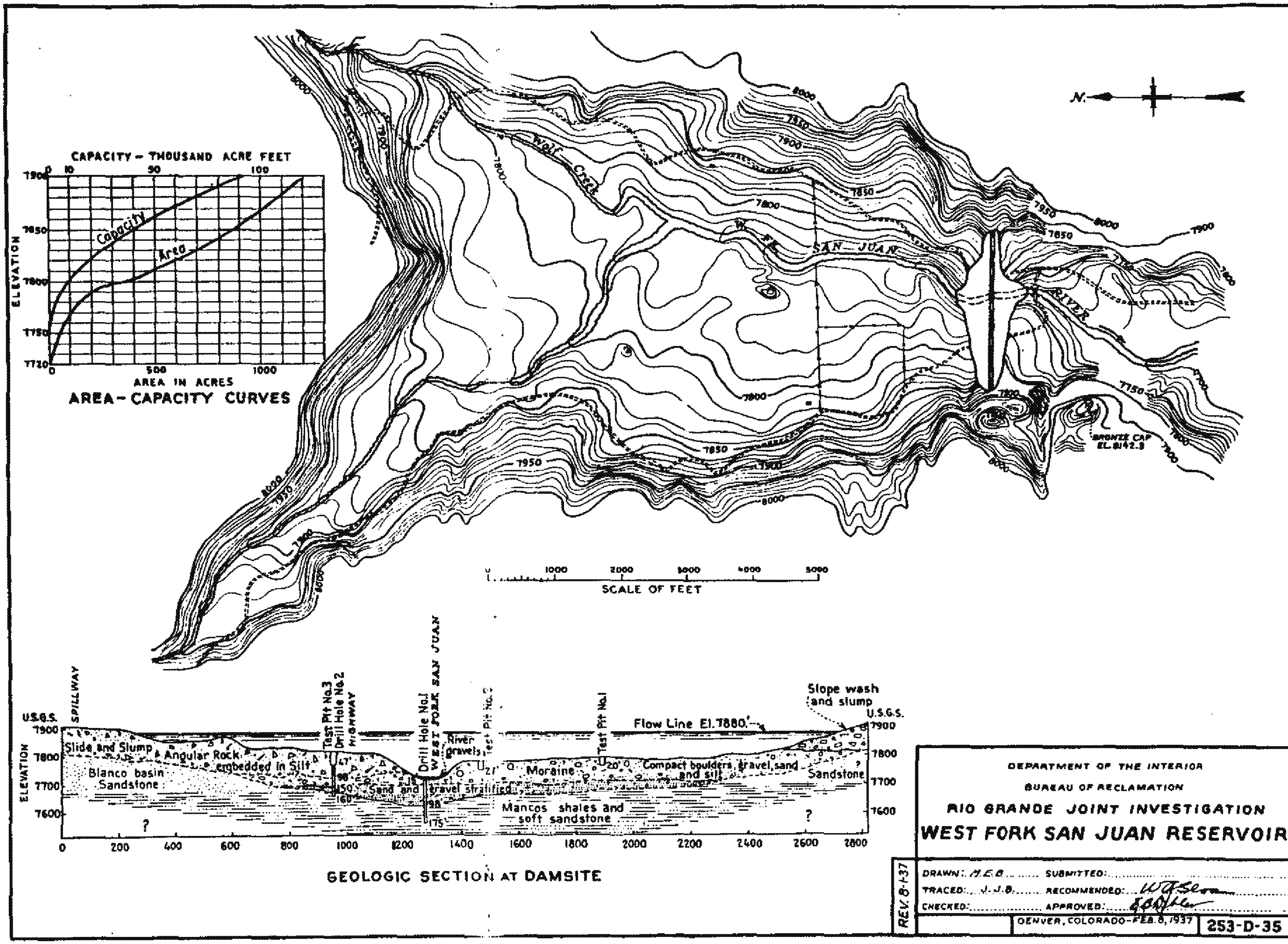
CAPACITY - THOUSAND ACRE FEET
ELEVATION
AREA IN ACRES
Capacity
Area
AREA - CAPACITY CURVES
Wolf Creek
W. FK. SAN JUAN RIVER
BRONZE CAP EL. 8142.3
N
SCALE OF FEET
SPILLWAY
Test Pit No.3
Drill Hole No.2
HIGHWAY
Drill Hole No.1
WEST FORK SAN JUAN
Test Pit No.2
Test Pit No.1
Slope wash and slump
Flow Line El. 7880
U.S.G.S.
Slide and Slump
Angular Rock embedded in Silt
Blanco basin Sandstone
River gravels
Sand and gravel stratified
Moraine
Compact boulders, gravel, sand and silt
Sandstone
Mancos shales and soft sandstone
GEOLOGIC SECTION AT DAMSITE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
WEST FORK SAN JUAN RESERVOIR
DRAWN: M.E.B.
TRACED: J.J.B.
CHECKED:
SUBMITTED:
RECOMMENDED:
APPROVED:
REV. 8-1-37
DENVER, COLORADO - FEB. 8, 1937
253-D-35

Figure 107

In the basin, the underlying shales and sandstones are heavily mantled with a variety of detrital materials. asional knobs of glacial debris rise above the strati- sands and gravels laid down by the stream. On ıne sides, thick wash and slough areas are progressively overriding the bottom gravels.

Vegetative cover on the floor of the basin consists of wild hay meadows, scattered spruce and cottonwood trees, while the sides are more heavily timbered with oak, brush, aspens, spruce, and pine. A water table tributary to the river is indicated by spring and seep occurrences. It is believed that reservoir losses can only occur by seeping down the valley in the sands and gravels overlying the relatively impervious bedrock.

West Fork dam site geology.—The dam site occupies a portion of the valley narrowed by deposition of extensive morainal material in which the stream is now flowing (fig. 107).

The right abutment is a chaotic mass of andesite boulders, cobbles, sand, and silt, somewhat lensed, but probably relatively impervious when considered as a whole, as disclosed by three test pits (nos. 1, 1a, and 2) (fig. 108) on which percolation tests were run. One drill hole (no. 1) indicates that between the morainal material which was found to be 20 feet thick, and the underlying shales, there is a 78 foot layer of sands and silts which was evidently a lake deposit later over- ...en by the moraine.

ı the left abutment the morainal material has been ...u is progressively being covered with a compact slough and wash material of angular rock and fragments embedded in silt, eroded from the adjoining hills. This mantle wedges out on the moraine exposed at the river bank. Material eroded from the side hills appears to be more compact and impervious than the morainal deposit. Again, as on the right abutment, a drill hole (no. 2) disclosed a layer of loose sand and gravel beneath the morainal deposit but much thinner (23 feet).

The moraine terminates upstream and downstream on the stream axis outside the foundation limits of the dam itself, thus leaving exposed to percolation the rather loose porous sand and gravel strata found beneath the moraine on the dam axis. The percolating distance is adequate to preclude heavy or dangerous leakage.

Dam.—This dam site is known as the upper site. The lower site is about 3 miles downstream, or about a mile above the confluence of the East and West Forks. Planetable topography was secured at the lower site in 1936 and at the upper site in 1937. Rough estimates disclosed that a dam for the same reservoir capacity at the lower site would be much more expensive than one at the upper site and would not permit ...ion for the canal in plan B without pumping. ...ure 108 shows the general plan and sections for the proposed dam at the upper site. The proposed section for the dam is of the compacted embankment type with a deep cutoff trench. Sufficient rock is placed on the downstream slope to protect the embankment and the rather steep abutments against sloughing. The dam is 2,500 feet long on top and attains a maximum height of 160 feet at the river crossing. Ample embankment borrow material is believed to be available within a mile of the site. Sand and gravel deposits occur about one-half mile upstream from the site but have not been analyzed. Adequate sand proportions may be lacking.

The entire foundation will require surface stripping. The material from the cutoff trench excavation can be used in construction of the downstream portion of the embankment.

Spillway.—The drainage area of the reservoir, exclusive of the Turkey Creek intercepted area is 83 square miles. A spillway with a maximum capacity of 13,000 second-feet is to be constructed on the glacial moraine formation near the left end of the dam, as bedrock will not be available. A radial gate structure was adopted to provide an 8-foot freeboard without raising the dam. Three automatic radial gates 20 feet long by 17 feet high and of substantial construction to withstand ice pressure are proposed. The gate structure is of reinforced concrete, counterfort and cantilever wall construction. The spillway channel is of concrete cantilever wall construction. A roadway is provided over the dam and spillway, to connect with the proposed relocation of U. S. Highway No. 160.

Outlet works.—For outlet and diversion purposes a 12-foot standard horseshoe tunnel of liner plate and concrete lining construction is provided under the left abutment of the dam. The bottom of the trash rack is placed above the tunnel to keep sand and gravel out of the completed tunnel, provide protection for fish, and to prevent complete draining with unsightly exposure of the reservoir bed.

A gate chamber containing one 57-inch ring follower emergency gate is placed just upstream from the axis of the dam. A 57-inch steel pipe leads down the tunnel from the gate chamber to the single 48-inch needle valve. The needle valve house contains the necessary pumps, piping, cranes, etc., required for operation. A gas-driven generator set is planned for lighting and operation of the valves and spillway gates. The needle valve discharges into the spillway stilling basin. The outlet crest of the stilling basin is placed at elevation 7,724 in order to control the flow into the outlet canal. The water surface in the canal is at elevation 7,723.5.

Construction.—It will require approximately 3 years to construct the dam and appurtenant works. There is no local power available for construction purposes. Estimate of cost is given in table 3.

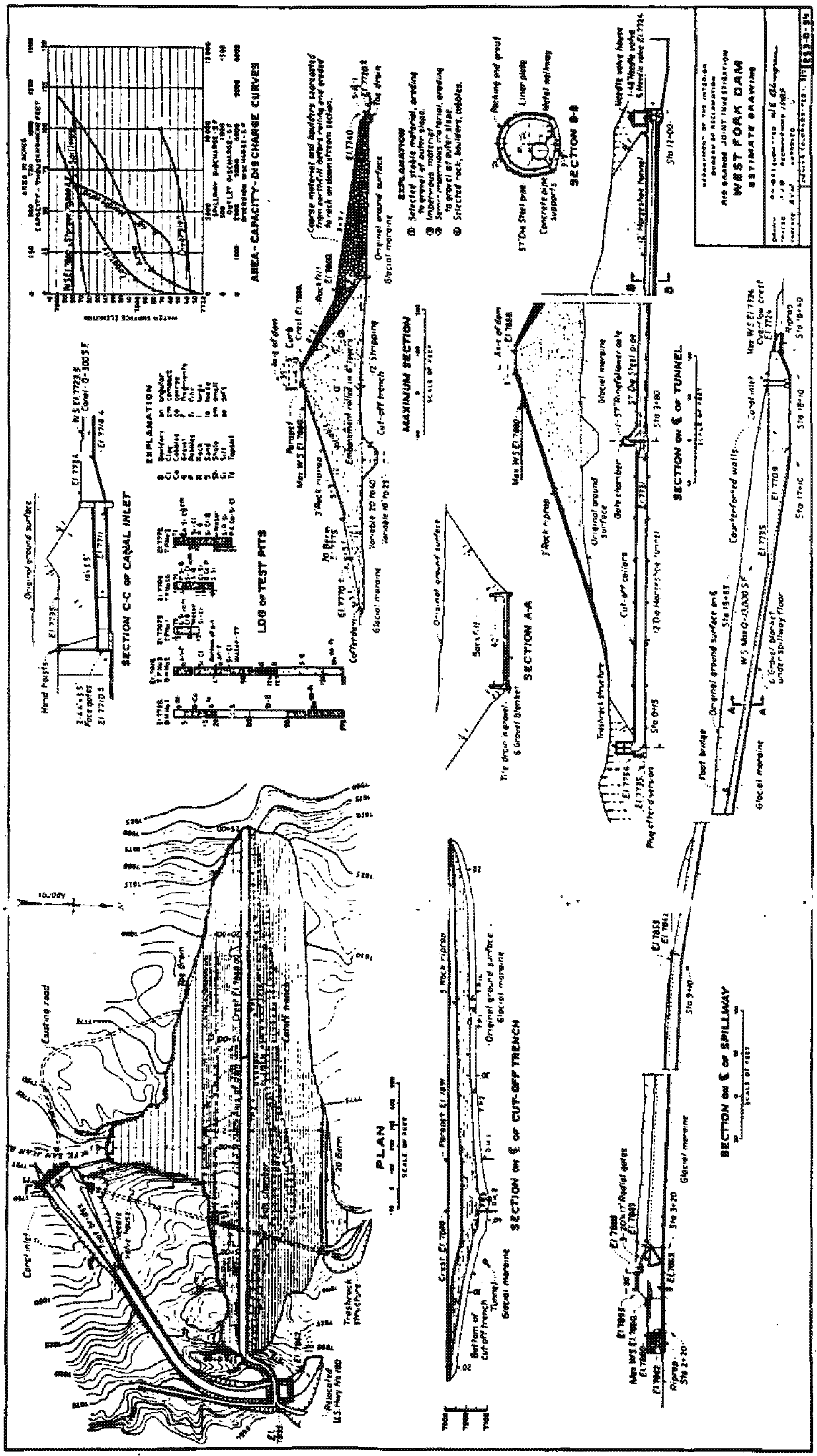
AREA-CAPACITY-DISCHARGE CURVES
EXPLANATION
LOG OF TEST PITS
SECTION C-C OF CANAL INLET
MAXIMUM SECTION
SECTION A-A
SECTION B-B
SECTION ON ℄ OF TUNNEL
PLAN
SECTION ON ℄ OF CUT-OFF TRENCH
SECTION ON ℄ OF SPILLWAY
RIO GRANDE JOINT INVESTIGATION
WEST FORK DAM
ESTIMATE DRAWING

FIGURE 108

TABLE 3.—*Department of the Interior, Bureau of Reclamation, Rio Grande joint investigations, Colorado, West Fork San Juan Dam, preliminary estimate, Jan. 30, 1937*

[bankment: Top of dam, elevation 7,888; normal water surface, elevation, 7,880; maximum water surface, elevation, 7,880; maximum height of dam, 160 feet; drawing no. 253-D-34]

[Storage capacity, 70,000 acre-feet; spillway capacity, 13,000 second-feet; diversion capacity, 4,000 second-feet; required outlet capacity, 300 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion and unwatering foundations	[1]		[1]	$3,000			[1]	$3,000.00
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	53,000	Cubic yard	$0.30	15,900			$0.30	15,900.00
Stripping, borrow pits	145,000	Cubic yard	.30	43,500			.30	43,500.00
Toe drains and cut-off trenches	159,400	Cubic yard	.40	63,760			.40	63,760.00
Spillway	199,800	Cubic yard	.30	59,940			.30	59,940.00
Spillway and tunnel inlet and outlet	22,400	Cubic yard	.40	8,960			.40	8,960.00
Tunnel	8,300	Cubic yard	7.50	62,250			7.50	62,250.00
Roadway	1,800	Cubic yard	.75	1,350			.75	1,350.00
Borrow and transportation to dam	2,111,200	Cubic yard	.25	527,800			.25	527,800.00
Excavation, rock: Borrow and transportation to dam	218,000	Cubic yard	.75	163,500			.75	163,500.00
Embankment:								
Earth fill compacted	2,056,800	Cubic yard	.08	164,544			.08	164,544.00
Dumped rock on downstream slope	278,800	Cubic yard	.20	55,760			.20	55,760.00
Riprap rock on upstream slope	81,200	Cubic yard	.40	32,480			.40	32,480.00
Backfill about structures	24,200	Cubic yard	.50	12,100			.50	12,100.00
Gravel for roadway and spillway	5,440	Cubic yard	1.25	6,800			1.25	6,800.00
Oversized gravel and boulders downstream slope	92,900	Cubic yard	.10	9,290			.10	9,290.00
Spillway riprap	750	Cubic yard	.40	300			.40	300.00
GROUTING AND DRAINAGE								
Drain tile:								
12-inch diameter clay tile in gravel	800	Linear foot	.70	560	$0.45	360	1.15	920.00
8-inch diameter clay tile in gravel	5,000	Linear foot	.60	3,000	.30	1,500	.90	4,500.00
6-inch diameter clay tile in gravel	1,300	Linear foot	.50	650	.20	260	.70	910.00
Pressure grouting: Tunnel	5,000	Linear foot	1.00	5,000	.80	4,000	1.80	9,000.00
CONCRETE WORK								
Concrete:								
Parapets and curb walls	970	Cubic yard	18.00	17,460	4.00	3,880	22.00	21,340.00
Trash rack and transition	180	Cubic yard	14.75	2,655	4.00	720	18.75	3,375.00
... operating floor of gate chamber	180	Cubic yard	12.50	2,250	3.60	648	16.10	2,898.00
... and gate chamber	1,950	Cubic yard	12.00	23,400	4.00	7,800	16.00	31,200.00
...y floor and cut-off walls	4,300	Cubic yard	9.00	38,700	4.00	17,200	13.00	55,900.00
...y walls	1,275	Cubic yard	11.25	14,344	4.00	5,100	15.25	19,444.00
...ay counterforted walls	1,130	Cubic yard	14.00	15,820	4.00	4,520	18.00	20,340.00
Spillway piers and bridge	415	Cubic yard	12.50	5,187	3.60	1,494	16.10	6,681.00
Channel to valve house	215	Cubic yard	11.50	2,473	4.00	860	15.50	3,333.00
Valve house substructure	100	Cubic yard	12.50	1,250	3.60	360	16.10	1,610.00
Valve house superstructure	30	Cubic yard	22.00	660	4.00	120	26.00	780.00
Canal outlet	350	Cubic yard	16.50	5,775	4.00	1,400	20.50	7,175.00
Special finishing of concrete surfaces	2,000	Square yard	.60	1,200			.60	1,200.00
METALWORK								
Metal:								
Trash rack	32,000	Pound	.02	640	.08	2,560	.10	3,200.00
Reinforcement steel	1,065,000	Pound	.02	21,300	.03	31,950	.05	53,250.00
Steel liner plate	500,000	Pound			.05	25,000	.05	25,000.00
57-inch ring-follower gate and control mechanism	43,600	Pound	.04	1,744	.24	10,464	.28	12,208.00
48-inch needle valve and control mechanism	37,600	Pound	.03	1,128	.22	8,272	.25	9,400.00
8-ton hoist	28,000	Pound	.02	560	.19	5,320	.21	5,880.00
Gas-electric generator set and equipment	[1]		[1]	200	[1]	800	[1]	1,000.00
57-inch inside diameter outlet pipes	212,000	Pound	.025	5,300	.07	14,840	.095	20,140.00
20- by 17-foot radial gates and operating mechanism	109,000	Pound	.03	3,270	.09	9,810	.12	13,080.00
44- by 55-foot face gates and operating mechanism	8,300	Pound	.02	166	.08	664	.10	830.00
Miscellaneous metalwork	20,000	Pound	.10	2,000	.10	2,000	.20	4,000.00
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	[1]		[1]	300	[1]	1,200	[1]	1,500.00
Transporting freight except cement for Government from South Fork, Colorado, to the dam site (29.5 miles)	1,040	Ton	3.25	3,380				3,380.00
Highway construction	3	Mile	15,000.00	45,000				45,000.00
Telephone and utility lines	3	Mile	300.00	900	200.00	600	500.00	1,500.00
Right-of-way	1,100	Acre			37.00	40,700	37.00	40,700.00
Subtotals				1,457,506		204,802		1,662,308.00
Contingencies: 15 percent								249,346.00
Total estimated field cost								1,911,654.00
Investigations and surveys	[1]						[1]	5,000.00
Engineering and inspection, 5 percent								95,583.00
Superintendence and accounts, 1 percent								19,117.00
General expense, 2 percent								38,234.00
Total estimated cost								2,069,588.00
Cost per acre-foot of storage								29.57

[1] Lump sum.

CO - 003439

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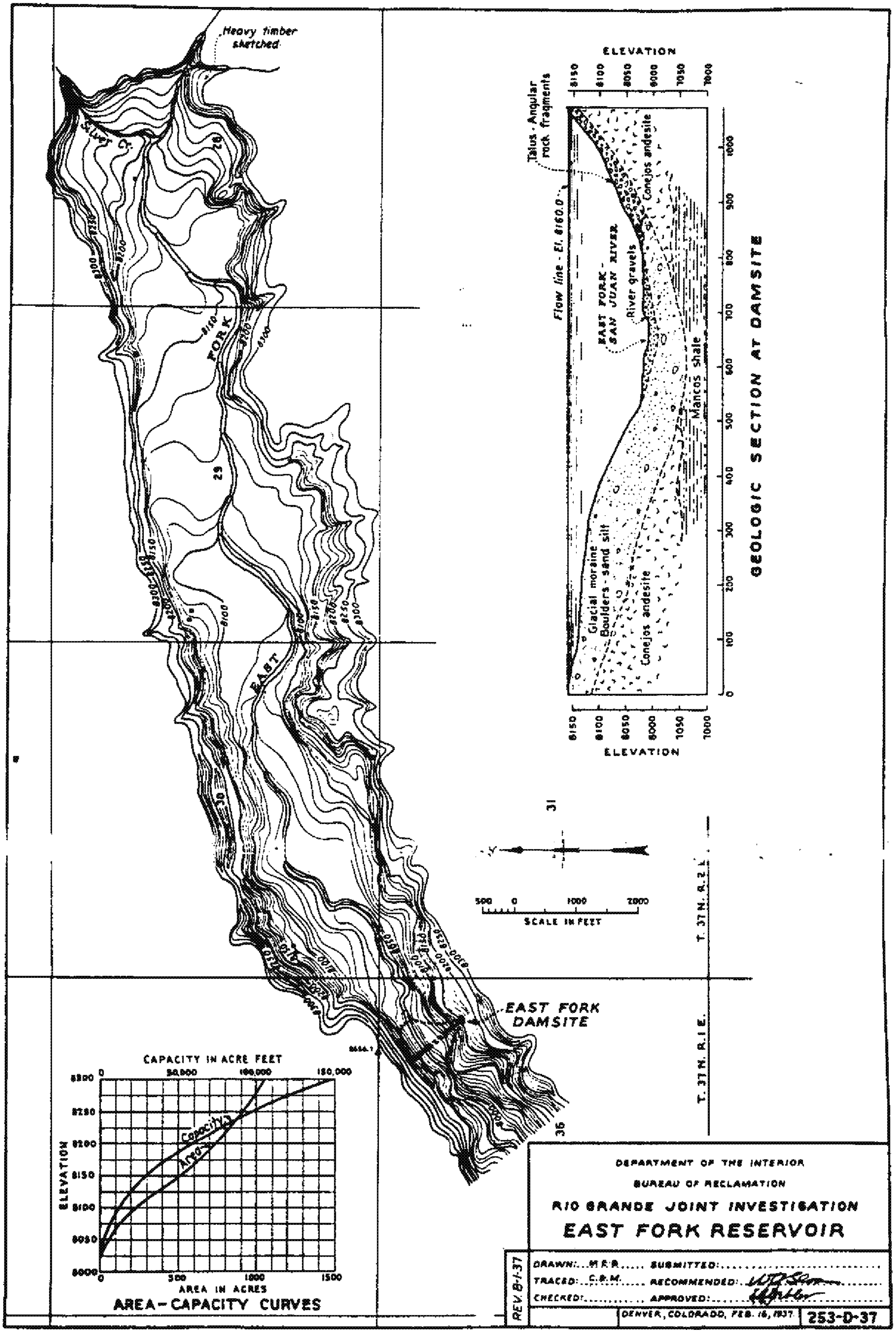
Heavy timber sketched
Silver Cr.
EAST FORK
GEOLOGIC SECTION AT DAMSITE
ELEVATION
Talus - Angular rock fragments
Flow line - El. 8160.0
Conejos andesite
EAST FORK - SAN JUAN RIVER
River gravels
Mancos shale
Glacial moraine Boulders - sand silt
Conejos andesite
SCALE IN FEET
EAST FORK DAMSITE
T. 37 N. R. 2 E.
T. 37 N. R. 1 E.
CAPACITY IN ACRE FEET
AREA IN ACRES
AREA-CAPACITY CURVES
Capacity
Area
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
EAST FORK RESERVOIR
DRAWN: M.F.R.
SUBMITTED:
TRACED: C.S.M.
RECOMMENDED:
CHECKED:
APPROVED:
REV. 8-1-37
DENVER, COLORADO, FEB. 16, 1937
253-D-37

FIGURE 109

East Fork Reservoir

The East Fork dam site is in section 36, T. 37 N., R. E., of Mineral County, Colo., and approximately es above the junction of the East and West Forks of the San Juan River.

A storage capacity of 35,000 acre-feet capacity is required for regulation of East Fork waters for diversion to Rio Grande.

Summary of estimate data:

Storage capacity	35,000 acre-feet.
Spillway capacity	10,000 second-feet.
Outlet capacity at low water	300 second-feet.
Elevation—top of dam	8,167.
Maximum and normal reservoir water-surface elevation	8,160.
Reservoir area at elevation 8,160	570 acres.
Height of dam	150 feet.
Total estimated cost—dam and reservoir	$1,449,000.
Preliminary estimate	Table 4
Reservoir topography and geologic cross-section	Figure 109.
General plan and sections	Figure 110.

Geological summary.—The basin is a normal erosional valley eroded into a somewhat unusual and interesting bedrock complex. In brief, the foundation rock is believed to be irregularly eroded black shale (Mancos) over which a series of volcanic andesite flows (Conejos) was erupted. Recent erosion has reached shale in the basin while immediately below the axis the river is flowing on andesite. The bottom flats in the reservoir are heavily mantled with stratified gravels, while terrace remnants of similar loose, permeable gravels line the sides. Irregular wash, slide, and glacial deposits are also to be found. The water table is tributary to the stream and no reservoir seepage is to be expected other than some downstream movement through the detrital deposits.

The dam site occupies the only economical narrows commanding this basin. The old shale surface, on which the andesites were extruded, dips downstream in this area. This contact zone comes to the surface in the vicinity of the dam site, so that the immediate rock foundation on the axis is probably shale or sandstone, although andesite may be encountered. The only bedrock that possibly can be utilized during construction, provided the detrital foundation materials are not excavated, is the andesite in the right abutment. This rock is more in the nature of a flow breccia, an angularly broken and fractured andesite that is somewhat recemented. The character of the contact materials is not known, as no exposures were found.

The site must depend almost entirely upon the control and use of the various overburden materials. On the right abutment a talus deposit of unknown character possibly 100 feet deep overlies andesite breccia. debris may prove to be quite permeable depending upon the amount of interstitial silts. No pits have been dug. The foundation gravels may extend for some distance under the right talus and possibly also under the left moraine. These loose permeable gravels are of unknown depth. The left abutment is composed entirely of a glacial moraine of undetermined quality but surface exposure indicates an unusually thick assemblage of semiangular boulders, gravel, sand and silt, the whole appearing unusually compact. It is believed that this moraine is lying on and against landslide rubble.

Dam.—Since the dam foundation consists of glacial moraine material, a compacted embankment type was selected. It is estimated there is sufficient embankment borrow material within 1 mile of the site. There appear to be ample sand and gravel deposits along the river within one-half mile upstream for the required amount of concrete. No tests have yet been made to determine suitability of these materials for construction purposes. Rock for the downstream toe is available in nearby talus slopes.

The dam is 1,140 feet in length along the crest and attains a maximum height of 140 feet above river bed. A deep cut-off trench extends the entire length of the dam, the excavation from which can be used in the downstream portion of the embankment. Sufficient rock is to be placed against the downstream side of the embankment to make it stable. The entire area under the dam will require stripping of vegetation.

The spillway, located in the left abutment, contains three 17 feet long by 16 feet high automatic radial gates constructed to withstand ice pressure. The gate structure, spillway channel, and stilling basin, are of reinforced concrete, with counterforted and cantilever wall construction. With water at elevation 8,160, the discharge capacity of the spillway is 10,000 second-feet. The drainage area is 60 square miles.

A 12-foot diameter horseshoe tunnel with steel liner plates and concrete lining will be used for diversion of stream flow and later as outlet tunnel. The inlet and trash rack is placed a short distance above the reservoir floor to provide a depth for storage of materials brought in by the stream and for protection of fish. A single 57-inch emergency ring follower gate is placed in a chamber in the tunnel under the axis of the dam. From the gate chamber a 57-inch steel pipe leads downstream in the tunnel to a single 48-inch needle valve. The needle valve, which is located in a valve house at the downstream end of the tunnel, discharges into the spillway stilling basin. The gate chamber and valve house are to be equipped with the necessary pumps, piping, cranes, etc., required for operation. It is planned to install a gas-engine-driven generator to supply energy to operate gates and furnish lights.

It will require approximately 2½ years to construct the dam and appurtenant works. No electric power is

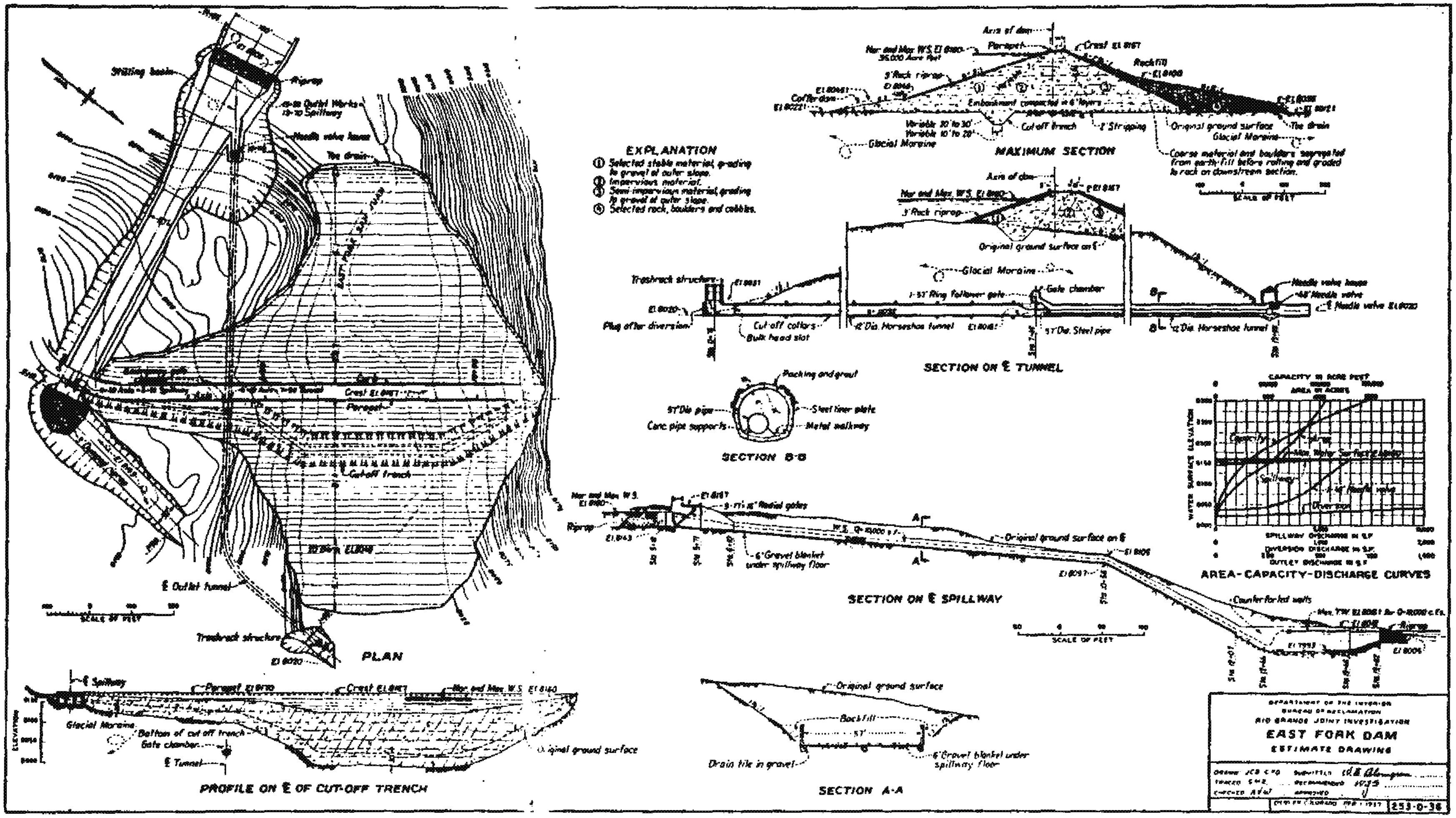
EXPLANATION
① Selected stable material, grading to gravel at outer slope.
② Impervious material.
③ Semi-impervious material, grading to gravel at outer slope.
④ Selected rock, boulders and cobbles.
MAXIMUM SECTION
SECTION ON ℄ TUNNEL
SECTION B-B
SECTION ON ℄ SPILLWAY
AREA-CAPACITY-DISCHARGE CURVES
PLAN
PROFILE ON ℄ OF CUT-OFF TRENCH
SECTION A-A
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
EAST FORK DAM
ESTIMATE DRAWING
253-D-36

FIGURE 110

TABLE 4.—*Department of the Interior, Bureau of Reclamation, Rio Grande joint investigations, Colorado East Fork San Juan Dam, preliminary estimate, Jan. 30, 1937*

...h embankment: Top of dam, elevation 8,167; normal water surface elevation, 8,160; maximum water surface elevation, 8,160; maximum height of dam, 150 feet; drawing 253–D–36.]

[Storage capacity, 35,000 acre-feet; spillway capacity, 10,000 second-feet; diversion capacity, 2,000 second-feet; required outlet capacity, 300 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion, and unwatering foundation	(1)		(1)	$3,000			(1)	$3,000
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	49,000	Cubic yard	$0.30	14,700			$0.30	14,700
Stripping, borrow pits	67,000	Cubic yard	.30	20,100			.30	20,100
Tunnel	8,700	Cubic yard	7.50	65,250			7.50	65,250
Toe drains and cut-off trenches	54,300	Cubic yard	.40	21,720			.40	21,720
Spillway, and tunnel inlet and outlet	114,000	Cubic yard	.40	45,600			.40	45,600
Spillway	87,100	Cubic yard	.30	26,130			.30	26,130
Borrow, and transportation to dam	1,181,000	Cubic yard	.25	295,250			.25	295,250
Excavation, rock: Borrow, and transportation to dam	161,200	Cubic yard	.75	120,900			.75	120,900
Embankment:								
Earth fill compacted	1,182,000	Cubic yard	.10	118,200			.10	118,200
Dumped rock on downstream slope	184,500	Cubic yard	.20	36,900			.20	36,900
Riprap rock on upstream slope and spillway	30,500	Cubic yard	.40	12,200			.40	12,200
Backfill about structures	6,000	Cubic yard	.50	3,000			.50	3,000
Gravel for roadway and under spillway	2,700	Cubic yard	1.25	3,375			1.25	3,375
Oversized boulders and gravel on downstream slope	61,500	Cubic yard	.10	6,150			.10	6,150
GROUTING AND DRAINAGE								
Pressure grouting: Tunnel	5,000	Cubic foot	1.00	5,000	$1.00	$5,000	2.00	10,000
Drain tile:								
12-inch diameter clay tile in gravel	600	Linear feet	.70	420	.45	270	1.15	690
8-inch diameter clay tile in gravel	2,500	Linear feet	.60	1,500	.30	750	.90	2,250
6-inch diameter clay tile in gravel	1,000	Linear feet	.50	500	.20	200	.70	700
4-inch diameter clay tile in gravel	200	Linear feet	.30	60	.20	40	.50	100
CONCRETE WORK								
Concrete:								
Tunnel cut-off collars	100	Cubic yard	9.00	900	4.00	400	13.00	1,300
Spillway floor and cut-off walls	3,500	Cubic yard	9.00	31,500	4.00	14,000	13.00	45,500
Spillway walls	330	Cubic yard	11.25	3,712	4.00	1,320	15.25	5,032
Spillway counterforted walls	760	Cubic yard	14.00	10,640	4.00	3,040	18.00	13,680
...llway piers and bridge	320	Cubic yard	12.50	4,000	3.60	1,152	16.10	5,152
...unel to valve house	100	Cubic yard	11.50	1,150	4.00	400	15.50	1,550
...pet and curb walls	400	Cubic yard	18.00	7,200	4.00	1,600	22.00	8,800
...h rack and transition	100	Cubic yard	14.75	1,475	4.00	400	18.75	1,875
...low operating floor of gate chamber	180	Cubic yard	12.50	2,250	3.60	648	16.10	2,898
Tunnel and gate chamber	1,900	Cubic yard	12.00	22,800	4.00	7,600	16.00	30,400
Needle-valve house substructure	100	Cubic yard	12.50	1,250	3.60	360	16.10	1,610
Needle-valve house superstructure	30	Cubic yard	22.00	660	4.00	120	26.00	780
Special concrete finishing	710	Square yard	.60	426			.60	426
METALWORK								
Metal:								
Trash rack	17,300	Pound	.02	346	.08	1,384	.10	1,730
Reinforcement steel	649,500	Pound	.02	12,990	.03	19,485	.05	32,475
Steel liner plates	517,000	Pound			.05	25,850	.05	25,850
57-inch inside diameter outlet pipes	210,000	Pound	.025	5,250	.07	14,700	.095	19,950
57-inch ring-follower gate and control mechanism	43,600	Pound	.04	1,744	.24	10,464	.28	12,208
48-inch needle valve and control mechanism	37,600	Pound	.03	1,128	.22	8,272	.25	9,400
8-ton hoist	28,000	Pound	.02	560	.19	5,320	.21	5,880
Gas-electric generator set and equipment	(1)		(1)	200	(1)	800	(1)	1,000
Miscellaneous metalwork	26,100	Pound	.10	2,610	.10	2,610	.20	5,220
3 17- by 16-foot radial gates and operating mechanism	85,000	Pound	.03	2,550	.09	7,650	.12	10,200
MISCELLANEOUS ITEMS								
Items:								
Control house, except concrete	(1)		(1)	300	(1)	1,200	(1)	1,500
Transporting freight except cement for Government from South Fork, Colo., to the dam site (43 miles).	791	Ton	4.75	3,757				3,757
Highway construction	5	Mile	20,000.00	100,000			20,000	100,000
Telephone and utility lines	2	Mile	300.00	600	200	400	500	1,000
Clearing reservoir	50	Acre	25.00	1,250			25.00	1,250
Right-of-way	250	Acre			25.00	6,250	25.00	6,250
Subtotals				1,021,203		141,685		1,162,888
Contingencies, 15 percent								174,433
Total estimated field cost								1,337,321
Investigations and surveys	(1)						(1)	5,000
Engineering and inspection, 5 percent								66,866
Superintendence and accounts, 1 percent								13,373
General expense, 2 percent								26,746
Total estimated cost								1,449,306
Cost per acre-foot of storage								41.41

[1] Lump sum.

CO - 003443

TX_MSJ_000523

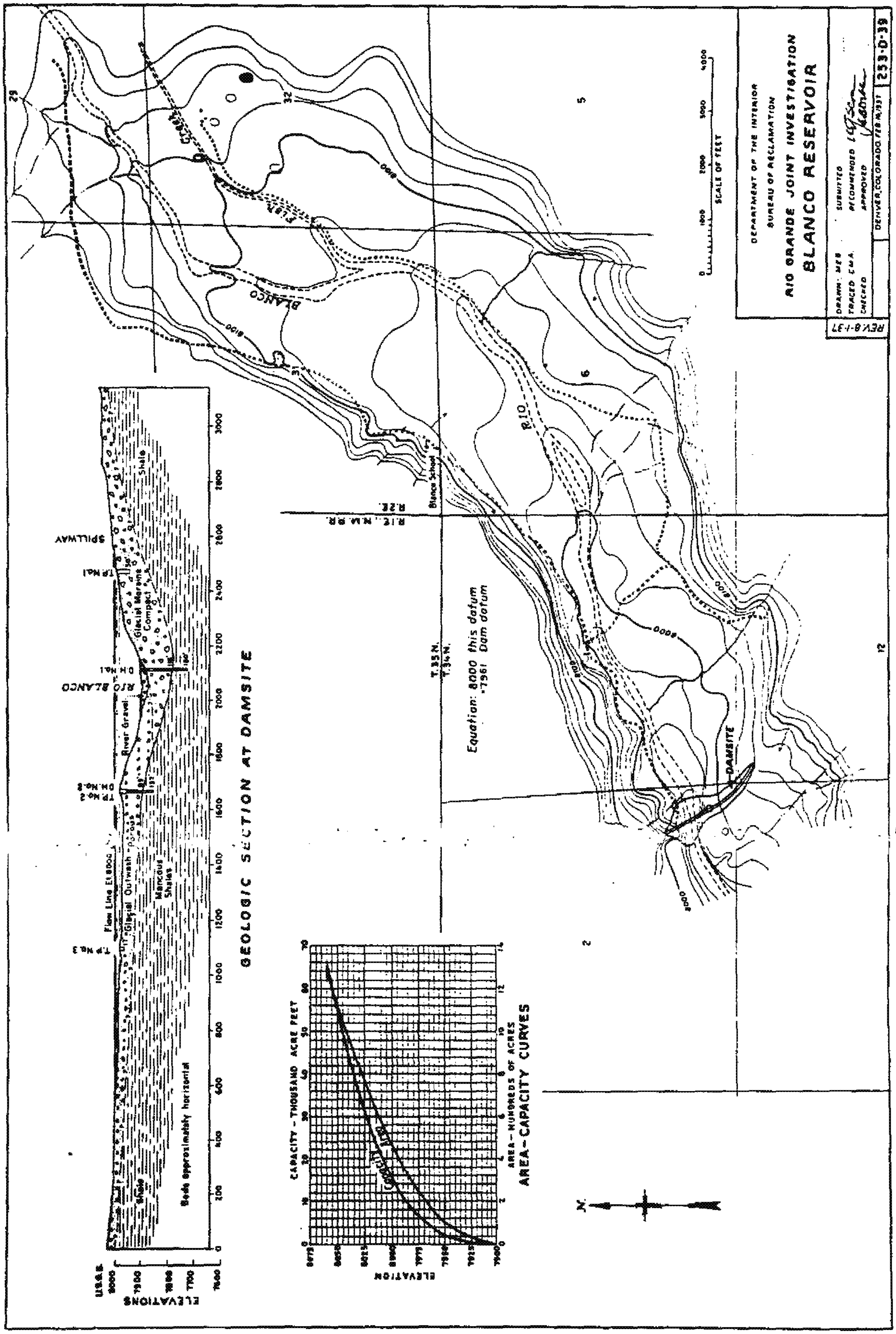
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
BLANCO RESERVOIR
DENVER, COLORADO, FEB. 16, 1937
253-D-39
SCALE OF FEET
RIO
BLANCO
DAMSITE
Blanco School
Equation: 8000 this datum
7961 Dam datum
GEOLOGIC SECTION AT DAMSITE
ELEVATIONS
SPILLWAY
River Gravel
Glacial Moraine Compact
Glacial Outwash Porous
Mancos Shales
Beds approximately horizontal
AREA-CAPACITY CURVES
CAPACITY - THOUSAND ACRE FEET
AREA - HUNDREDS OF ACRES
ELEVATION

FIGURE 111

available in this locality. The nearest railroad shipping point is South Fork, Colo., a distance of 38 miles, of 'ch 33 miles is U. S. Highway No. 160, over Wolf :k Summit, and 5 miles will be new road of difficult construction. About 50 acres of the reservoir site will require clearing.

Blanco Reservoir

The Blanco dam site is located on the Rio Blanco, a tributary of the San Juan River, in sections 1 and 12, T. 34 N., R. 1 E., of Archuleta County, Colo., about 13 miles southeast of Pagosa Springs. A storage capacity of 15,000 acre-feet is required at this site to detain flood waters in excess of the capacity of the San Juan-Chama Canal.

Summary of data:

Storage capacity	15,000 acre-feet.
Spillway capacity	12,000 second-feet.
Outlet capacity at low water	500 second-feet.
Elevation—top of dam	8,007.
Normal and maximum water surface elevation.	8,000.
Height of dam above stream level	102 feet.
Total estimated cost—dam and reservoir.	$1,060,494.
Preliminary estimate	Table 5.
Reservoir topography and geologic sections.	Figure 111.
General plan and sections of dam	Figure 112.

The reservoir area at elevation 8,007 is 325 acres, which 150 acres are privately owned lands and approximately 100 acres will require clearing. The area of the watershed is 69 square miles.

Geological summary.—The Blanco Basin is a normal erosional feature cut into black shale of the Mancos series which is found in the bottom beneath a thick deposit of river gravels. This shale is substantially horizontal but may dip slightly upstream. Overlying this shale but everywhere well above the flow line, is found a capping of Conejos andesite. The contact between the two is very irregular, the andesite having submerged the hills and valleys of the eroded shale topography. Intrusive igneous dikes are apparently common in the shale, and examples were encountered by the churn drill at the dam site. The entire reservoir floor is heavily mantled with porous river gravels, while the basin sides are covered with glacial terrace gravel and moraine, as well as extensive, erratic wash, and slump debris. Consideration of the bedrock character, together with observation of springs and seeps, suggests that the ground water is tributary to the stream and that no reservoir loss can occur, except as seepage downstream through the various detrital materials.

The dam site must depend entirely upon similar overburdens both for support and adequate impermeability. Two alternative axes were explored at the ar narrows before selection of the final proposed dam site. Three pits were dug on the rejected axis while three pits and two churn drill holes were completed at the present axis. The eventual bedrock is the Mancos formation of the reservoir; a black, compact shale that in itself should be sufficiently impervious and stable for earth-dam construction. A study of the overburdens shows that several types of deposits will be encountered. The immediate foundation, in the river, is a recent stratified gravel probably resting at no great depth on glacial moraine. The latter debris forms the right abutment, where pits indicate a fairly compact assemblage of boulders, gravel, sand, and clay that appears quite stable and relatively impervious. On the other hand, the left abutment is composed largely of glacial terrace outwash; a stratified deposit that has alternating gravel, silt, and clay layers. Erratic moraine debris is also found as evidenced by several extremely large boulders 20 to 30 feet in diameter. Layers of the outwash will prove to be very porous and although these can be expected to have a lensed character, some horizons may extend over long distances, long enough to pass entirely beneath the dam. In this regard, the lensing will be more pronounced laterally, while channellike areas are more likely to extend up and down stream. The water table in this debris fluctuates widely, depending upon the amount of irrigation. With none, it is believed that it would be found close to the present river level. Two drill holes show the shale to be 118 feet beneath the surface in the river channel and 88 feet under the left abutment.

Dam.—Figure 112 shows the general plan and sections for the proposed dam. Excavation to bedrock was considered too costly and not necessary. The proposed dam is of the compacted embankment type with a deep cut-off trench, the material from which can be used in the downstream portion of the embankment. Sufficient rock is placed on the downstream slope to make the embankment stable. The crest of the dam is 2,300 feet in length and the maximum height at the river section is 102 feet. There appears to be sufficient embankment material adjacent to the site. Sand and gravel deposits are about one-half mile upstream but no pits have been dug nor analyses made to determine their extent or quality. The entire dam foundation will require stripping of vegetation.

A gate spillway with a maximum capacity of 12,000 second-feet will be constructed in glacial debris material on the right abutment. The gate structure provides the necessary freeboard without raising the dam. Three automatic radial gates, 18 feet long by 17 feet high, will be constructed to withstand ice pressure. The gate structure is of reinforced concrete with counterfort type side walls. A roadway over the dam and spillway may be extended to join the present road at the right abutment.

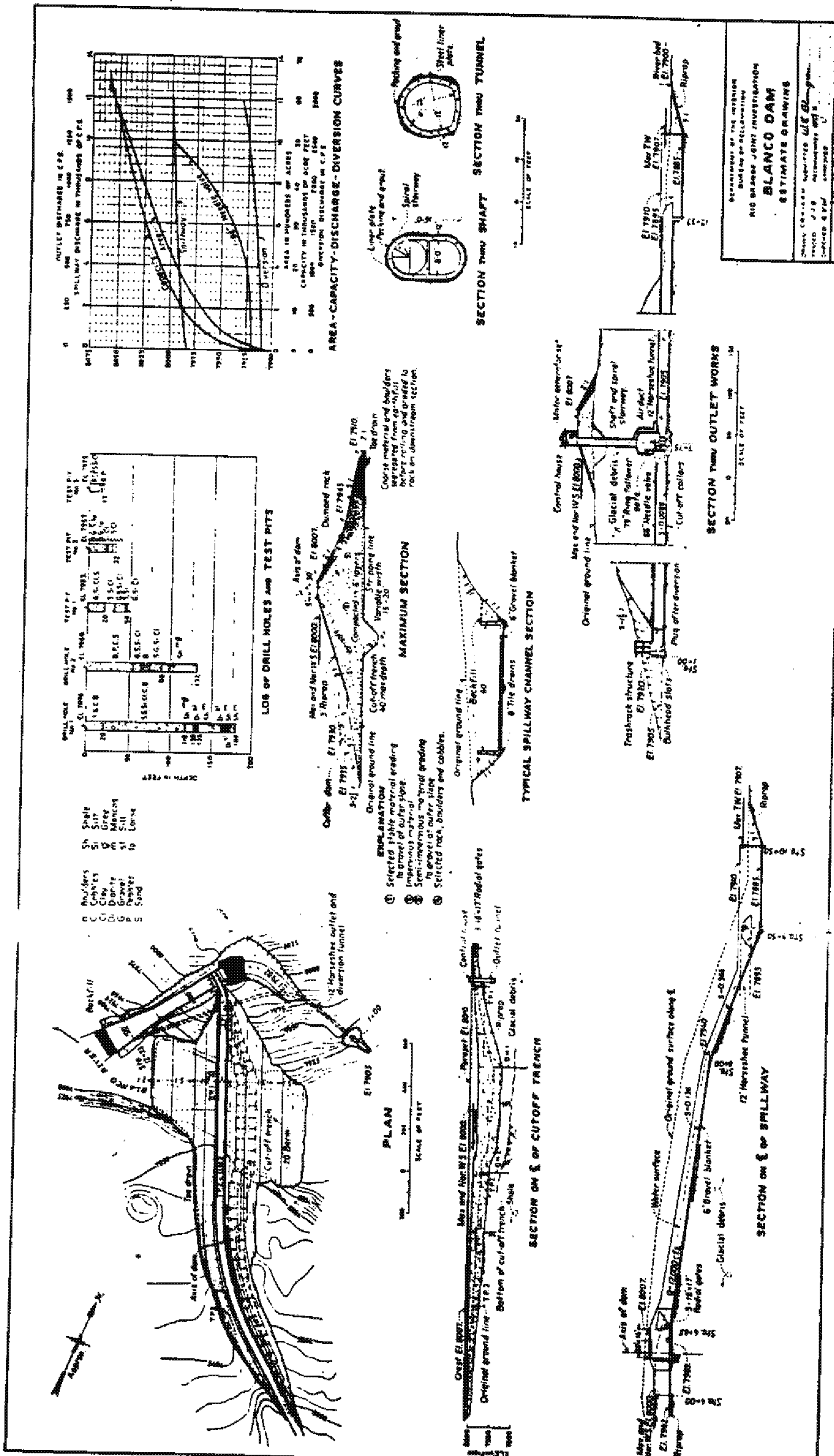

FIGURE 112

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For diversion and outlet purposes, a 12-foot diameter horseshoe tunnel with steel liner plates and concrete "ining is provided under the right abutment. The et and trash rack is placed above the floor of the .servoir to keep sand and gravel washed in by the river out of the outlet, and for protection of fish. The outlet works consist of one 66-inch needle valve and one 54-inch ring follower emergency gate located in a chamber in the tunnel under the axis of the dam. The needle valve discharges into the tunnel which, in

TABLE 5.—*Blanco Dam, preliminary estimate, Jan. 30, 1937*

Earth embankment: top of dam, elevation 8,007; normal water surface, elevation 8,000; spillway crest, elevation 7,983; maximum height of dam, 110 feet; drawing no. 253-D-38

[Storage capacity, 15,000 acre-feet; spillway capacity, 12,000 second-feet; diversion capacity, 3,000 second-feet; required outlet capacity, 500 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion and unwatering foundations	(1)		(1)	$4,000			(1)	$4,000.00
EARTHWORK								
Excavation common:								
Stripping dam foundation	41,000	Cubic yard	$0.30	12,300			$0.30	12,300.00
Stripping borrow pits	33,000	Cubic yard	.30	9,900			.30	9,900.00
Toe drains, and cut-off trenches	135,000	Cubic yard	.40	54,000			.40	54,000.00
Spillway, tunnel inlet and outlet	115,000	Cubic yard	.40	46,000			.40	46,000.00
Tunnel shaft and gate chamber	8,600	Cubic yard	7.50	64,500			7.50	64,500.00
Borrow and transportation to dam	738,500	Cubic yard	.25	184,625			.25	184,625.00
Excavation rock: Borrow and transportation to dam	78,100	Cubic yard	.75	58,575			.75	58,575.00
Embankment:								
Earthfill compacted	887,500	Cubic yard	.10	88,750			.10	88,750.00
Dumped rock on downstream slope	70,500	Cubic yard	.20	14,100			.20	14,100.00
Riprap rock on upstream slope of dam and spillway channel	35,000	Cubic yard	.40	14,000			.40	14,000.00
Backfill about structures	10,000	Cubic yard	.50	5,000			.50	5,000.00
Gravel for roadway and spillway	3,600	Cubic yard	1.25	4,500			1.25	4,500.00
Oversized gravel and boulders on downstream slope	23,500	Cubic yard	.10	2,350			.10	2,350.00
GROUTING AND DRAINAGE								
Drilling: Weep holes	300	Linear foot	1.00	300			1.00	300.00
Pressure grouting: Tunnel	4,500	Linear foot	1.00	4,500			1.00	4,500.00
Drain tile:								
12-inch diameter clay tile drain in gravel	700	Linear foot	.70	490	$0.45	$315	1.15	805.00
8-inch diameter clay tile drain in gravel	2,300	Linear foot	.60	1,380	.30	690	.90	2,070.00
6-inch diameter clay tile drain in gravel	1,800	Linear foot	.50	900	.20	360	.70	1,260.00
CONCRETE WORK								
...rete:								
Trashrack and transition	100	Cubic yard	14.75	1,475	4.60	460	19.35	1,935.00
Tunnel and shaft lining	1,900	Cubic yard	14.00	26,600	4.60	8,740	18.60	35,340.00
Gate chamber	375	Cubic yard	12.00	4,500	4.15	1,556	16.15	6,056.00
Spillway gate structure	1,200	Cubic yard	11.00	13,200	4.15	4,980	15.15	18,180.00
Spillway channel	3,700	Cubic yard	11.75	43,475	4.60	17,020	16.35	60,495.00
Parapets and curb walls	850	Cubic yard	18.00	15,300	4.60	3,910	22.60	19,210.00
Control house	25	Cubic yard	18.00	450	4.60	115	22.60	565.00
Special concrete finishing	825	Square yard	.60	495			.60	495.00
METAL WORK								
Metal:								
Tunnel and shaft liner plates	407,000	Pound			.05	20,350	.05	20,350.00
Trashrack	14,000	Pound	.02	280	.08	1,120	.10	1,400.00
Reinforcement bars	400,000	Pound	.02	8,000	.03	12,000	.05	20,000.00
1 79-inch ring follower gate and control mechanism	81,000	Pound	.04	3,240	.24	19,440	.28	22,680.00
1 66-inch needle valve and operating mechanism	66,000	Pound	.03	1,980	.22	14,520	.25	16,500.00
3 18 by 17-foot radial gates and operating mechanism	98,000	Pound	.03	2,940	.09	8,820	.12	11,760.00
Metal stairways and walkways	17,000	Pound	.03	510	.11	1,870	.14	2,380.00
Pipe handrailing	2,700	Pound	.03	81	.09	243	.12	324.00
Grout and drain pipe	2,500	Pound	.05	125	.07	175	.12	300.00
Miscellaneous metalwork	5,000	Pound	.10	500	.10	500	.20	1,000.00
Gas-electric generator set and equipment	(1)		(1)	200	(1)	800	(1)	1,000.00
8-ton hoist	28,000	Pound	.02	560	.19	5,320	.21	5,880.00
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)		(1)	200	(1)	800	(1)	1,000.00
Transporting freight except cement for Government from Lumberton, N. Mex., to the dam site (33.8 miles).	550	Ton	4.00	2,200			4.00	2,200.00
Highway construction	4	Mile	5,000.00	20,000			5,000.00	20,000.00
Telephone and utility lines	3	Mile	300.00	900	200.00	600	500.00	1,500.00
Clearing reservoir	100	Acre	25.00	2,500			25.00	2,500.00
Right-of-way	150	Acre			35.00	5,250	35.00	5,250.00
Subtotal				719,881		129,954		849,835.00
Contingencies, 15 percent								127,475.00
Total estimated field cost								977,310.00
Investigations and surveys	(1)						(1)	5,000.00
Engineering and inspection, 5 percent								48,865.00
Superintendence and accounts, 1 percent								9,773.00
General expense, 2 percent								19,546.00
Total estimated cost								1,060,494.00
Cost per acre-foot of storage								70.70

[1] Lump sum.

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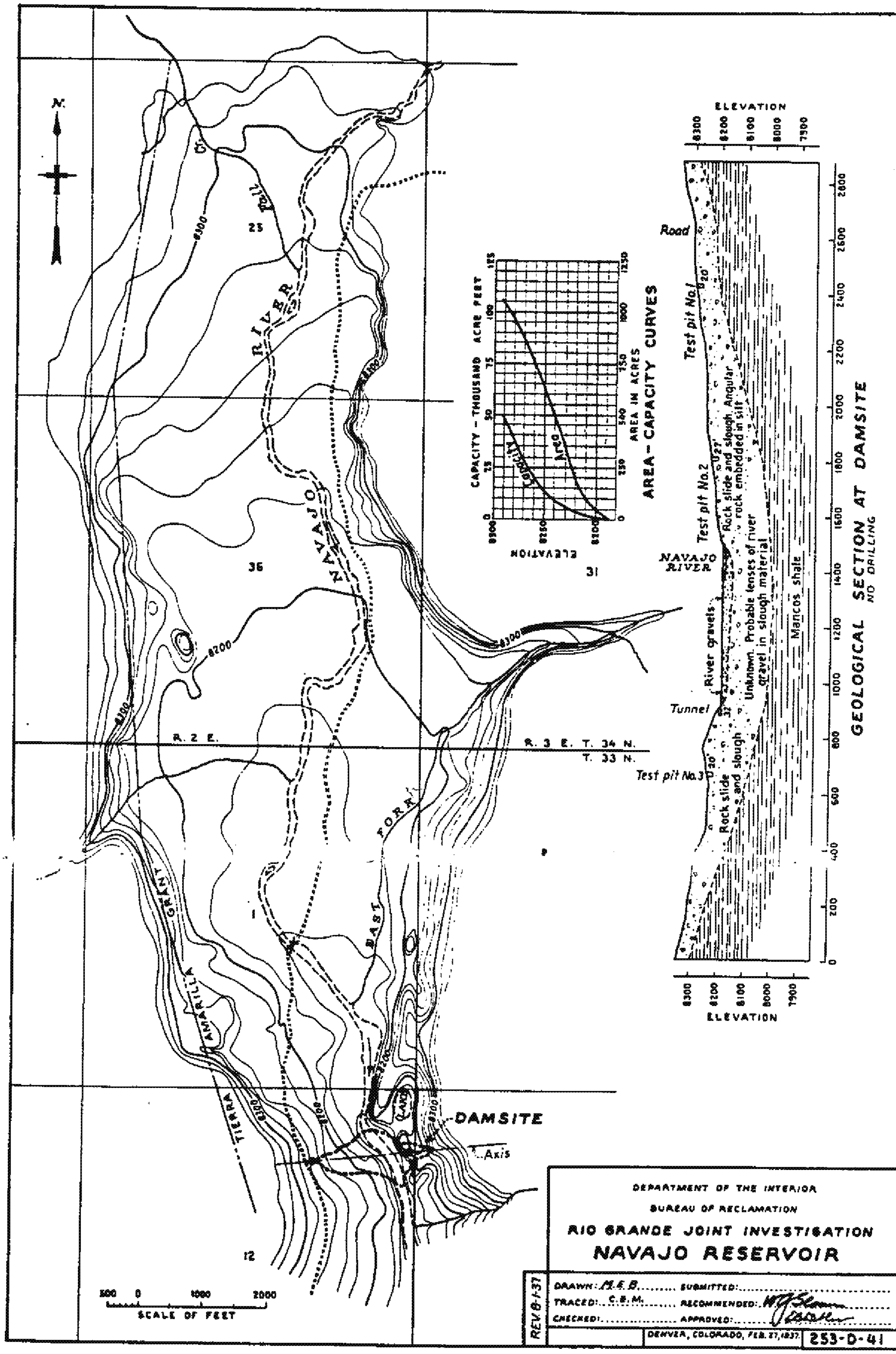
DAMSITE
Axis
NAVAJO RIVER
EAST FORK
R. 2 E.
R. 3 E. T. 34 N.
T. 33 N.
SCALE OF FEET
AREA - CAPACITY CURVES
GEOLOGICAL SECTION AT DAMSITE
NO DRILLING
Manco shale
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
NAVAJO RESERVOIR
DENVER, COLORADO, FEB. 27, 1937.
253-D-41

FIGURE 113

turn, empties into the spillway stilling basin. A control house on top of the dam is connected to the outlet chamber by means of a vertical shaft containing a stairway. The outlet chamber is equipped with necessary pumps, piping, cranes, etc., required for the operation of the gate and needle valve. It is planned to install a gasoline-electric generator set in the control house for the operation of the outlet works, spillway gates, and to provide lighting.

It will require approximately 2 years to construct the dam and appurtenant works.

No electric power is available locally for construction purposes. The nearest railroad shipping point is Lumberton, N. Mex. a distance of 33.8 miles over a dry-weather road (now being graveled in part) on the narrow-gage Denver & Rio Grande Western Railroad Co. line from Alamosa to Durango.

Navajo Reservoir

The Navajo dam site is located in section 13, T. 33 N., R. 2 E., N. M. P. M., of Archuleta County, about 20 miles southeast of Pagosa Springs.

The storage requirement at this site is 50,000 acre-feet to regulate the stream to the capacity of the San Juan-Chama Canal.

Summary of estimate data:

Storage capacity	50,000 acre-feet.
Spillway capacity	10,000 second-feet.
Outlet capacity at low levels	300 second-feet.
Elevation—top of dam	8,300.
Normal and maximum water-surface elevation.	8,293.
Height of dam above stream	120 feet.
Estimated cost—dam and reservoir	$1,515,000.
Topography of reservoir and geologic sections.	Figure 113.
General plan and sections	Figure 114.
Preliminary estimate	Table 6.

The reservoir at elevation 8,293 covers 1,075 acres of privately owned lands. No clearing is required.

Geological summary.—The reservoir basin is a normal erosional valley cut by both water and ice action into a foundation rock of Mancos shale, a dark-gray siltstone containing some brown sandstone lenses. Blanco Basin soft sandstones are probably also present. These are overlain by igneous andesite flows and flow breccias (Conejos formation) the lower contact of which is quite irregular. Most of this andesite is well above the flow line in the lower half of the basin but is to be found exposed in the bottom, to the north. All of the area is heavily mantled with various overburden deposits. The floor is covered with deep, porous river gravels, while the sides have irregular deposits of wash, slump and glacial terrace deposits. In view of the foundation shale, together with normal spring occurrences, the water table is undoubtedly tributary to the stream; so that no reservoir seepage is to be expected except as underflow downstream through the various detrital deposits.

No bedrock will be encountered during construction at the dam site, where the proposed dam must utilize overburden foundation and abutments. The eventual bedrock is in all probability Mancos shale. No drilling was done and depths to this rock are unknown, but three test pits and one drift were completed to give some indications of the overburden character. The shale in all probability has been intruded by igneous dikes and sills, which were accompanied by alteration and mineralizing solutions. Much of this alteration material from both the shale and overlying andesite is to be found in the slump material forming the abutments. Both abutments are of similar slump origin. The debris is composed of angular shale rock and rock fragments, embedded for the most part in a silty clay. Pits indicated a remarkably tight and impervious deposit, as compact perhaps as natural overburden materials can become. Both sides are of similar land slump material which in slow transit down the slopes has picked up and incorporated some glacial debris. Such slumping should be expected in this area, where the shale emerges from under the andesite to form soft, unresistant valley walls. It is believed that the material is now quite stable except, perhaps, high up on the sides and well above the flow line. The immediate river channel is covered with a veneer of recent river gravels (10–50 feet).

Dam.—The general plan and sections for the proposed dam are shown in figure 114. No information is available as to the depth to bedrock. However, it is considered at too great a depth for a cut-off to rock. The proposed dam is of the compacted embankment type with a deep cut-off trench. Sufficient rock is placed on the downstream slope to make the embankment stable.

The crest of the dam is 1,950 feet in length and the maximum height, at the river section, is 120 feet.

Sufficient quantities of embankment borrow material are thought to be available adjacent to the site. Sand and gravel deposits occur about one-half of a mile upstream but have been neither prospected nor analyzed.

The entire dam foundation will require stripping of vegetation. Excavation from the cut-off trench can be used to construct the downstream portion of the embankment.

The spillway at the right end of the dam will be a radial gate structure to obtain the required capacity and to provide the necessary free-board without raising the dam. From the test pit records the spillway will be in slide material, as test pits show bedrock will not be available at reasonable depth. Three 17-foot long

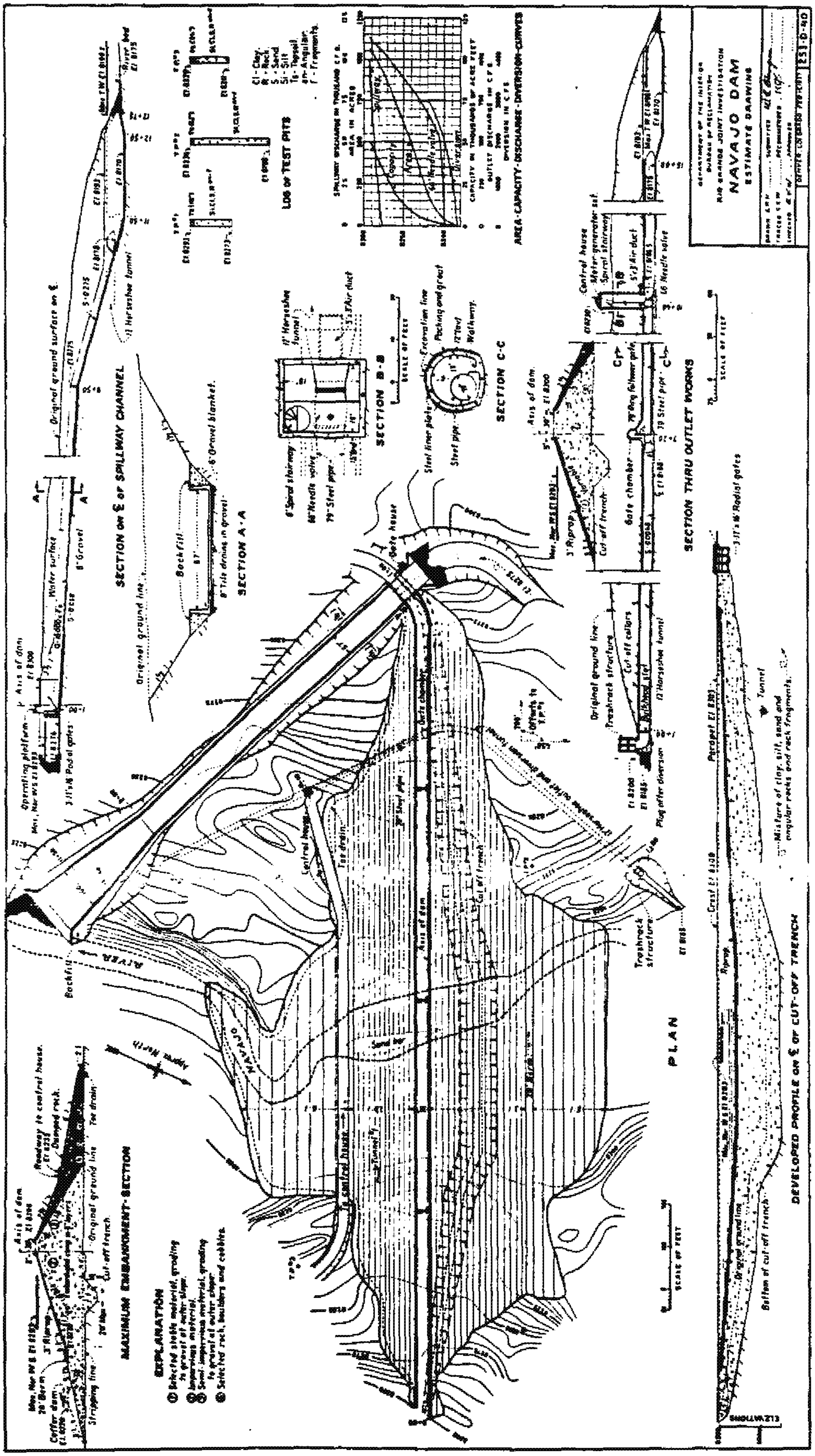
NAVAJO DAM
ESTIMATE DRAWING
PLAN
SECTION ON ℄ OF SPILLWAY CHANNEL
SECTION A-A
SECTION B-B
SECTION C-C
SECTION THRU OUTLET WORKS
LOG OF TEST PITS
AREA-CAPACITY-DISCHARGE-DIVERSION-CURVES
MAXIMUM EMBANKMENT SECTION
EXPLANATION
DEVELOPED PROFILE ON ℄ OF CUT-OFF TRENCH

FIGURE 114

by 16-foot high radial gates constructed to withstand ice pressure are provided. The gate structure is of ·ounterfort and cantilever type wall construction. A ·dway is provided to connect with the existing road ..ong the right abutment. The drainage area is 58 square miles.

For diversion and outlet purposes a 12-foot diameter horseshoe tunnel with steel liner plates and concrete lining is provided under the right abutment. The inlet of the trash rack is placed above the floor of the reservoir to keep sand and gravel out of the outlet and for fish protection.

TABLE 6.—*Navajo Dam, preliminary estimate, Jan. 30, 1937*

[Earth embankment: Top of dam elevation 8,300; normal water surface elevation 8,293; maximum water surface elevation 8,293; maximum height of dam, 120 feet. Drawing no. 253-D-40]

[Storage capacity, 50,000 acre-feet; spillway capacity, 10,000 second-feet; Diversion capacity, 3,000 second-feet; required outlet capacity 500 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion, and unwatering foundations	(1)	Lump sum		$4,000				$4,000
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	53,000	Cubic yard	$0.30	15,900			$0.30	15,900
Stripping, borrow pits	70,800	Cubic yard	.30	21,240			.30	21,240
Toe drains and cut-off trenches	97,500	Cubic yard	.40	39,000			.40	39,000
Spillway, and tunnel inlet and outlet	145,900	Cubic yard	.40	58,360			.40	58,360
Borrow, and transportation to dam	1,246,600	Cubic yard	.25	311,650			.25	311,650
Tunnel, shaft, and gate chamber	10,000	Cubic yard	7.50	75,000			7.50	75,000
Excavation, rock: Borrow, and transportation to dam	169,000	Cubic yard	.75	126,750			.75	126,750
Embankment:								
Earth fill compacted	1,324,300	Cubic yard	.10	132,430			.10	132,430
Dumped rock on downstream slope	183,700	Cubic yard	.20	36,740			.20	36,740
Riprap rock on upstream slope	43,100	Cubic yard	.40	17,240			.40	17,240
Backfill about structures	6,100	Cubic yard	.50	3,050			.50	3,050
Gravel for roadway and spillway	4,650	Cubic yard	1.25	5,813			1.25	5,813
Riprap in spillway channel	1,200	Cubic yard	.60	720			.60	720
GROUTING AND DRAINAGE								
Drilling: Weep holes	330	Linear foot	1.00	330			1.00	330
Pressure grouting: Tunnel	5,000	Cubic yard	1.00	5,000	$0.80	$4,000	1.80	9,000
Drain tile:								
·-inch diameter clay tile in gravel	1,600	Linear foot	.70	1,120	.45	720	1.15	1,840
·ich diameter clay tile in gravel	1,750	Linear foot	.60	1,050	.30	525	.90	1,575
·ch diameter clay tile in gravel	2,300	Linear foot	.50	1,150	.20	460	.70	1,610
CONCRETE WORK								
Concrete:								
Parapets and curb walls	800	Cubic yard	17.50	14,000	4.60	3,680	22.10	17,680
Trash rack and transition	90	Cubic yard	14.25	1,282	4.60	414	18.85	1,696
Below operating floor of gate chamber	300	Cubic yard	11.50	3,450	4.15	1,245	15.65	4,695
Tunnel, shaft, and gate chamber	2,800	Cubic yard	13.50	37,800	4.60	12,880	18.10	50,680
Spillway	4,750	Cubic yard	11.25	53,438	4.60	21,850	15.85	75,288
Spillway-gate structure	300	Cubic yard	10.50	[illegible]	[illegible]	2,490	14.65	[illegible]
·ontrol house	25	Cubic yard	17.50	438	4.60	115	22.10	553
·pecial finishing surfaces	1,270	Square yard	.60	762			.60	762
METALWORK								
Metal:								
Trash rack	14,000	Pound	.02	280	.08	1,120	.10	1,400
Reinforcement steel	600,000	Pound	.02	12,000	.03	18,000	.05	30,000
Spiral stairway	15,000	Pound	.05	750	.10	1,500	.15	2,250
Water stops	45	Linear foot	.25	11	.40	18	.65	29
3 17- by 16-foot radial gates and operating mechanism	85,000	Pound	.03	2,550	.09	7,650	.12	10,200
Pipe hand-railing	2,700	Pound	.10	270	.10	270	.20	540
79-inch ring-follower gate and control mechanism	81,000	Pound	.04	3,240	.24	19,440	.28	22,680
66-inch needle valve and control mechanism	66,000	Pound	.03	1,980	.22	14,520	.25	16,500
15-ton hoist	35,000	Pound	.02	700	.19	6,650	.21	7,350
Gas-electric generator set and equipment	(1)	Lump sum	(1)	200	(1)	800	(1)	1,000
Miscellaneous metalwork	5,000	Pound	.10	500	.10	500	.20	1,000
Grout and drain pipe	1,600	Pound	.05	80	.07	112	.12	192
Steel liner plates	573,000	Pound			.05	28,650	.05	28,650
79-inch steel pipe	108,000	Pound	.025	2,700	.07	7,560	.095	10,260
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)	(1)	(1)	200	(1)	800	(1)	1,000
Transporting freight except cement for Government from Chama, N. Mex., to the dam site (20.7 miles)	680	Ton	2.50	1,700			2.50	1,700
Highway construction	1	Mile	5,000	5,000			5,000	5,000
Right-of-way	1,075	Acre			50.00	53,750	50.00	53,750
Subtotal				1,006,174		209,719		1,215,893
Contingencies, 15 percent								182,384
Total estimated field cost								1,398,277
Investigations and surveys	(1)						(1)	5,000
Engineering and inspection, 5 percent								69,913
Superintendence and accounts, 1 percent								13,982
General expense, 2 percent								27,966
Total estimated cost								1,515,138
Cost per acre-foot of storage								30.30

[1] ·p sum.

A gate chamber containing a single 79-inch ring follower emergency gate is placed in the tunnel at the axis of the dam. A 79-inch steel pipe leads downstream in the tunnel to a single 66-inch needle valve. The needle valve discharges into the tunnel, which in turn discharges into the stilling basin. A spiral stairway connects the control house on the surface with the needle valve chamber. The valve chamber contains one 66-inch needle valve with the necessary pumps, piping, cranes, etc., required for operation. It is planned to install a gas-electric set in the control house to supply energy for the operation of the valves and spillway gates and to provide lighting.

Construction.—It will require approximately 2½ years to complete this dam and appurtenant works.

There is no local power available for construction purposes. The nearest railroad shipping point is Chama, N. Mex., on the narrow gage line from Alamosa to Durango, a distance of 20.7 miles over a dry weather road.

Boulder Lake Reservoir

Boulder Lake dam site is located about five miles south of Hillcrest, N. Mex., in the Jicarilla Apache Indian Reservation. The reservoir site is entirely on Government land under the supervision of the United States Indian Service.

This is an alternative site for Stinking Lake Reservoir. It has been adopted temporarily as a terminal reservoir for plan A of the San Juan-Chama Canal in this report because of its cheaper first cost, although further studies may show the desirability of using Stinking Lake Reservoir. A storage capacity of 290,000 acre-feet is required for regulation of waters brought in by the San Juan-Chama Canal to fit irrigation demands in the event sufficient reregulation is not secured at El Vado and Elephant Butte Reservoirs.

Summary of estimate data:

Storage capacity	290,000 acre-feet.
Spillway capacity	Emergency only.
Outlet capacity	2,000 second-feet.
Elevation—top of dam	7,313.
Maximum reservoir water-surface elevation	7,305.
Maximum height of dam	138 feet.
Total estimated cost—dam and reservoir	$1,350,000.
Topography of reservoir and geologic sections	Figure 115.
General plan and sections	Figure 116.
Preliminary estimate	Table 7.

The reservoir area at elevation 7,305 is 4,750 acres, of which the present lake area is 250 acres. No clearing will be required on the reservoir area. There are no improvements.

Geological summary.—The regional and basin geological conditions have not been studied in detail. Inspection shows the valley to be the result of imposed or antecedent erosion on a bedrock complex of tilted sandstones and alternating shales. The drainage pattern has been inherited from that originally prese[illegible] on overlying, horizontal, tertiary sandstones, n[illegible] entirely removed by erosion. The reservoir is underlain by compact shales of the Lewis Formation that overlie the same massive sandstones (Mesa Verde) which are found at the dam site. The rocks dip upstream, or 6° NW., strike N. 15° E. The compact impervious shale and the presence of the existing lake, suggest that the ground water is tributary to the stream and that no appreciable reservoir seepage is to be expected. The entire basin is heavily mantled with detrital silts so that bedrock is rarely observed. The sides of the valley also are covered with erratic talus or wash deposits depending upon the erosional form and the character of the bedrock.

In all probability, no unusual or serious problems would be encountered by an exploratory program. The bedrock is made up of a stratigraphic column of massive sandstone and alternating shale seams and beds of the Mesa Verde formation, which in this locality strike N. 15° E. and dip 6° NW. On account of this dip, the rocks become progressively more shaly both up and downstream from the proposed axis. The rock is somewhat fractured and jointed, so that some grouting may be required, but there is no evidence of any faulting. The rock on the abutments is similar. the strike extending undisturbed across the strea[illegible] The dip is a favorable feature, since water percolati[illegible] along the bedding planes would be forced eventually to cross the beds to continue any movement downstream. The overburden condition of most importance to the dam site is found in the deep foundation silts, below the stream bed. The intermittent character of this stream has resulted in a partial back-filling of debris, which from surface exposures appears to be largely silt with occasional rock fragments. This silt may prove to be excessively deep (50–100 ft.), which, together with any tendency to become plastic on saturation, may allow considerable settlement and possible flowage.

There is no question as to the stability and imperviousness of the bedrock but some attention should be given to the fissle character of the interbedded shales and allowances made for possible dehydration and resultant surface disintegration.

Dam.—The compacted embankment type of dam was selected for this site due to excessive hauling distance for concrete materials and the close proximity of sufficient embankment materials. Although the greater portion of the site shows sandstone outcroppings, the central portion is overlain with silts and the underlying rock is at unknown depths. Location of sand and gravel deposits are uncertain but are thought to available about 10 miles from the site, for the limited amount of concrete necessary and are so assumed. bankment materials can probably be found in :by silt deposits. Figure 116 shows the general plan and sections of the proposed dam.

The dam is 825 feet long at the crest and attains a maximum height of 138 feet.

The typical embankment section as shown on the drawings consists of a 35-foot top width at elevation 7,313 carrying a graveled roadway and with typical

TABLE 7.—*Boulder Lake Dam, preliminary estimate Jan. 30, 1937*

[Earth embankment: Top of dam elevation 7,313; normal water surface, elevation 7,305; maximum water surface, elevation 7,305; maximum height of dam, 138 feet; drawing no 253-D-42]

[Storage capacity, 290,000 acre-feet; spillway capacity, emergency only; diversion capacity, none; required outlet capacity, 2,000 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	35,500	Cubic yard	$0.30	$10,650			$0.30	$10,650
Stripping, borrow pits	144,000	Cubic yard	.30	43,200			.30	43,200
Toe drains and cut-off trenches	23,500	Cubic yard	.40	9,400			.40	9,400
Tunnel inlet and outlet	23,900	Cubic yard	.40	9,560			.40	9,560
Borrow, and transportation to dam	1,314,000	Cubic yard	.25	328,500			.25	328,500
Excavation, rock:								
Cut-off wall	110	Cubic yard	4.00	440			4.00	440
Tunnel inlet and outlet channel	2,500	Cubic yard	2.50	6,250			2.50	6,250
Borrow, and transportation to dam	128,800	Cubic yard	.75	96,600			.75	96,600
Outlet tunnel and shaft	10,100	Cubic yard	10.00	101,000			10.00	101,000
Embankment:								
Earth fill compacted	1,179,295	Cubic yard	.10	117,930			.10	117,930
Dumped rock on downstream slope	161,200	Cubic yard	.20	32,240			.20	32,240
Riprap rock on upstream slope	27,100	Cubic yard	.40	10,840			.40	10,840
Riprap rock in outlet channel	360	Cubic yard	.40	144			.40	144
Gravel for roadway	1,400	Cubic yard	2.50	3,500			2.50	3,500
Backfill about structures	100	Cubic yard	.50	50			.50	50
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 25 feet deep	11,100	Linear feet	1.00	11,100			1.00	11,100
Weep holes	200	Linear feet	1.00	200			1.00	200
Pressure grouting: Tunnel, shaft, and cut-off wall	20,000	Cubic yards	1.00	20,000	$0.80	$16,000	1.80	36,000
Drain tile:								
12-inch diameter clay tile in gravel	500	Linear feet	.70	350	.45	225	1.15	575
'uch diameter clay tile in gravel	1,200	Linear feet	.60	720	.30	360	.90	1,080
·ch diameter clay tile in gravel	750	Linear feet	.50	375	.20	150	.70	525
.ch split tile for spillway	600	Linear feet	.30	180	.20	120	.50	300
CONCRETE WORK								
Concrete:								
Cut-off wall not formed	80	Cubic yard	11.00	880	4.15	332	15.15	1,212
Cut-off wall formed	230	Cubic yard	12.50	2,875	4.60	1,058	17.10	3,933
Parapets and curb walls	320	Cubic yard	18.50	5,920	4.60	1,472	23.10	7,392
Trash rack, transition, and stilling basin	450	Cubic yard	15.75	7,087	4.60	2,070	20.35	9,157
Below operating floor of gate chamber	630	Cubic yard	13.00	8,190	4.15	2,614	17.15	10,804
Tunnel shaft and gate chamber	2,700	Cubic yard	15.00	40,500	4.15	11,205	19.15	51,705
Special finishing concrete surfaces	550	Square yard	.60	330			.60	330
Control house	20	Cubic yard	20.25	405	4.60	92	24.85	497
METALWORK								
Metal:								
Trash rack	50,000	Linear foot	.02	1,000	.08	4,000	.10	5,000
Reinforcement steel	168,000	Pound	.02	3,360	.03	5,040	.05	8,400
Spiral stairway	21,700	Pound	.05	1,085	.10	2,170	.15	3,250
Water stops	120	Linear foot	.25	30	.40	48	.65	75
Gate-chamber stairway	1,200	Pound	.05	60	.10	120	.15	188
Pipe hand-railing	1,120	Pound	.10	112	.10	112	.20	220
2 79-inch ring-follower gates and control mechanism	164,000	Pound	.04	6,560	.24	39,360	.28	45,920
2 66-inch needle valves and control mechanism	140,000	Pound	.03	4,200	.22	30,800	.25	35,000
15-ton hoist	35,000	Pound	.02	700	.19	6,650	.21	7,350
Gas-electric generator set and equipment	[1]		[1]	200	[1]	800	[1]	1,000
Miscellaneous items	2,000	Pound	.10	200	.10	200	.20	400
Grout and drain pipe	3,700	Pound	.05	185	.07	259	.12	444
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	[1]		[1]	300	[1]	1,200	[1]	1,500
Transporting freight except cement for Government from Dulce, N. Mex., to dam site (20 miles).	304	Ton	2.20	669			2.20	669
Highway construction	3	Mile	10,000.00	30,000			10,000.00	30,000
Right-of-way	3,000	Acre			10.00	30,000	10.00	30,000
Emergency spillway in saddle		[1]	[1]	5,000			[1]	5,000
Subtotal				923,077		156,457		1,079,534
Contingencies, 15 percent								161,930
Total estimated field cost								1,241,464
Investigations and surveys	[1]						[1]	5,000
Engineering and inspection, 5 percent								62,073
Superintendence and accounts, 1 percent								12,415
General expense, 2 percent								24,829
Total estimated cost								1,345,781
Cost per acre foot of storage								4.64

ump sum.

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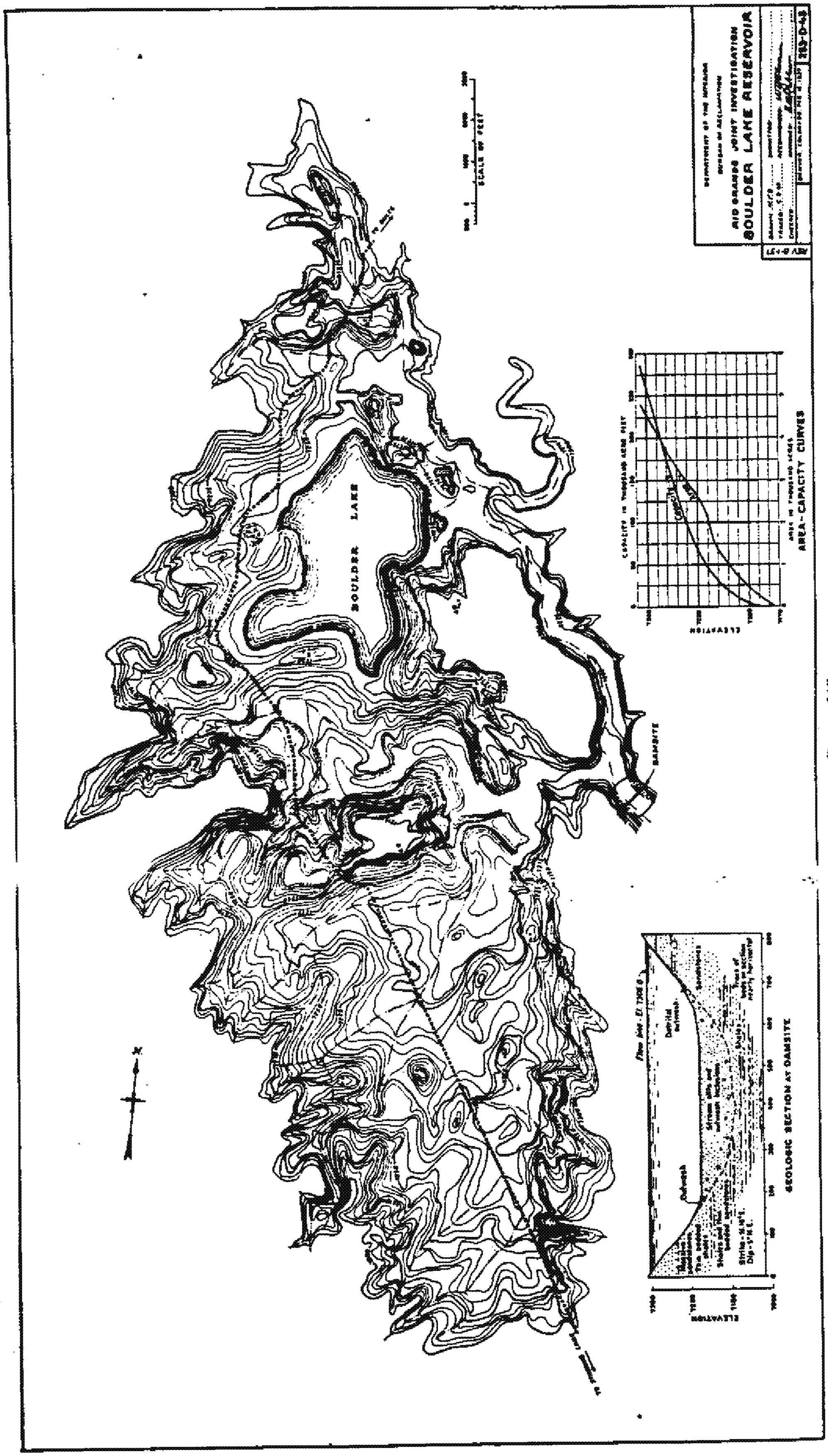
RIO GRANDE JOINT INVESTIGATION
BOULDER LAKE RESERVOIR
SCALE OF FEET
BOULDER LAKE
DAMSITE
AREA-CAPACITY CURVES
ELEVATION
GEOLOGIC SECTION AT DAMSITE

FIGURE 115

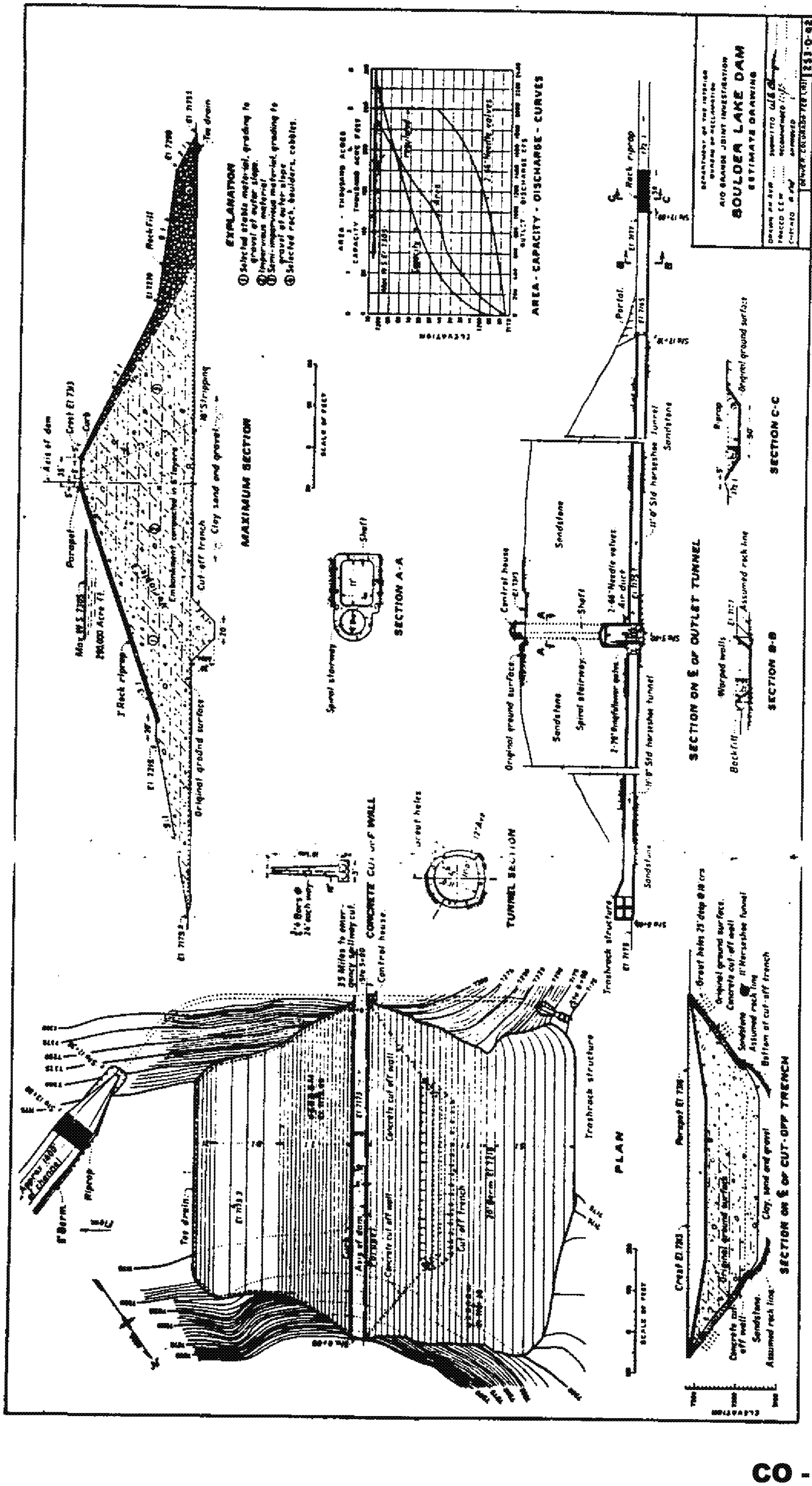
MAXIMUM SECTION
EXPLANATION
AREA - CAPACITY - DISCHARGE - CURVES
SECTION A-A
TUNNEL SECTION
SECTION ON ℄ OF OUTLET TUNNEL
SECTION B-B
SECTION C-C
PLAN
SECTION ON ℄ OF CUT-OFF TRENCH
BOULDER LAKE DAM
ESTIMATE DRAWING

FIGURE 116

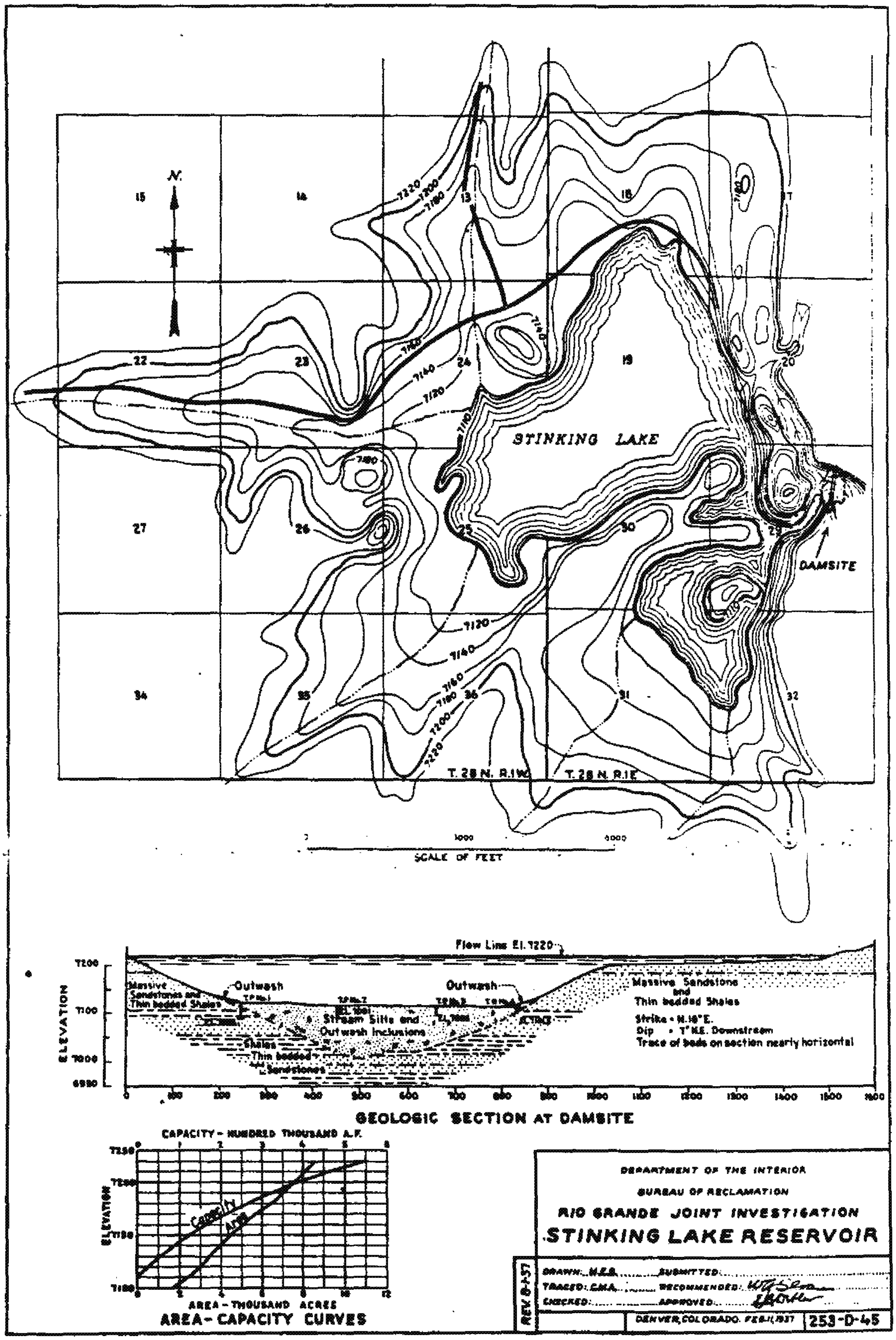
N.
STINKING LAKE
DAMSITE
T. 28 N. R.1 W.
T. 28 N. R.1 E.
SCALE OF FEET
Flow Line El. 7220
Massive Sandstones and Thin bedded Shales
Outwash
Stream Silts and Outwash Inclusions
Shales Thin bedded Sandstones
Massive Sandstone and Thin bedded Shales
Strike = N.18°E.
Dip = 7° N.E. Downstream
Trace of beds on section nearly horizontal
ELEVATION
GEOLOGIC SECTION AT DAMSITE
CAPACITY - HUNDRED THOUSAND A.F.
Capacity
Area
AREA - THOUSAND ACRES
AREA - CAPACITY CURVES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
STINKING LAKE RESERVOIR
DRAWN: M.E.S.
SUBMITTED:
TRACED: C.M.A.
RECOMMENDED:
CHECKED:
APPROVED:
DENVER, COLORADO, FEB. 1, 1937
253-D-45

FIGURE 117

concrete parapets and curbs. The upstream slope is 3:1 with 3 feet of rock riprap. A 20-foot berm is placed ·levation 7,215 and a 5:1 slope from there down. downstream slope is 2:1 to elevation 7,220, 8:1 to elevation 7,200, and 2:1 for the remainder of the rock-fill section. A typical concrete cut-off with a maximum height of 10 feet, extends upward along both abutments of the rock slopes connecting with a 30-foot cut-off trench in the deep stream wash materials in the central portion. Stripping for a depth of 18 inches is provided over the entire dam area. Depth to bedrock under the dam across the channel has not been determined, and for this reason a 30-foot deep cut-off trench was assumed. Should further investigations disclose shallow depths to bedrock the estimated cost may be somewhat reduced.

An emergency spillway located on a saddle about 3½ miles from the dam site was estimated as a lump-sum item. No data are available on this feature. The drainage area does not exceed 15 square miles.

An 11-foot diameter concrete-lined horseshoe tunnel will serve as an outlet tunnel only and for stream diversion during the construction period. It is planned to install two 79-inch diameter ring follower emergency gates and two 66-inch needle valves for outlet operation, in the gate chamber. An 8- by 11-foot concrete-lined shaft, with a 6-foot diameter concrete spiral ·way shaft, will extend from the control chamber e top of the dam, where the shaft is surmounted by control house, provided with a 15-ton hoist. It is planned to install a gas-electric generator set in the control house for lighting and operating purposes. At the upstream end of the tunnel the trash rack structure is placed at the bottom of the tunnel inlet, there being sufficient capacity below this elevation to allow for reservoir silting. The outlet end of the tunnel discharges into the stilling basin and from there into a 50-foot bottom width canal section some 1,400 feet long.

It will require approximately two seasons to construct this dam. The nearest railroad shipping point is at Dulce, N. Mex., a distance of 20 miles over fair roads. About 3 miles of new road will be required to reach the dam.

Stinking Lake Reservoir

Stinking Lake dam site is located about 9 miles west of El Vado, N. Mex., in the Jicarilla Apache Indian Reservation. It is 33 miles via highway from the nearest railroad shipping point, Chama, N. Mex., all but 8 miles of which is improved and graveled. The reservoir is entirely in Government land under the supervision of the United States Indian Service. Data designs on this dam are here included since it may ually be chosen as a terminal reservoir in place of Boulder Lake Reservoir in the event plan A is adopted.

Summary of estimate data:

Storage capacity—active	500,000 acre-feet.
Spillway capacity	Emergency only.
Outlet capacity at low levels	1,000 second-feet.
Elevation—top of dam	7,230.
Reservoir water-surface elevation	7,220.
Maximum height of dam	115 feet.
Total estimated cost—dam and reservoir	$1,400,000.
Topography of reservoir and geologic sections	Figure 117.
General plan and sections	Fig. 118.
Preliminary estimate	Table 8.

The reservoir area at elevation 7,220 is 8,500 acres, all located in the Indian reservation. No clearing will be required in the reservoir area. No improvements exist.

Geology.—There has been no opportunity to study in detail the regional geology or the immediate valley conditions. Inspection has shown that the present stream pattern is the result of antecedent or imposed erosion. The gaps forming the dam sites at Stinking and Boulder Lakes are unusual topographic features.

The reservoir basin is underlain by shales and soft sandstones, the same as those in the Boulder Lake Basin. They overlie the more massive sandstone at the dam site but are part of the same series. All rock is heavily mantled with detrital silts, in which the present lake is found. The strata strike N. 18° E. and dip 5°–7° NW. The water table is believed to be tributary to the stream, considering the character of the bedrock and the presence of the existing lake.

There is no reason to suspect unusual or unsatisfactory dam site conditions to develop in an exploratory program other than considerable depth of foundation silts in the stream bed. One test pit near the right abutment encountered sandstone at 8½ feet. Due to the intermittent stream character the canyon has partially filled with detrital wash and stream silts, which, from logs of test pits 1, 2, 3, and 4, appear to be predominantly silt with some boulders and rock fragments The sides of the canyon are irregularly covered with talus and wash which becomes progressively deeper toward the toe of the slopes.

The dam site is a canyon carved in massive sandstone with alternating shale layers. The rock becomes progressively more shaly both up and downstream from the immediate proposed dam axis. The dip is a fortunate occurrence insofar as seepage must pass through the beds rather than circulate along bedding planes. The rock is somewhat fractured, a condition accentuated by surface weathering, so that some grouting may be required. No faulting was noted in the area and no soluble salt seams were noted in the stratigraphic column.

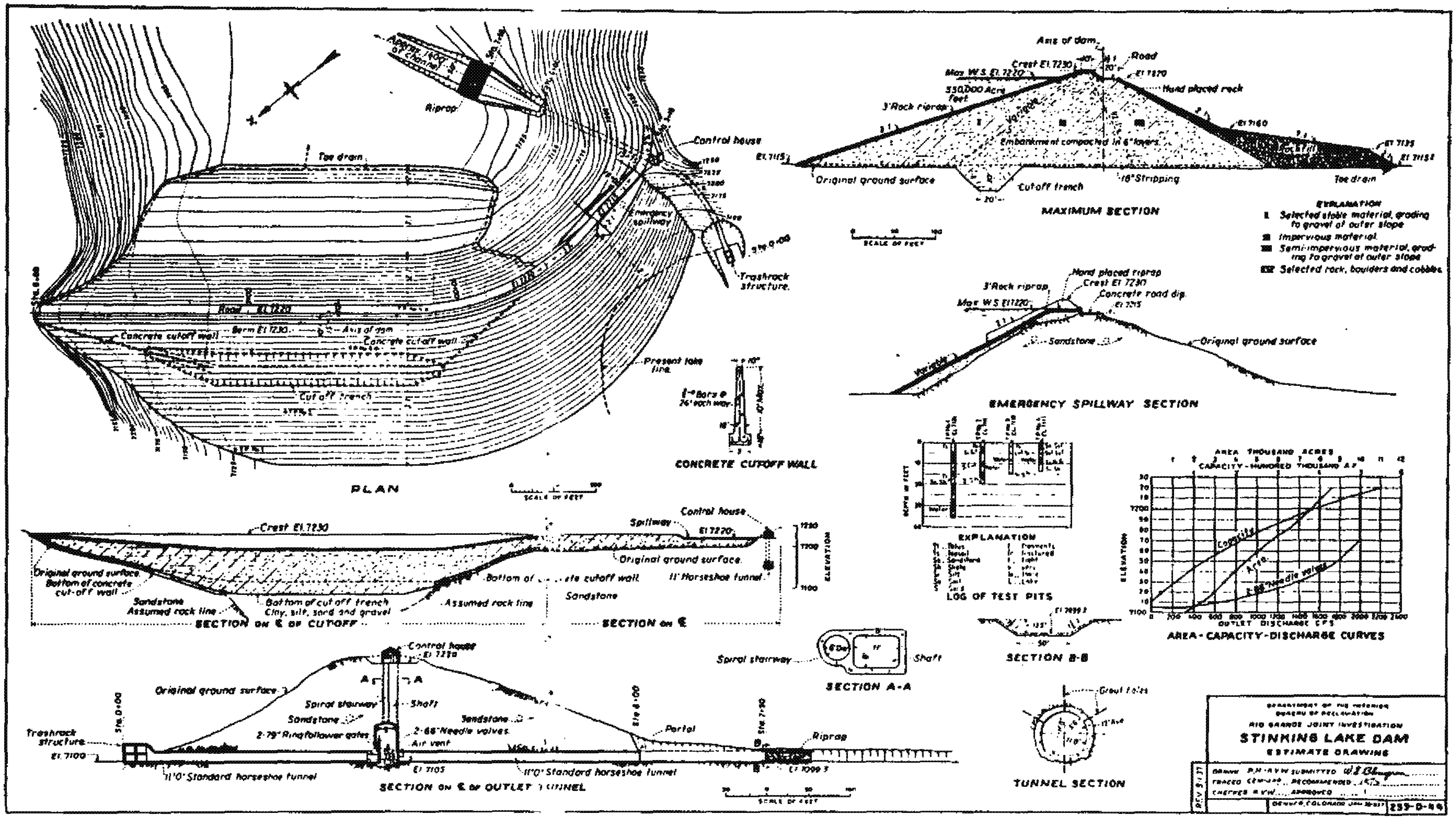
PLAN
Toe drain
Riprap
Control house
Emergency spillway
Trashrack structure
Road El. 7220
Berm El. 7230
Axis of dam
Concrete cutoff wall
Cut off trench
Present lake line
CONCRETE CUTOFF WALL
MAXIMUM SECTION
Axis of dam
Road
Crest El. 7230
Max. W.S. El. 7220
550,000 Acre feet
3' Rock riprap
Hand placed rock
Embankment compacted in 6" layers
Original ground surface
Cutoff trench
18" Stripping
Toe drain
EXPLANATION
Selected stable material, grading to gravel at outer slope
Impervious material
Semi-impervious material, grading to gravel at outer slope
Selected rock, boulders and cobbles
SCALE OF FEET
Hand placed riprap
Crest El. 7230
Concrete road dip
3' Rock riprap
Max. W.S. El. 7220
Sandstone
Original ground surface
EMERGENCY SPILLWAY SECTION
LOG OF TEST PITS
EXPLANATION
AREA THOUSAND ACRES
CAPACITY - HUNDRED THOUSAND A.F.
Capacity
Area
2-66" Needle valves
OUTLET DISCHARGE C.F.S.
AREA-CAPACITY-DISCHARGE CURVES
Crest El. 7230
Original ground surface
Bottom of concrete cut-off wall
Sandstone
Assumed rock line
Bottom of cut off trench
Clay, silt, sand and gravel
Assumed rock line
SECTION ON ℄ OF CUTOFF
Control house
Spillway
El. 7220
Original ground surface
11' Horseshoe tunnel
Sandstone
SECTION ON ℄
ELEVATION
Spiral stairway
Shaft
SECTION A-A
SECTION B-B
Control house
El. 7230
Original ground surface
Spiral stairway
Shaft
Sandstone
2-79" Ringfollower gates
2-66" Needle valves
Air vent
Trashrack structure
El. 7100
11'0" Standard horseshoe tunnel
El. 7105
11'0" Standard horseshoe tunnel
Portal
Riprap
SECTION ON ℄ OF OUTLET TUNNEL
Grout holes
TUNNEL SECTION
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
STINKING LAKE DAM
ESTIMATE DRAWING
DENVER, COLORADO
253-D-44

Figure 118

There is no question as to the stability of the bedrock. The stream silts, however, are moderately us and may upon saturation become soft and tic. It may become necessary to remove those entirely under the dam.

Dam.—The compacted embankment type of dam was selected. It is estimated that embankment materials in adequate amount are available about 1 mile downstream from the site. Sources of sand and gravel are uncertain but they are thought to be available about 10 miles from the site, for the limited amount of concrete necessary for this dam. Figure 118 shows the general plan and sections of the proposed dam.

TABLE 8.—*Stinking Lake Dam, preliminary estimate, Jan. 30, 1937*

[Earth embankment: Top of dam, elevation 7,230; normal water surface, elevation 7,220; maximum water surface, elevation 7,220; maximum height of dam, 115 feet; drawing no. 253-D-44]

[Storage capacity, 550,000 acre-feet; spillway capacity, emergency only; diversion capacity, none; required outlet capacity, 2,000 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	46,100	Cubic yard	$0.30	$13,830			$0.30	$13,830
Stripping, borrow pits	68,000	Cubic yard	.30	20,400			.30	20,400
Toe drains and cut-off trenches	32,100	Cubic yard	.40	12,840			.40	12,840
Tunnel inlet and outlet channel	28,500	Cubic yard	.40	11,400			.40	11,400
Borrow, and transportation to dam	1,319,200	Cubic yard	.25	329,800			.25	329,800
Excavation, rock:								
Cut-off wall	120	Cubic yard	4.00	480			4.00	480
Tunnel inlet and outlet channel	7,600	Cubic yard	2.50	19,000			2.50	19,000
Outlet tunnel and shaft	3,500	Cubic yard	10.00	35,000			10.00	35,000
Borrow, and transportation to dam	158,800	Cubic yard	.75	119,100			.75	119,100
Embankment:								
Earth fill compacted	1,221,100	Cubic yard	.10	122,110			.10	122,110
Dumped rock on downstream slope	175,000	Cubic yard	.20	35,000			.20	35,000
Riprap rock on upstream slope	53,500	Cubic yard	.40	21,400			.40	21,400
Backfill about structures	500	Cubic yard	.50	250			.50	250
Gravel for roadway	1,000	Cubic yard	2.50	2,500			2.50	2,500
Hand-placed rock	1,500	Cubic yard	1.00	1,500			1.00	1,500
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 25 feet deep	4,300	Linear foot	1.00	4,300			1.00	4,300
ain holes	1,000	Linear foot	1.00	1,000			1.00	1,000
sp holes	200	Linear foot	1.00	200			1.00	200
e grouting: Tunnel, shaft, and cut-off wall	10,400	Cubic foot	1.00	10,400	$0.80	$8,320	1.80	18,720
dle:								
2-inch diameter clay tile in gravel	2,200	Linear foot	.70	1,540	.45	990	1.15	2,530
8-inch diameter clay tile in gravel	600	Linear foot	.60	360	.30	180	.90	540
6-inch diameter clay tile in gravel	700	Linear foot	.50	350	.20	140	.70	490
4-inch split tile	600	Linear foot	.30	180	.20	120	.50	300
CONCRETE WORK								
Concrete:								
Cut-off wall not formed	120	Cubic yard	11.25	1,350	4.15	498	15.40	1,848
Cut-off wall formed	300	Cubic yard	13.00	3,900	4.60	1,380	17.60	5,280
Curbs and emergency spillway	445	Cubic yard	15.00	6,675	4.15	1,847	19.15	8,522
Trash rack, transition, and stilling basin	450	Cubic yard	16.00	7,200	4.60	2,070	20.60	9,270
Below operating floor of gate chamber	630	Cubic yard	13.25	8,348	4.15	2,614	17.40	10,962
Tunnel, shaft, and gate chamber	1,620	Cubic yard	15.25	24,705	4.15	6,723	19.40	31,428
Control house	20	Cubic yard	20.75	415	4.60	92	25.35	507
METALWORK								
Metal:								
Trash rack	50,000	Pound	.02	1,000	.08	4,000	.10	5,000
Reinforcement steel	302,000	Pound	.02	6,040	.03	9,060	.05	15,100
Spiral stairway	20,100	Pound	.05	1,005	.10	2,010	.15	3,015
Water stops	120	Linear foot	.25	30	.40	48	.65	78
2 79-inch ring-follower gates and control mechanism	164,000	Pound	.04	6,560	.24	39,360	.28	45,920
2 66-inch needle valves and control mechanism	140,000	Pound	.03	4,200	.22	30,800	.25	35,000
15-ton hoist	35,000	Pound	.02	700	.19	6,650	.21	7,350
Gas-electric generator set and equipment	[1]	[1]	[1]	200	[1]	800	[1]	1,000
Miscellaneous metalwork	3,500	Pound	.10	350	.10	350	.20	700
Grout and drain pipe	2,400	Pound	.05	120	.07	168	.12	288
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	[1]	[1]	[1]	300	[1]	1,200	[1]	1,500
Transporting freight except cement for Government from Chama, N. Mex., to the dam site (33 miles).	360	Ton	3.30	1,188			3.30	1,188
Highway construction	8	Mile	10,000.00	80,000			10,000.00	80,000
Right-of-way	8,500	Acre			10.00	85,000	10.00	85,000
Subtotal				917,226		204,420		1,121,646
Contingencies, 15 percent								168,247
Total estimated field cost								1,289,893
Investigations and surveys	[1]						[1]	5,000
Engineering and inspection, 5 percent								64,494
Superintendence and accounts, 1 percent								12,899
General expense, 2 percent								25,798
Total estimated cost								1,398,084
Cost per acre-foot of storage								2.54

np sum.

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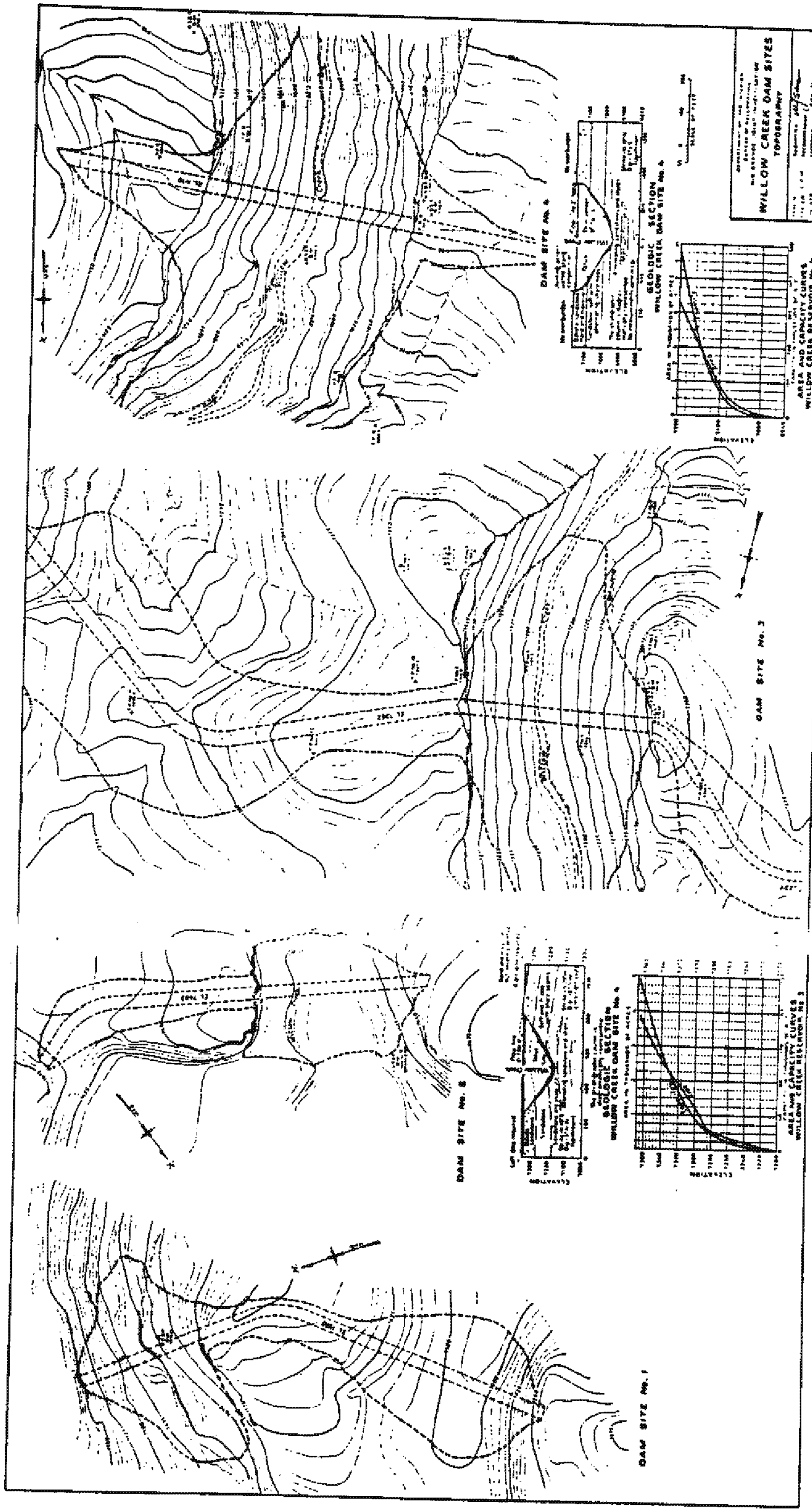
WILLOW CREEK DAM SITES
TOPOGRAPHY
DAM SITE No. 4
DAM SITE No. 3
DAM SITE No. 2
DAM SITE No. 1
GEOLOGIC SECTION
AREA AND CAPACITY CURVES

FIGURE 119

The dam is 1,560 feet long at the crest and attains a maximum height of 115 feet. The dam has a free-rd of 10 feet with a top width of 30 feet, of which eet only is at the very top. The balance is a 20-ioot graveled roadway on a back slope berm at water level elevation 7,220. The upstream slope is 3 : 1 on the main portion of the dam and 2 : 1 on the right-hand blanket section below the emergency spillway, overlain with 3 feet of rock riprap. The downstream slope is 2 : 1 to elevation 7,160, 7 : 1 to elevation 7,135, and 2 : 1 for the remainder of the rock-fill section. A typical concrete cut-off wall, with a maximum height of 10 feet, extends along both abutments of the rock slope, connecting with a 30-foot depth cut-off trench in the deep overlying earth material in the central portion. Stripping for a depth of 18 inches was estimated over the entire dam area.

It is doubtful whether the reservoir water surface will ever rise above elevation 7,220, but as an added safety factor an emergency spillway 100 feet long at elevation 7220 was located in the right abutment section. The roadway in this section was made of concrete and the dam slopes paved with hand-placed riprap.

An 11-foot diameter concrete-lined horseshoe tunnel will serve as an outlet tunnel only. No diversion will be required during construction and the entrance to outlet structure is above the present water surface e lake. It is planned to install two 79-inch di-eter ring follower emergency gates and two 66-inch needle valves for outlet control and operation in the tunnel gate chamber. An 8-foot by 11-foot concrete-lined shaft containing a 6-foot diameter concrete spiral stairway shaft will extend from the control chamber to the top of the dam, where the shaft is surmounted by a control house equipped with a 15-ton hoist. It is planned to install a gas-electric generator set in the control house for lighting and operation purposes.

At the upstream end of the tunnel the trash-rack structure is placed at the bottom of the tunnel inlet, there being sufficient capacity below this elevation to allow for reservoir silting. The outlet end of the tunnel discharges into the stilling basin and from there into a 50-foot bottom width canal section some 1,400 feet long.

Construction.—It will require approximately two construction seasons to construct this dam.

The nearest railroad shipping point is at Chama, N. Mex., on the narrow gage Denver & Rio Grande Western Railroad Co. line from Alamosa to Durango, a distance of 33 miles over fair roads.

Power Development on Chama River

ture utilization of the water delivered by the San -Chama diversion is not known at present. Preliminary studies indicate that a terminal storage capacity of 300,000 acre-feet would enable deliveries into the Chama River, averaging 350,000 acre-feet, to be regulated to irrigation demands from 1911 to date without shortage.

Sufficient terminal storage capacity is available in Boulder Lake for such reregulation with plan A. Elevation of the outlet portal of the tunnel above the reservoir is 7,401 and high water level in Boulder Lake is 7,305. The outlet of Boulder Lake is 7,175. A minimum head of 96 feet can thus be used for power above Boulder Lake but for 2 months of the year no water could be delivered. There would also be severe fluctuations from year to year with considerable fluctuations from month to month. The average head available at Boulder Lake Dam would probably be about 90 feet. Thus only 180 feet of the total fall between the end of the diversion canal and El Vado Reservoir can be utilized for power.

If Stinking Lake is used for a terminal reservoir instead of Boulder Lake only about 150 feet of total fall can be made available for power above El Vado.

Elevation of the divide tunnel portal on the "B" plan is 7,575 or 174 feet higher than on the "A" plan. Surveys on Willow Creek below the portal and above El Vado Reservoir show four reservoir possibilities as follows:

Name	Maximum storage capacity acre-feet	Estimated cost of dam and reservoir only
Chama (no. 1)	40,000	$575,000
Parkview (no. 2)	20,000	375,000
Upper Willow Creek (no. 3)	164,000	1,850,000
Lower Willow Creek (no. 4)	239,000	1,900,000
Total	[illegible]63,000	[illegible]4,700,000

For irrigation use only, either of the Willow Creek sites is probably sufficient for reregulation of the diverted waters with only minor shortages in low years. The cost per acre-foot for terminal storage will be higher than for an equivalent amount of reregulation on the "A" plan.

For the dual purpose of power and irrigation, "B" plan offers the more interesting possibilities, especially when power and storage opportunities below El Vado are also considered.

The lower Willow Creek Reservoir sites (nos. 3 and 4) have been surveyed by the United States Geological Survey and detailed surveys of the dam sites were made by the Bureau. The Chama and Parkview (nos. 1 and 2) dam sites were mapped by the Bureau but storage capacity was not determined as the reservoirs are small and would be kept full to maintain power head. No drilling has been done at any of the sites but geological reconnaissances at each of them have shown favorable conditions.

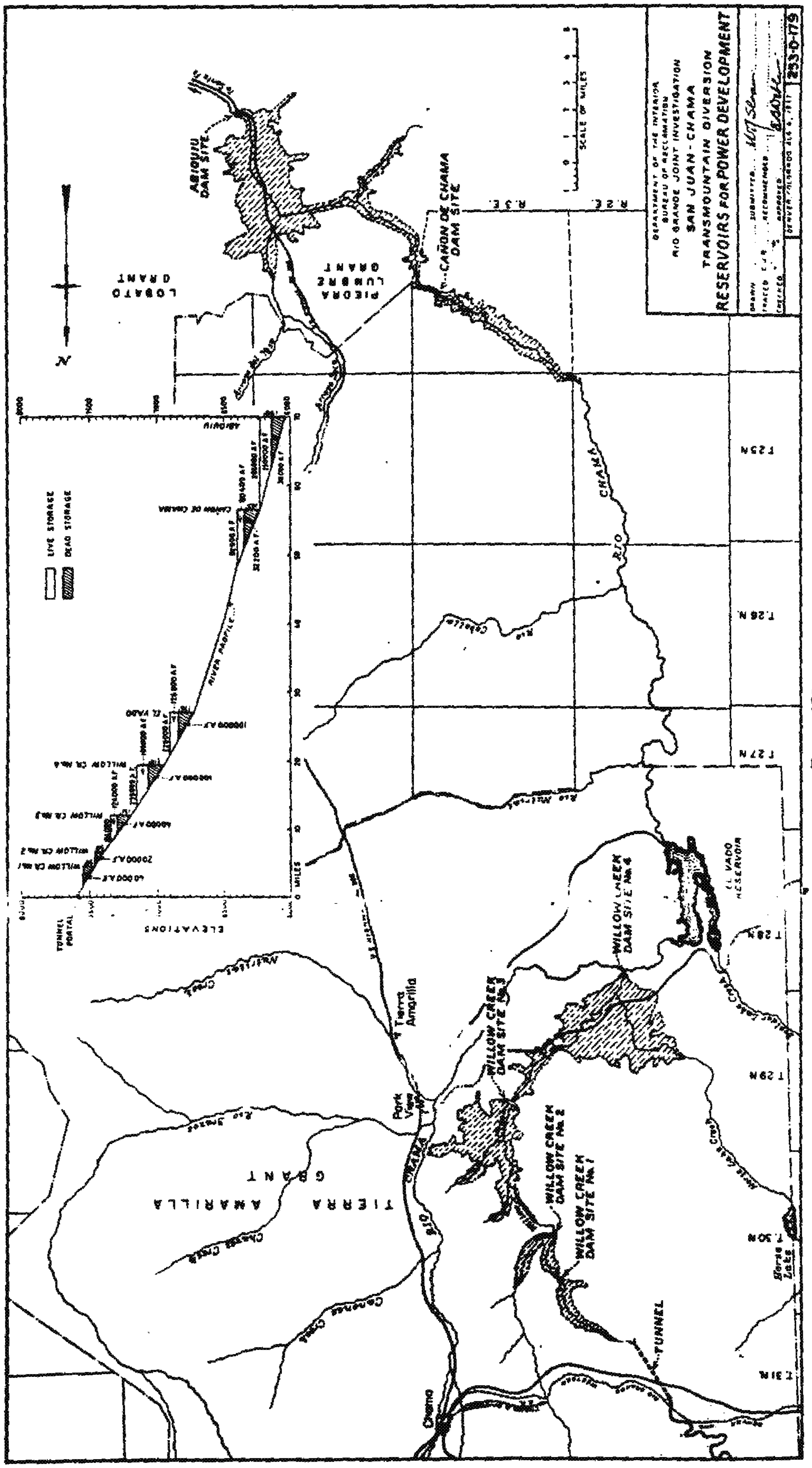
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
SAN JUAN - CHAMA
TRANSMOUNTAIN DIVERSION
RESERVOIRS FOR POWER DEVELOPMENT
SCALE OF MILES
ABIQUIU DAM SITE
CAÑON DE CHAMA DAM SITE
PIEDRA LUMBRE GRANT
LOBATO GRANT
RIO CHAMA
EL VADO RESERVOIR
WILLOW CREEK DAM SITE No. 4
WILLOW CREEK DAM SITE No. 3
WILLOW CREEK DAM SITE No. 2
WILLOW CREEK DAM SITE No. 1
TUNNEL
TIERRA AMARILLA GRANT
Tierra Amarilla
Park View
Chama
LIVE STORAGE
DEAD STORAGE
ELEVATIONS
TUNNEL PORTAL
RIVER PROFILE
MILES

Figure 120

Power output at the Willow Creek sites can be increased by diversion of the Chama River at Chama Willow Creek above the Parkview (no. 2) Reser- A fly line for this diversion was surveyed and the diversion cost estimated at $190,000 for a canal of 500 second-feet capacity, 3.2 miles long.

Development at and below El Vado Reservoir.—A reconnaissance of the Chama River below El Vado Reservoir shows two additional power and storage possibilities, as follows:

Name	Maximum storage capacity acre-feet	Estimated cost for dam and reservoir only	Maximum head in feet
Abiquiu site	286,000	$3,339,800	190
Canon De Chama site	92,600	2,500,000	165
El Vado Reservoir [1]	226,000		176
Total	604,600	$5,839,800	531

[1] Constructed.

These reservoir sites have been surveyed by the United States Geological Survey. The Bureau surveyed the Abiquiu dam site in detail and rough estimates of cost were prepared. The cost of the Canon de Chama Reservoir has been estimated by comparison with the other sites. Two geological reports are available on the Abiquiu site, both of which indicate favorable conditions for a dam of the proposed height. No ···logical reports are available on the Canon de Chama No drilling was done at either site. Figure 120 general map of the Chama watershed showing potential power development. Figure 121 shows topography at the Abiquiu and Canon de Chama sites.

Total power possibilities on Willow Creek and Chama River.—Potential power output has been calculated by using all of the reservoirs above described including the Chama River diversion to Willow Creek.

Data for power studies

Reservoir	Capacity, acre-feet			Head in feet	
	Total	Active	Dead	Maximum	Minimum
Willow Creek No. 1 (Chama)	40,000	0	40,000	90	90
Willow Creek No. 2 (Parkview)	30,000	0	30,000	50	50
Willow Creek No. 3	164,000	124,000	40,000	151	103
Willow Creek No. 4	239,000	199,000	40,000	210	129
El Vado	226,000	126,000	100,000	176	130
Canon de Chama	92,600	60,400	32,200	165	120
Abiquiu	286,000	250,000	36,000	190	98
Total	1,067,600	759,400	308,200	1,032	720

Estimated mean annual controlled flow:
Chama River at Abiquiu .... acre-feet .. 320,000
San Juan-Chama Diversion .... do .. 320,800

Total .... do .. 640,800
Equivalent flow .... second-feet .. 885

Mass curves of the reconstructed flow at Abiquiu from 1916 to date indicate that the flow of 885 second- can be maintained prior to 1931 with very little ge regulation and with large blocks of secondary power available every year. The critical period from 1931 to early in 1936 has been studied in more detail, a summary of which is shown in the following table.

The studies indicate a firm power output of 250,000,000 kilowatt-hours per year with an average output of 400,000,000 kilowatt-hours per year over long periods.

Effect of power regulation of Chama River on irrigation supply for Rio Grande.—If the Chama River and San Juan waters are regulated for power only in accordance with the schedule shown in table 9, the mean monthly flow below Abiquiu Reservoir becomes approximately 53,000 acre-feet in minimum years. The maximum monthly irrigation demand for the Middle Rio Grande Conservancy District is about 100,000 acre-feet. With Rio Grande modified only to the extent of such a modification at the Abiquiu dam site, the resulting flows would at practically all times equal or exceed the diversion requirements for the Middle Rio Grande Conservancy District. The minor modifications needed to fully meet such requirements would not materially affect power output.

TABLE 9.—*Summary of power production—Chama River—Period 1931–35, inclusive*

Date	Outflow from Abiquiu River in 1,000 acre-feet	Power output in million kilowatt-hours by all plants [1]		
		Primary	Secondary	Total
(1)	(2)	(3)	(4)	(5)
1931				
January	82.4	22.5	7.6	30.1
February	74.4	20.4	6.7	27.1
March	82.4	22.5	7.5	30.0
April	79.2	21.8	7.1	28.9
May	71.4	22.5	7.7	30.2
June	5.5	21.8	7.2	29.0
July	9.4	22.5	7.5	30.0
August	32.4	22.5	7.5	30.0
September	79.2	21.8	7.2	29.0
October	82.4	22.5	7.5	30.0
November	79.2	21.8	7.2	29.0
December	82.4	22.5	7.5	30.0
Total	810.3	265.1	88.2	353.3
1932				
January	82.4	22.5	7.6	30.1
February	77.0	21.1	7.0	28.1
March	82.4	22.5	7.5	30.0
April	79.2	21.8	7.3	29.1
May	7.0	22.5	7.5	30.0
June	31.8	21.8	21.3	43.1
July	70.1	22.5	25.9	48.4
August	59.4	22.5	21.0	43.5
September	51.1	21.8	18.2	40.0
October	53.6	22.5	19.0	41.5
November	51.3	21.8	18.1	39.9
December	45.4	22.5	12.7	35.2
Total	690.7	265.8	173.1	438.9
1933				
January	82.4	22.5	7.5	30.0
February	74.4	20.4	6.7	27.1
March	82.4	22.5	7.7	30.2
April	79.2	21.8	7.2	29.0
May	31.5	22.5	7.5	30.0
June	6.3	21.8	14.5	36.3
July	65.8	22.5	23.4	45.9
August	61.2	22.5	21.8	44.3
September	42.6	21.8	7.2	29.0
October	82.4	22.5	7.5	30.0
November	79.2	21.8	7.3	29.1
December	82.4	22.5	7.5	30.0
Total	769.8	265.1	125.8	390.9

[1] Based on over-all efficiency of 80 percent.

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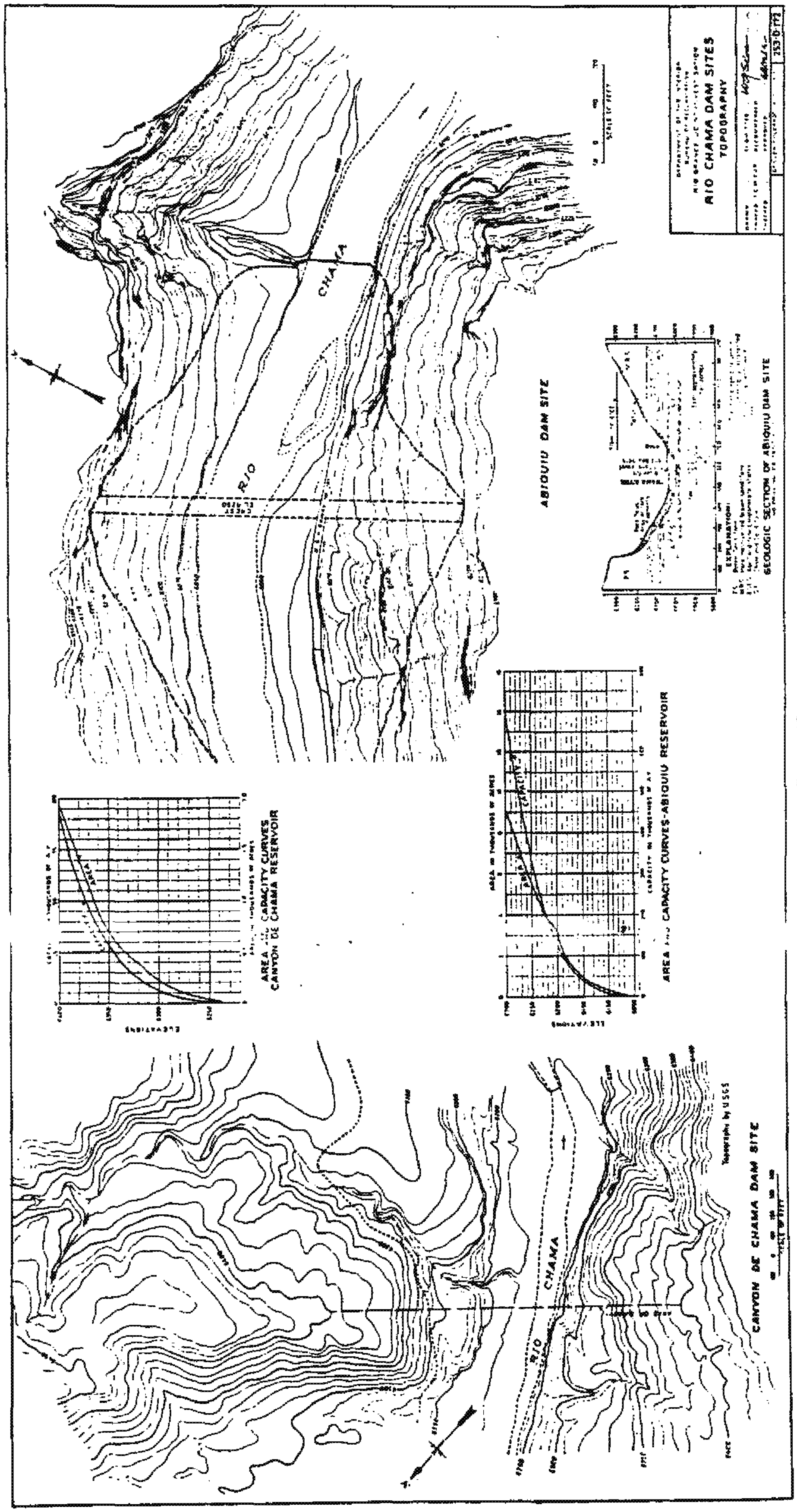
RIO CHAMA DAM SITES
TOPOGRAPHY
ABIQUIU DAM SITE
RIO CHAMA
GEOLOGIC SECTION OF ABIQUIU DAM SITE
EXPLANATION
AREA AND CAPACITY CURVES-ABIQUIU RESERVOIR
AREA AND CAPACITY CURVES CANYON DE CHAMA RESERVOIR
CANYON DE CHAMA DAM SITE
Topography by U.S.G.S.

FIGURE 121

TABLE 9.—*Summary of power production—Chama River—Period 1931–35, inclusive*—Continued

Date	Outflow from Abiquiu River in 1,000 acre-feet	Power output in million kilowatt-hours by all plants		
		Primary	Secondary	Total
(1)	(2)	(3)	(4)	(5)
1934				
January	82.4	22.5	7.5	30.0
February	74.4	20.4	6.7	27.1
March	82.4	22.5	7.5	30.0
April	36.2	21.9	0	[2] 21.9
May	40.5	22.5	0	22.5
June	79.7	21.8	0	21.8
July	82.4	22.5	0	22.5
August	65.9	22.5	0	22.5
September	47.3	21.7	0	21.7
October	51.1	22.5	0	22.5
November	49.7	21.8	0	21.8
December	48.8	22.6	0	22.0
Total	740.8	265.2	21.7	286.9
1935				
January	50.4	22.6	0	22.6
February	47.9	20.5	0	20.5
March	19.8	[3] 7.4	0	7.4
April	74.6	21.8	7.2	[4] 29.0
May	82.4	22.5	7.5	30.0
June	66.3	21.8	7.4	29.2
July	46.0	22.5	7.5	30.0
August	48.6	22.5	7.6	30.1
September	46.4	21.8	7.3	29.1
October	47.0	22.5	7.6	30.1
November	43.5	21.8	7.2	29.0
December	45.0	22.5	7.5	30.0
Total	617.9	250.2	66.8	317.0
1936				
January	66.4	22.5	7.5	30.0
February	65.5	21.1	7.0	28.1

'out cut 25 percent due to poor outlook for water.
'age of 15.1 million kilowatt-hours of firm power.
off forecast favorable—returned to normal output.

Power market.—The census of 1930 shows a total population of 500,000 in the Arkansas, Rio Grande, and San Juan valleys, within a 200-mile radius of the center of the proposed power development. Growth curves based upon census data beginning in 1910 and projected to 1950 indicate a population on the latter date of 550,000.

Per-capita annual power production in Colorado in 1935 was 517 kilowatt-hours while in New Mexico it was 453. From 1920 to 1935 the per-capita production in Colorado increased from 423 to 517 kilowatt-hours, while in New Mexico, during the same period, the increase was from 42 to 453 kilowatt-hours. Total power production within the area in 1935 was 264,000,000 kilowatt-hours based upon per-capita production in each State.

Predictions of power consumption in 1950 are hazardous but it is not unreasonable to assume that if cheaper power becomes available, potential per-capita consumption may reach 1,000 kilowatt-hours and total consumption 546,000,000 kilowatt-hours.

The total potential output of plants herein outlined probably cannot be utilized by 1950 but the system ' itself to construction by units as the need arises.

Cost of power development.—Installations and total estimated costs for the seven plants herein outlined are as follows:

Name	Kilowatt installed capacity	Cost of dam	Total cost
Chama No. 1	5,700	$575,000	$1,145,000
Parkview No. 2	3,300	375,000	804,000
Upper Willow Creek No. 3	8,000	1,850,000	2,370,000
Lower Willow Creek No. 4	11,500	1,900,000	2,475,000
El Vado	12,000	[1]	624,000
Canon de Chama	12,000	2,500,000	3,136,000
Abiquiu	16,000	3,340,000	4,156,000
Total	68,500	10,540,000	14,710,000

[1] Constructed.

State Line Reservoir

General.—This reservoir (fig. 122) has been under consideration for many years and was specifically mentioned in the Rio Grande Compact. The site was also considered by the Middle Rio Grande Conservancy District to provide river regulation and flood control.

Three sites have been considered: the original State line site about 1½ miles below State Line Bridge and 1½ miles above the Colorado-New Mexico State line; the lower State line or Costilla site at the mouth of Costilla Creek; and the Ute Mountain site about 10 miles south of the State line.

A summation of pertinent data on the three sites considered follows:

Site	Height of dam required in feet		Storage capacity acre-feet	
	Elevation, 7,500	Elevation, 7,510	Elevation, 7,500	Elevation, 7,510
State line	80	[illegible]0	294,000	[illegible]87,335
Costilla	135	145	399,338	436,716
Ute Mountain	185	195	454,423	700,000

The original site was considered by the Middle Rio Grande Conservancy District in 1929. It offers the lowest and probably the cheapest dam of the three but its capacity is limited by right-of-way difficulties above elevation 7,500. At this elevation its capacity is only 294,000 acre-feet. Its height would only be 80 feet, but foundation conditions appear to be the least satisfactory of the three sites.

No. 2 site (Costilla site) offers ample capacity for a moderate height of dam but has underground water conditions quite unfavorable. At this lower elevation of the river, additional storage space becomes available in the basin just above the mouth of Costilla Creek.

Disclosure of the conditions at each of the above sites by drilling prompted a further search in a section of the river where ground water conditions obviously were more favorable. Ute Mountain site is the result of this search.

Reservoir geology.—The reservoir area presents two distinct geological conditions. The San Luis Hills near the northern end of the basin are a geologic arch of dense impervious andesite in an old peneplain surface, while the valley proper above the hills is a downwarp with troughs at the east and west ends of the arch. This warping was attended by considerable contemporary faulting.

This downwarping was following by a cycle of erosion which, south of the hills, resulted in a wide valley much deeper than the present gorge, but which was arrested at the San Luis Hills by the harder composition of the basement rock, thus permitting the deposition in the San Luis Basin of silts and alluviums in strata of varying origin and permeability.

Coincident with, and eventually overcoming the erosion, intermittent vulcanism from sources at or near Ute Mountain, San Antonio Mountain, and other similar buttes in the vicinity, spread recent basalts over the southern portion to eventually fill the older channel to its present level, the older San Luis Hills arch acting as an effective barrier to prevent any considerable flow into the northern area.

Thus, north of the arch, ground water must necessarily be, and is, near the surface, but where the river emerges into the porous basalts downstream the water table drops below the stream surface. It is 66 feet below the stream at State Line site, 39 feet below at Costilla site, and again on the surface at Ute Mountain. The water table gradient in the trough from the San Luis Hills to Ute Mountain is 2 feet per mile while the river gradient is approximately 8 feet.

The water table apparently has the form of a broad trough in the bottom of which is a local rise under the immediate stream channel, indicating seepage losses from the stream. However, no appreciable loss developed in a careful series of seepage measurements made by the bureau in the spring of 1937. Below Ute Mountain, springs are visible along the base of the canyon walls but the gain measured at Embudo is not greater than may be expected from side drainage.

Why the water table approaches the stream surface below Ute Mountain is important but poorly understood. Drilling has shown that no basement andesite or granite approaches the surface sufficiently to form a bottle-neck, nor is it likely that interflow clay beds Ute are alone responsible. No clay beds were found at Mountain, but they were observed further downstream.

Permeability of the basalts which form the entire floor and sides of the reservoir basin south of the San Luis hills is the most important consideration in the selection of a dam site. In this basin, the basalt flow contacts, enhanced by columnar jointing should prove quite permeable. Water tests in the drill holes confirm this belief. A dam at any of the sites, to create a reservoir for irrigation and power purposes where long hold-over is required, may be of questionable usefulness by reason of heavy leakage. For flood protec[illegible] tightness is not a factor of prime importance since l[illegible] around the dam can hardly damage the structure an[illegible] all water will eventually return to the stream.

Summing up the situation, the area north of the San Luis hills is underlain and surrounded by dense, crystalline rocks which are watertight. Numerous springs abound in the area; nearly everywhere the water table is within a few feet of the surface. No visible springs feed the river in its cut through the hills, but the dense character of the rock allows no leakage from the river channel.

A dam 40 feet high at the north end of this canyon would impound 170,000 acre-feet of water but the cost of right-of-way would far exceed the cost of the dam. There would, however, be no questionable features as to its watertightness.

South of the San Luis hills the problems multiply rapidly. Approximately 60 square miles of basalt flows are included in the basin above the Ute Mountain site, 14,000 acres of which will be under the flow line of the reservoir. Throughout the area the water table is beneath the river and the possibility of extensive leakage from the reservoir becomes important. Eight miles below the Ute Mountain site the basin again becomes restricted by a ridge of hills, not unlike th[illegible] San Luis hills, but the cut-off to underground flo[illegible] not as definite nor is the throat as restricted.

South of the San Luis hills, this latter location probably offers the best opportunity for a dam with a tight reservoir but unfortunately beginning at a point about 3 miles south of the Ute Mountain site the river bed increases its gradient rapidly and to secure a reservoir of a capacity comparable to the sites above would require a dam more than 300 feet in height and with a longer crest length than any of the other sites.

The Ute Mountain site was finally adopted to determine estimated costs. While it is the most expensive of the three sites, it has the advantage of large capacity for flood control without unduly flooding San Luis Valley, and of high power head if such development should prove desirable.

Dam-site geology—State bridge dam site.[1]—This site has been ably considered in a geological report by Kirk Bryan. The following brief attempts merely to summarize the available information. The site has been partially diamond drilled but no pits have been dug.

The dam site is a narrow canyon eroded into a horizontal series of basalt flows containing erratic interflow clay beds. Both abutments are of horizontal basalts, each individual flow having dense centers and perme-

[1] Geology of the State Line dam site, Kirk Bryan, for the State of New Me[illegible] Albuquerque, August 1927.

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able, vesicular tops or flow contacts. Columnar jointing is prominent but widening by rim creep has not progressed to the extent found at the lower sites. Un- ıbtedly many of the vesicular zones will prove to ȷuite permeable. Several interflow clay beds occur between flows; a 30- to 40-foot seam occurs on both abutments above elevation 7,430, while another thinner seam is encountered (5 to 8 feet) beneath the foundation at elevation 7,395.

The foundation is mantled with a thin veneer (10 to 15 feet) of silt and gravel in which there are many large basalt boulders. Typical talus or loose angular rock and rock fragments line the foot of the basalt cliffs and similar material covers the higher clay seam so that it is not exposed.

The water table is found 66 feet beneath the river and probably does not substantially rise to the left for many miles. With storage it undoubtedly would rise on the andesite several hundred feet back from the right abutment, where the impervious basement comes to the surface in the San Luis Hills. There is reason to suspect that seepage past the dam and reservoir may prove excessive.

Costilla dam site.—This site was diamond drilled and no test pits were considered necessary. Five holes were drilled across the proposed axis and one at the head of Costilla Gulch.

The rock narrows is an erosional canyon cut into horizontal basalt flows, which in this locality has only inconsequential interflow clay beds. The older ley into which these basalts accumulated was probably wide and quite deep, the bottom possibly mantled with gravels below the basalt. These basalts extend back from both abutments for many miles, in which the water table rises slowly to the sides (5 to 10 feet per mile) but is 40 feet beneath the stream level and 46 feet beneath the abutments. This bulge must indicate present stream loss.

Both basalt abutments are made up of numerous flows with dense centers and vesicular tops and contacts. Normal columnar jointing is evident and some widening by rim creep was noted. Abutment drilling encountered only a few interflow clay seams, none of which were over 3 inches thick. A 3-foot seam was encountered 85 feet below the river under the left abutment. The foundation is covered with 8 to 10 feet of sand, gravel, and incorporated talus boulders of a porous character. The canyon walls are uncovered except for a normal thin talus lying along the base.

There is no doubt as to the stability of this basalt, considering its hard character and the absence of clay beds. A concrete structure can probably be utilized. The jointed character of the abutments make grouting necessary to bind the blocks into a unit mass. A high ɾ ıability is indicated.

Ute Mountain dam site.—The selected Ute Mountain site was not drilled but two diamond drill holes were located downstream and to the west in determining the water-table conditions. No test pits were utilized.

The lower drill hole shows that no impervious basement rock approaches the surface and that no thick or extensive interflow clay bed is present for at least 250 feet below the stream bed. Ute Mountain, undoubtedly a source area for some of the valley basalts, lies 4 miles to the northeast and the deeper flows around this vent may be more massive and thereby somewhat less permeable. The mass may then form a partial barrier to downstream percolating ground waters on the left side of the valley. However, no such mass is found on the right side where horizontal basalts extend back for many miles. A drill hole (elevation 7,575 approximately) encountered a thick interflow clay member from 40 to 78 feet and struck water at 247 feet or only 15 feet above the river.

Both abutments are of horizontal basalts but the number and thickness of possible interflow clay beds has not been determined. The basalt flows are similar to those at the upper sites but the deeper canyon has allowed more creep with the resultant widening of columnar joints. In fact, this axis is one of the lowest remaining areas where such slump has not seriously disrupted the walls or given rise to landslides. Downstream, possible sites become increasingly less attractive. Water tests in the drill hole located 3 miles downstream (elevation 7,318) were unfavorable and much fracturing of the rock was evident. The foundation basalts should prove the equal of those encountered in the other sites.

The water table is probably within a few feet of the river surface, for immediately downstream springs appear at the surface while the water level in the lower drill hole remained at stream elevation. Overburden conditions are not severe; the foundation should contain only 10 to 15 feet of sand, gravel, and basalt boulders, while the base of the basalt cliffs are lined with normal talus deposits.

Summary of estimated data

Ute Mountain Dam:

Storage capacity	452,000 acre-feet.
Spillway capacity	15,000 second-feet.
Outlet capacity (required at elevation 7,470).	4,500 second-feet.
Elevation top of dam	7,508.
Maximum reservoir water-surface elevation.	7,500.
Maximum height of dam	198 feet.
Total estimated cost, dam and reservoir	$2,600,751.
Topography of reservoir and geological sections.	Fig. 122.
General plan and section	Fig. 123.
Preliminary estimate	Table 10.

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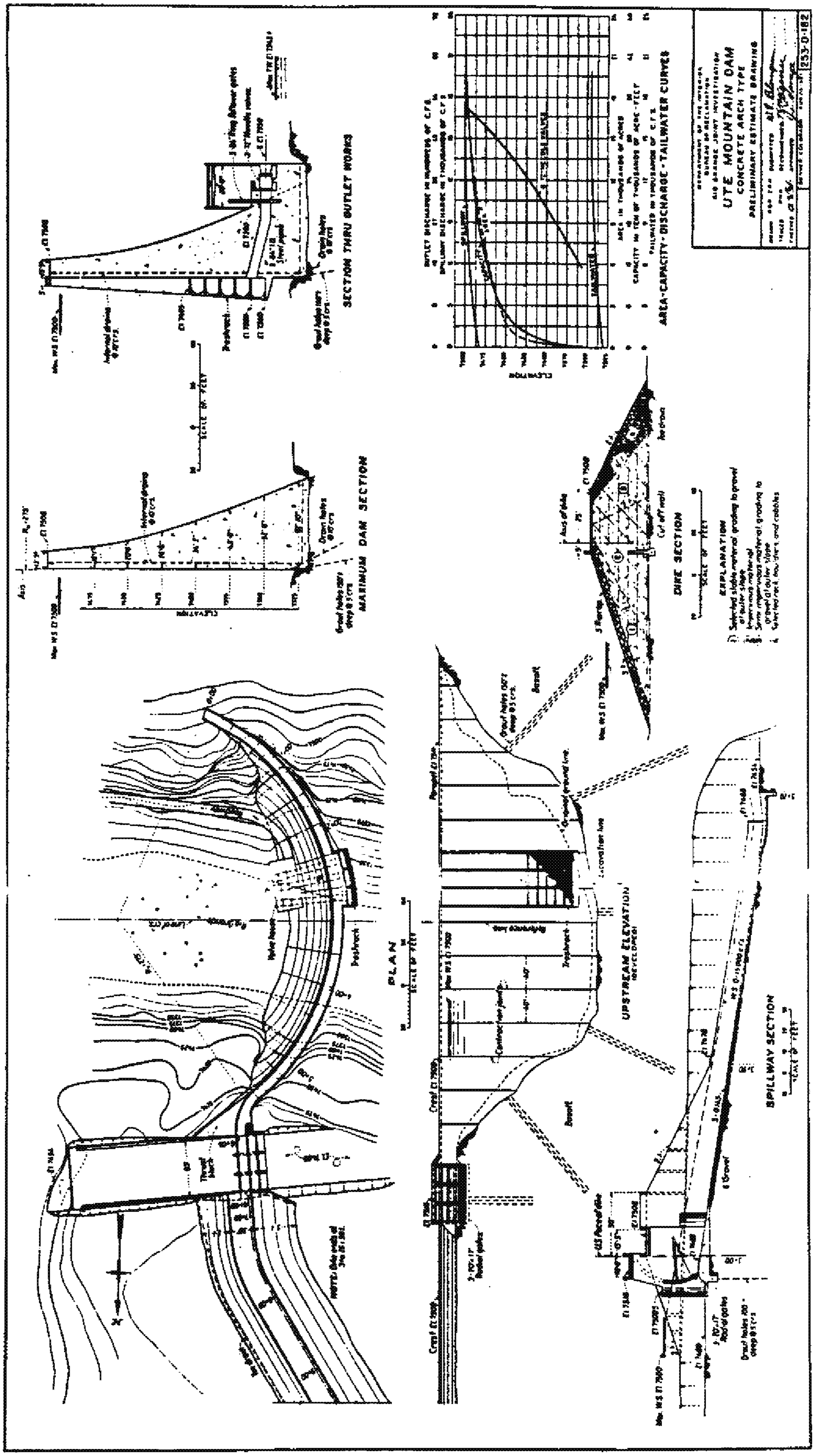

FIGURE 123

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Reservoir.—The reservoir area at elevation 7,500 is 20,000 acres, about 2,000 acres of which will require clearing of brush and willows. Nine thousand five hundred acres has no improvements, and is believed to have no value. Cost of right-of-way for the balance is estimated as follows:

	Acres	Cost of right-of-way
Cultivated area	[1] 1,960	$137,200
Hay land	[2] 4,220	168,800
Meadow land	[3] 4,320	129,600
Total	10,500	435,600

[1] $70 per acre. [2] $40 per acre. [3] $30 per acre.

It is assumed that all utility lines in the reservoir area will be abandoned and replacement will not be necessary. About 14 miles of roads will be submerged, and the cost of highway relocation is estimated as follows:

Relocate 2¼ miles of highway at $6,000	$13,500
Bridge piers and abutments	15,000
Raise old bridge spans	8,000
Approach fills, 9,100 cubic yards at $1	9,100
Total cost	45,600

The removal of houses, barns, etc. from the reservoir area will cost approximately $20,000.

Dam.—The almost perpendicular walls of the narrow basalt canyon indicate that the most economical and suitable type of dam for this site is a concrete arch with an abutment spillway. However, there are possibilities for a diamond-head overflow buttress dam, but limitations of time and funds did not permit an estimate of cost for this type. No tests were made to determine the strength of the rock, and no drilling of the foundation was done. There is nothing to indicate any geological defects at this dam site. It is assumed that there is an average of 8 feet of sand and gravel above the basalt bedrock of the river bed. About 2,000 feet of earth dike is required on the left abutment. Material for embankment is scarce, but probably enough for the dike can be obtained on the hills in the vicinity and from excavation.

A straight overflow concrete gravity dam at this site would require approxmately (165,000 cubic yards) 90 percent more concrete than the arch dam and nearly double the cost of the dam.

The adopted plan is an arched concrete dam with an axial radius of 275 feet. The maximum dam section will be 198 feet high with a crest width of 13 feet 5 inches and a thickness of 62 feet 10 inches at elevation 7,325. The crest at elevation 7,508 is surmounted by two concrete parapets. This crest elevation was necessary in order to provide an 8-foot freeboard for the dike

The concrete arch terminates in a gravity thrust block section on the left abutment beyond which is the spillway.

Owing to the large outlet discharge requirements, spillway discharges will occur infrequently as outlets are sufficient for normal flood control. The spillway is of an emergency nature and consists of a straight concrete lined channel spilling into the ravine downstream from the left abutment of the dam. The channel is 65 feet wide inside and joins the thrust block on the river side. Three 20 feet long by 17 feet high radial gates will control the spillway flows. The outlet works will consist of trash racks with cleaning mechanism operated from the top of the dam, three 84-inch steel-lined conduits through the dam, each of which is controlled on the downstream end by an 84-inch ring follower emergency gate, and a 72-inch needle valve. A bulkhead gate is provided to close the conduits at the face of the dam for maintenance purposes. The outlets will discharge 4,500 second-feet with the reservoir elevation 7,467. A roadway to the valve house will be provided in the canyon below the dam.

Joining the spillway on the left will be an earth dike. The dike is of the typical rolled embankment type, 25 feet in maximum height with a 30-foot top width, 3 to 1 upstream and 2 to 1 downstream slopes. The upstream slope is protected by 3 feet of rock riprap and the downstream face with dumped rock. A concrete cut-off wall is placed on rock underneath the dike. A thin mantle of soil covers the rock under the dike.

It is planned to grout the foundation of the arch dam with holes 150 feet deep and at 5-foot centers. No doubt a certain amount of grouting will be required under the dike section. Owing to the thinness of the arch and the high altitude, cooling of the concrete will not be necessary other than possibly a certain amount in the lower base elevations which probably can be done with river water; however, detailed design studies will indicate the necessary requirements. The contraction joints of the arch are placed at 40-foot centers. Internal drainage is provided.

Construction schedule.—The construction schedule for this dam should cover a two-season period to allow ample time for the fabrication of gates and valves, otherwise no difficulty should be encountered during construction unless the acquisition of right-of-way should prove difficult.

Preliminary estimate.—The preliminary estimate of this dam is given in table 10. The estimate includes a lump sum of $40,000 for diversion of the river and unwatering the foundations. No specific plan has been worked out for diversion. However, the construction schedule will indicate the best plan. It is anticipated that diversion will be made through a conduit in the base of the dam and by leaving blocks at low elevations for maximum flows. Unit prices in the estimate are based on early 1937 prices and may vary considerably over a period of time. The contract cost for concrete items includes the cost of hauling the cement and furnishing aggregate. Sand and gravel can probably be procured at Sunshine Valley, a distance of 6 miles from the dam site.

TABLE 10.—*Ute Mountain Dam, preliminary estimate, Aug. 12, 1937*

[Concrete arch and earth embankment: Top of dam, elevation 7,508; spillway crest, elevation 7,483; normal water surface, elevation 7,500; maximum height of dam, 198 feet; reference drawing no. 253-D-145]

[Storage capacity, 452,000 acre-feet; spillway capacity, 15,000 second-feet; required outlet capacity, 4,500 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion and unwatering foundations	[1]		[1]	$40,000			[1]	$40,000
EARTH WORK								
Excavation, common:								
Dam foundation	4,000	Cubic yard	$1.00	4,000			$1.00	4,000
Stripping for embankment	11,800	Cubic yard	.30	3,540			.30	3,540
Stripping borrow pits	10,000	Cubic yard	.25	2,500			.25	2,500
Toe drains and cut-off trenches	2,600	Cubic yard	.75	1,950			.75	1,950
Roadway	10,000	Cubic yard	.60	6,000			.60	6,000
Spillway	500	Cubic yard	1.00	500			1.00	500
Borrow, and transportation to dam	70,000	Cubic yard	.35	24,500			.35	24,500
Excavation, rock:								
Dam foundation	16,900	Cubic yard	3.00	50,700			3.00	50,700
Cut-off wall footings	450	Cubic yard	5.00	2,250			5.00	2,250
Toe drains and cut-off trenches	100	Cubic yard	6.00	600			6.00	600
Roadway	12,000	Cubic yard	1.25	15,000			1.25	15,000
Spillway	15,000	Cubic yard	1.75	26,250			1.75	26,250
Embankment:								
Earthfill compacted	55,000	Cubic yard	.10	5,500			.10	5,500
Dumped rock on downstream slope	11,400	Cubic yard	.20	2,280			.20	2,280
Riprap rock on upstream slope	9,300	Cubic yard	.40	3,720			.40	3,720
Backfill	10,000	Cubic yard	.60	6,000			.60	6,000
Gravel for roadway and spillway	2,500	Cubic yard	2.00	5,000			2.00	5,000
Clay blanket for dam	5,000	Cubic yard	.40	2,000			.40	2,000
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 25 feet deep	5,000	Linear foot	.75	3,750			.75	3,750
Grout holes 25 to 50 feet deep	1,250	Linear foot	1.00	1,250			1.00	1,250
Grout holes 50 to 100 feet deep	2,500	Linear foot	1.25	3,125			1.25	3,125
Grout holes 100 to 150 feet deep	24,000	Linear foot	1.75	42,000			1.75	42,000
Drain holes not over 25 feet deep	500	Linear foot	1.00	500			1.00	
Drain holes 25 to 50 feet deep	1,000	Linear foot	1.50	1,500			1.50	
Drain holes 50 to 100 feet deep	3,750	Linear foot	2.00	7,500			2.00	
Weep holes	500	Linear foot	1.00	500			1.00	
Anchor bars and grouting in place	800	Linear foot	.40	320	$0.30	$240	.70	
Pressure grouting:								
Foundation	49,000	Cubic foot	1.00	49,000	.75	36,750	1.75	85,750
Contraction joints	400	Cubic foot	2.00	800	.90	360	2.90	1,160
Drain tile:								
12-inch diameter clay tile in gravel	300	Linear foot	.80	240	.60	180	1.40	420
8-inch diameter clay tile in gravel	1,500	Linear foot	.60	900	.40	[illegible]	[illegible]	[illegible]
6-inch diameter clay tile in gravel	1,300	Linear foot	.50	650	.30	390	.80	1,040
6-inch diameter porous concrete	6,400	Linear foot	.70	4,480	.20	1,280	.90	5,760
CONCRETE WORK								
Concrete:								
Dam	85,000	Cubic yard	5.75	488,750	3.25	276,250	9.00	765,000
Spillway floor	560	Cubic yard	9.00	5,040	3.75	2,100	12.75	7,140
Spillway walls	270	Cubic yard	11.00	2,970	4.00	1,080	15.00	4,050
Spillway gate structure	880	Cubic yard	10.50	9,240	3.75	3,300	14.25	12,540
Parapets on concrete section	150	Cubic yard	21.00	3,150	4.00	600	25.00	3,750
Parapets and curbs on embankment section	775	Cubic yard	18.00	13,950	4.00	3,100	22.00	17,050
Spillway bridge (roadway)	75	Cubic yard	14.75	1,106	4.00	300	18.75	1,406
Cut-off wall stem	900	Cubic yard	11.00	9,900	4.00	3,600	15.00	13,500
Cut-off wall footings	450	Cubic yard	9.50	4,275	4.00	1,800	13.50	6,075
Trash rack	425	Cubic yard	12.00	5,100	4.00	1,700	16.00	6,800
Valve-house substructure	850	Cubic yard	10.00	8,500	3.75	3,188	13.75	[illegible]
Valve-house superstructure	100	Cubic yard	21.00	2,100	4.50	450	25.50	2,550
Special finishing concrete surfaces	3,000	Square yard	.75	2,250	.05	150	.80	[illegible]
METALWORK								
Metal:								
Trash rack	126,000	Pound	.02	2,520	.06	7,560	.08	[illegible]
Reinforcement bars	570,000	Pound	.02	11,400	.035	19,950	.055	[illegible]
Grout and water stops	5,700	Linear foot	.25	1,425	.40	2,280	.65	3,705
Bulkhead gate, frames, and guides	17,500	Pound	.02	350	.09	1,575	.11	[illegible]
Outlet conduit lining	456,000	Pound	.03	13,680	.08	36,480	.11	[illegible]
3 72-inch needle valves and operating mechanism	290,000	Pound	.03	8,700	.24	69,600	.27	[illegible]
3 84-inch ring follower gates and operating mechanism	240,000	Pound	.03	7,200	.18	43,720	.21	[illegible]
Pipe and fittings for foundation grouting	30,000	Pound	.05	1,500	.08	2,400	.13	[illegible]
Pipe and fittings for contraction joint grouting	25,000	Pound	.15	3,750	.10	2,500	.25	[illegible]
Pipe hand railing	2,500	Pound	.10	250	.10	250	.20	[illegible]
1 30-ton crane	45,000	Pound	.02	900	.19	8,550	.21	[illegible]
3 20- by 17-foot radial gates and operating mechanism	75,000	Pound	.04	3,000	.11	8,250	.15	[illegible]
Miscellaneous metalwork	7,500	Pound	.10	750	.10	750	.20	[illegible]

[1] Lump sum.

CO - 003470

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TABLE 10.—*Ute Mountain Dam, preliminary estimate, Aug. 12, 1937*—Continued

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Unit cost	Unit cost	Total cost
MISCELLANEOUS ITEMS								
Items:								
Valve house, except concrete	(1)		(1)	2,500	(1)	2,500	(1)	5,000
Guard rail for roadway	3,000	Linear foot	.50	1,500	.50	1,500	1.00	3,000
Gas-electric generator set and equipment	(1)		(1)	500	(1)	1,500	(1)	2,000
Clearing reservoir	2,000	Acre	25.00	50,000			25.00	50,000
Construction camp and permanent buildings	(1)				(1)	40,000	(1)	40,000
Relocation of roads	(1)				(1)	45,600	(1)	45,600
Removing houses, barns, etc., from reservoir	(1)		(1)	20,000			(1)	20,000
Right of way	10,500	Acre			41.50	435,750	41.50	435,750
Transporting freight except cement for Government from Jaroso, Colo., to the dam (15 miles).	1,000	Ton	1.20	1,200			1.20	1,200
Subtotal				1,006,261		1,067,613		2,073,874
Contingencies, 15 percent								311,081
Total estimated field cost								2,384,955
Investigations and surveys								25,000
Engineering and inspection, 5 percent								119,246
Superintendence and accounts, 1 percent								23,850
General expense, 2 percent								47,700
Total estimated cost								2,600,751
Cost per acre-foot storage								5.75

[1] Lump sum.

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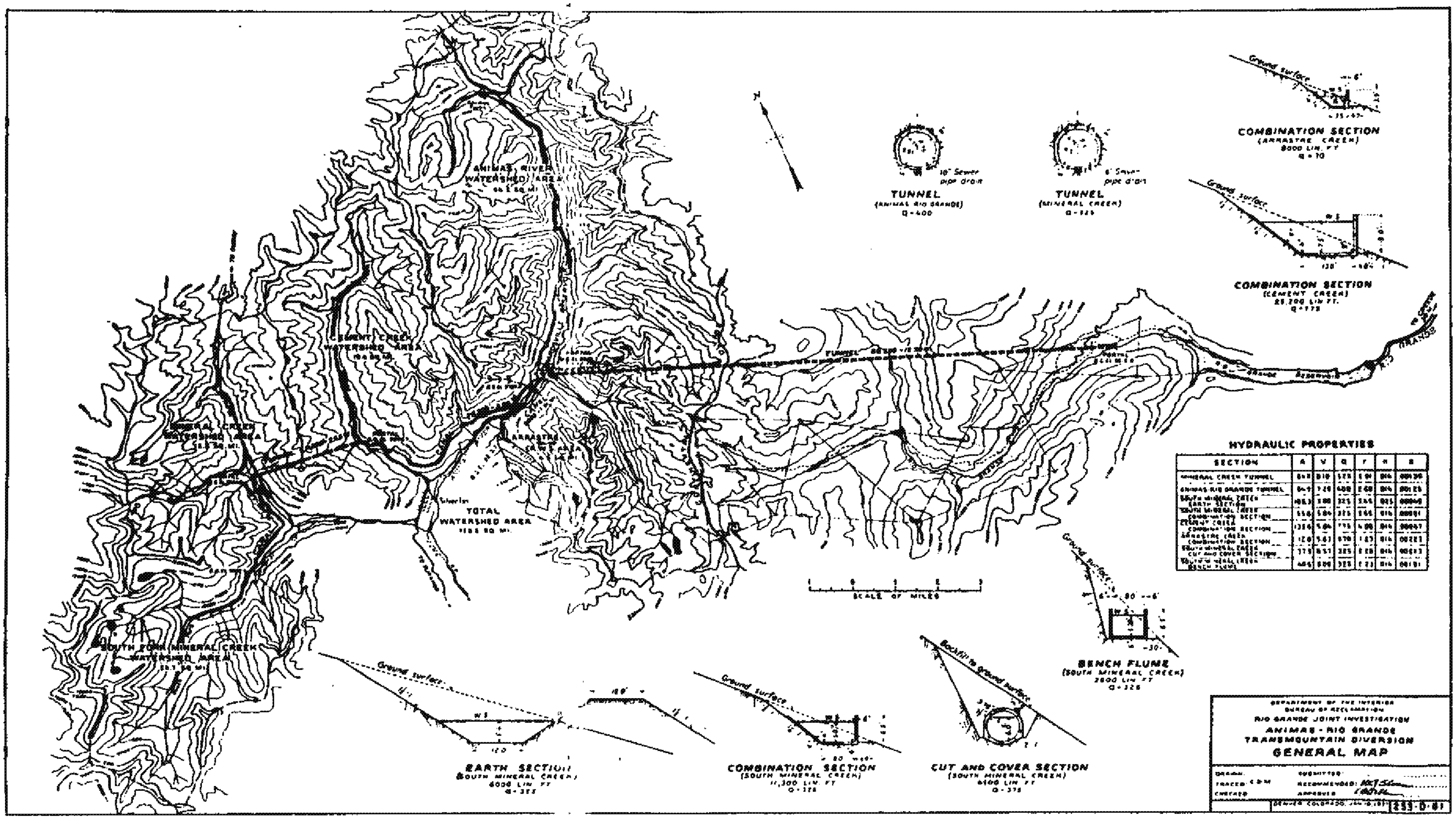

ANIMAS RIVER WATERSHED AREA
CEMENT CREEK WATERSHED AREA
MINERAL CREEK WATERSHED AREA
SOUTH FORK MINERAL CREEK WATERSHED AREA
TOTAL WATERSHED AREA
ARRASTRE CREEK
Silverton
TUNNEL
RIO GRANDE RESERVOIR
RIO GRANDE
TUNNEL (ANIMAS RIO GRANDE) Q=400
TUNNEL (MINERAL CREEK) Q=325
COMBINATION SECTION (ARRASTRE CREEK) 8000 LIN. FT.
COMBINATION SECTION (CEMENT CREEK)
HYDRAULIC PROPERTIES
SCALE OF MILES
BENCH FLUME (SOUTH MINERAL CREEK) 2800 LIN. FT. Q=325
EARTH SECTION (SOUTH MINERAL CREEK) 6000 LIN. FT. Q=325
COMBINATION SECTION (SOUTH MINERAL CREEK) 11,300 LIN. FT. Q=325
CUT AND COVER SECTION (SOUTH MINERAL CREEK) 6500 LIN. FT. Q=325
Ground surface
Backfill to ground surface
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
ANIMAS-RIO GRANDE TRANSMOUNTAIN DIVERSION
GENERAL MAP

FIGURE 124

PART V

SECTION 3.—COLORADO INVESTIGATIONS

Animas-Rio Grande Transmountain Diversion

General Plan [1]

The South Fork of Mineral Creek, Mineral Creek, and Cement Creek will be diverted to a reservoir at Howardsville on the main Animas River a few miles above Silverton, from which a tunnel will pierce the Continental Divide eastward to the Rio Grande about 60 feet above and a mile from the high-water line of the Rio Grande Reservoir.

The diversion from the South Fork of Mineral Creek is at elevation 9,852. The west portal of the main tunnel to the Rio Grande has a bottom grade at elevation 9,697.7 and the east portal at 9,612.

The principal features incorporated in the plan are as follows:

Collection system:		
Earth canal	miles	1.14
Combination section	do	8.62
Bench flume	do	.49
Cut and cover section	do	.85
Tunnel	do	2.56
Total in collection system	do	13.65
Ar[illegible]s-Rio Grande tunnel, 9.5-foot diameter	do	12.98
[illegible]sville Reservoir, maximum height of dam 255 feet, [illegible] 1,500 feet, capacity	acre-feet	53,000

The route traversed by the collection system is characterized by steep, barren side slopes, subject to frequent snowslides. For this reason most of the system has been designed for concrete lining, cut and cover section, or tunnel. The tunnel from Mineral Creek to Cement Creek is the only feasible method of connecting these two creeks, trial lines around the slopes having shown such steep slopes and extensive rockslides that no canal could there be maintained. There is a possibility that some storage can be found to regulate the flow of South Mineral Creek and Mineral Creek. If so, the size and cost of the collection canal can be reduced, but it is questionable whether the savings which may result will equal the cost of reservoir facilities on these creeks.

Howardsville Reservoir and Dam

The high dam required to obtain sufficient storage capacity, and the character of the property to be submerged make for high cost. Howardsville (a group of seven or eight buildings and homes), several old mine buildings at the mouth of Maggie Gulch, together with 5 miles of highway and 3 miles of railroad (narrow gage) are below high-water line. The railroad company has petitioned for abandonment of the tracks. The dam site itself has not been explored by test pits or drilling and there are three possible locations for the dam. If the upper one at the town should finally be selected there may be a considerable decrease in the cost of the dam, for the valley floor rises about 60 feet between the lower and upper sites with only a slight decrease in storage capacity. A rough estimate of cost for the lower site is presented. No detailed plans were prepared.

Animas-Rio Grande Tunnel

The main feature of the project is the tunnel from Howardsville Reservoir to the Rio Grande, 12.95 miles in length, and designed for 400 second-feet capacity. Physical conditions at each end limit the available fall and even with the plan here proposed, there will remain a small amount of dead storage in Howardsville Reservoir. The tunnel would have a capacity of 500 second-feet if given 28.4 feet of additional fall, but this will add 1,440 feet to the length and increase the cost by $90,000. Such an increase in capacity may prove desirable to increase water deliveries in late summer.

Water Supply

Altitude run-off curves previously developed for the San Juan-Chama diversion were also used for calculating run-off from the various watersheds on this project. The same period of years, 1916–25, was used in determining a mean run-off for that period, and the same type of annual and monthly curves were applied. Long concurrent run-off records for the Durango and Tacoma stations on the Animas River permit extension of estimates to a longer period. The results are incorporated in figure 126. The figures therein represent the sum of contributions from the individual watersheds of the South Fork of Mineral Creek, Mineral Creek, Cement Creek, Animas River above Howardsville, and Arastre Creek.

The capacity of each diversion ditch receiving an unregulated supply has been made 50 percent greater than the mean daily flow of the maximum mean month for the period 1916–25. The estimated diversion allows for undivertible peak flows above ditch capacities. Peak flows on intercepted tributaries were assumed to have the same relation to peak flows at Durango as the relation of their drainage areas.

[1] Fig. 134.

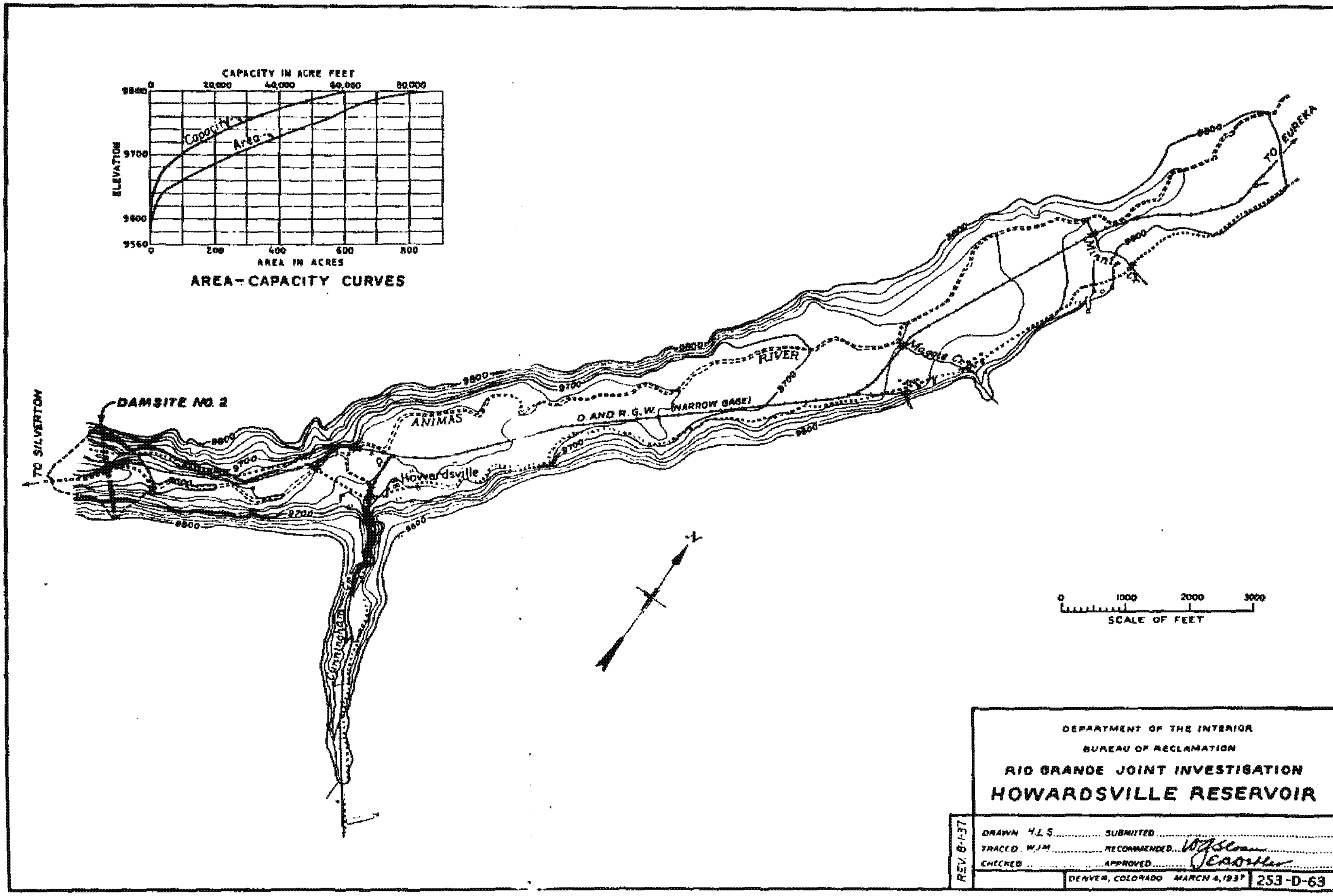


FIGURE 125

CO - 003474

It was concluded that undivertible water would be in the proportionate amount that the flow at Durango exceeded a flow of 5,000 second-feet during the day.

lopting any figure as to the reliable water supply t. obtained for the Animas-Rio Grande diversion or upon which to base an estimated cost per acre-foot, it must be borne in mind that the period 1916 to 1925 was one of comparatively high run-off. Since that time stream flows have been less. (See fig. 127.) For the period from 1927 to 1934, inclusive, the mean diversion would be only 123,250 acre-feet. In the minimum year of 1934 only 43,000 acre-feet could have been diverted, while the maximum in 1911 was 209,100 acre-feet. If a figure of 150,000 is adopted there would have been a full supply in 15 out of 25 years from 1911–35, inclusive, with shortages not exceeding 5,000 acre-feet in two additional years. A supply which could be secured 80 percent of the time would be about 122,000 acre-feet. The 1924–35 mean is 130,725 acre-feet.

Figure 127 presents the progressive 10-year means of divertible water, together with progressive 10-year means for the run-off of other San Juan Basin streams and of the Rio Grande at Del Norte. Significant in this figure is the more rapid drop in discharge of the San Juan River at Rosa as compared to the Animas River. Attention is also directed to the dry cycle which occurred on the Rio Grande from 1899 to 1910,

TABLE 11.—*Howardsville dam, preliminary estimate, Jan. 30, 1937*

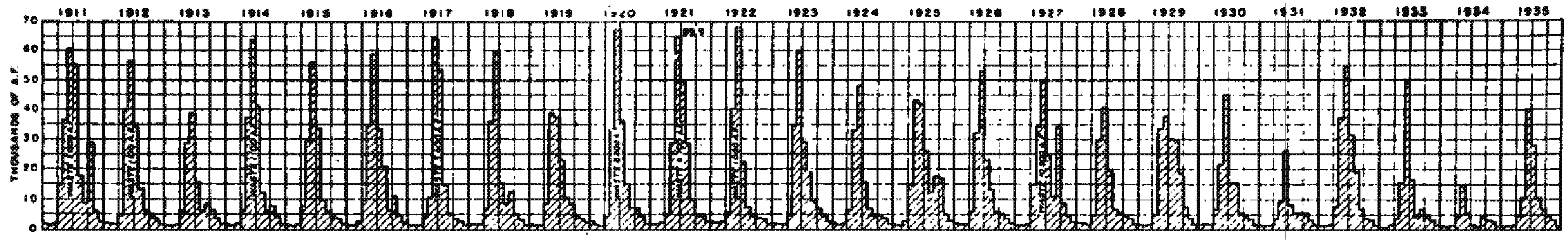
[Earth embankment: Top of dam elevation 9,800; normal water surface elevation, 9,792; maximum height of dam; 225 feet; drawing no. 253-D-63]

[Storage capacity, 55,000 acre-feet; spillway capacity, 7,000 second-feet; outlet capacity, 500 second-feet, diversion capacity, 3,000 second-feet]

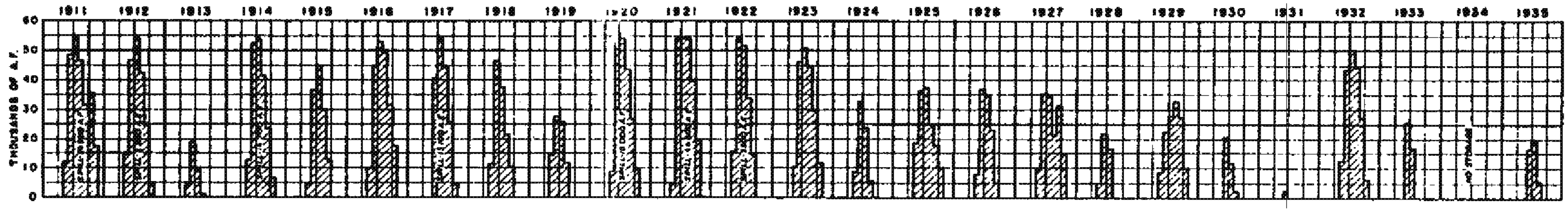
Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion and unwatering foundations	(1)		(1)	$10,000			(1)	$10,000
EARTHWORK								
Excavation, common:								
Stripping, borrow pits	$220,000	Cubic yard	0.30	66,000			$0.30	66,000
Stripping, dam foundation	566,000	Cubic yard	.30	169,800			.30	169,800
Spillway	22,000	Cubic yard	.30	6,600			.30	6,600
Borrow, and transportation to dam	3,060,000	Cubic yard	.25	765,000			.25	765,000
Excavation, rock:								
Outlet tunnel	5,600	Cubic yard	10.00	56,000			10.00	56,000
w, and transportation to dam	596,000	Cubic yard	.75	447,000			.75	447,000
walls	300	Cubic yard	4.00	1,200			4.00	1,200
ent:								
fill	3,250,000	Cubic yard	.10	325,000			.10	325,000
umped rock on downstream slope	684,000	Cubic yard	.20	136,800			.20	136,800
Riprap on upstream slope	59,500	Cubic yard	.40	23,800			.40	23,800
Backfill about structures	4,000	Cubic yard	.50	2,000			.50	2,000
GROUTING AND DRAINAGE								
Drilling: Grout holes 50–100 feet deep	12,000	Linear foot	2.50	30,000			[illegible]	30,000
Pressure grouting, Tunnel and dam	15,000	Cubic foot	1.00	15,000	$1.00	$15,000	2.00	30,000
Drain tile:								
12-inch diameter clay tile in gravel	1,500	Linear foot	.70	1,050	.45	675	1.15	1,725
8-inch diameter clay tile in gravel	1,000	Linear foot	.60	600	.30	300	.90	900
6-inch diameter clay tile in gravel	500	Linear foot	.50	250	.20	100	.70	350
CONCRETE WORK								
Concrete:								
Parapets and curbs	500	Cubic yard	20.00	10,000	4.00	2,000	24.00	12,000
Outlet tunnel lining	2,000	Cubic yard	14.00	28,000	3.60	7,200	17.60	35,200
Gate chamber and trash-rack structure	100	Cubic yard	15.00	1,500	4.00	400	19.00	1,900
Cut-off walls	925	Cubic yard	12.00	11,100	4.00	3,700	16.00	14,800
Spillway channel	4,000	Cubic yard	11.00	44,000	3.60	14,400	14.60	58,400
Control house	25	Cubic yard	20.00	500	4.00	100	24.00	600
METALWORK								
Metal:								
Trash rack and miscellaneous	50,000	Pound	.02	1,000	.08	4,000	.10	5,000
Reinforcement bars	500,000	Pound	.02	10,000	.03	15,000	.05	25,000
H. P. sluice gates and control apparatus	61,000	Pound	.03	1,830	.22	13,420	.25	15,250
MISCELLANEOUS ITEMS								
Items:								
Control house (except concrete)	(1)			200		800		1,000
Gate tender's house	(1)			1,000		2,000		3,000
Subtotal				2,165,230		79,095		2,244,325
Contingencies, 15 percent								336,649
Total estimated field cost (exclusive of reservoir, clearing, right-of-way, highways, telephones, etc.).								2,580,974
Investigations and surveys	(1)						(1)	6,000
Engineering and inspection, 6 percent								154,858
Superintendence and accounts, 1½ percent								38,715
General expense, 2½ percent								64,524
Total estimated cost (exclusive of clearing, right-of-way, highways, telephones, etc.).								2,845,071

[1] ... sum.

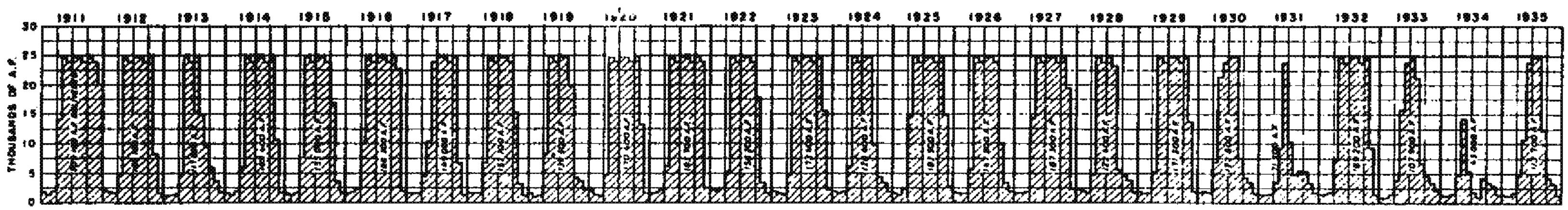
WATER SUPPLY – ANIMAS-RIO GRANDE DIVERSION



INFLOW HOWARDSVILLE RESERVOIR



HOWARDSVILLE RESERVOIR OPERATION
CAPACITY – 54,000 ACRE FEET



DELIVERED THROUGH TUNNEL

147,880 A.F. ..... 25 Year Mean
144,000 A.F. ..1916-1935 Mean
130,725 A.F. ..1924-1935 Mean

STREAM	[illegible]	[illegible]
Animas River	68.74	11,857
Cement Creek	19.41	11,546
Mineral Creek	15.79	11,368
So. Fk. Mineral Creek	24.65	11,926
Total	128.59	

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
ANIMAS-RIO GRANDE
TRANSMOUNTAIN DIVERSION
OPERATION DIAGRAM

DRAWN: D.L.M. ..... SUBMITTED: C.C.F. .....
TRACED: J.A.R. ..... RECOMMENDED: W.G.S.
CHECKED ..... APPROVED .....

DENVER COLORADO FEB 3, 1937 | 253-D-62

FIGURE 126

Rio Grande Joint Investigation

CO - 003476

the low points of which are still lower than have been reached in the present cycle.

F‾ ⁊ of Diversions on Irrigation 'he Animas River

..e land classification being made as a part of the Colorado River Basin Investigation authorized by section 15 of the Boulder Canyon Project Act, shows 4,153 acres being irrigated above Durango from the Animas River with little, if any, possibilities of further extension. Below Durango the existing irrigated area is 14,354 acres, with minor possibility of extension.

A tentative study of discharges of the Animas River at Tacoma and Durango, depleted for possible diversions to the Rio Grande for every month from 1911 to date, indicates that no shortages would have occurred at any time on existing rights or future developments now considered feasible.

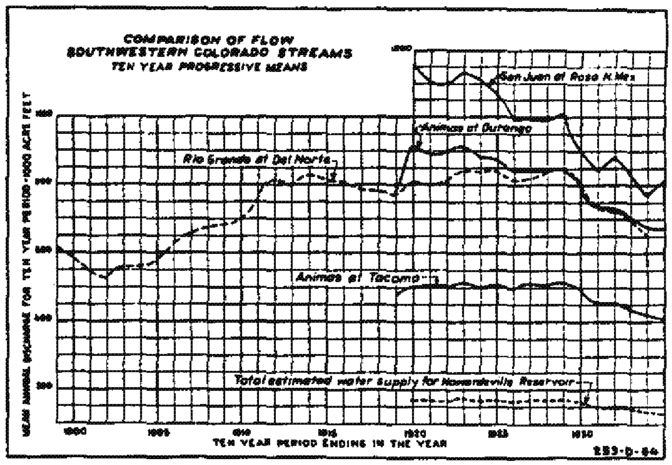


FIGURE 127

TABLE 12.—*Animas-Rio Grande transmountain diversion estimate*

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
Diversions (4) South Mineral Creek, Mineral Creek, Cement Creek, and Arrastre Creek:								
Diversion and care of creeks	(1)	4	$500.00	$2,000			$500.00	$2,000
Excavation, common	$1,000	Cubic yard	.75	750			.75	750
Excavation, rock	1,000	Cubic yard	3.00	3,000			3.00	3,000
Backfill	275	Cubic yard	.25	69			.25	69
Puddling backfill	275	Cubic yard	.50	138			.50	138
Concrete, structure	450	Cubic yard	18.00	8,100	3.75	$1,688	21.75	9,788
‾adial gates, three 3 by 5 feet, one 8 by 5 feet, two 6 by 5 feet	10,700	Pound	.05	535	.10	1,070	.15	1,605
'sts	3,800	Pound	.05	190	.25	950	.20	1,140
ıforcement steel	40,500	Pound	.02	810	.035	1,418	.055	2,228
z riprap	400	Cubic yard	1.50	600			1.50	600
Excavation, common	178,000	Cubic yard	.20	35,600			.20	35,600
Excavation, rock	166,200	Cubic yard	.80	132,960			.80	132,960
Backfill	27,000	Cubic yard	.25	6,750			.25	6,750
Trimming foundation	118,000	Square yard	.45	53,100			.45	53,100
Concrete, cut and cover section	3,375	Cubic yard	16.00	54,000	3.75	12,656	19.75	66,656
Concrete, combination section	23,900	Cubic yard	13.00	310,700	3.75	89,625	16.75	400,325
Concrete, bench flume	1,070	Cubic yard	18.00	19,260	3.75	4,013	21.75	23,273
Reinforcement steel	2,934,000	Pound	.02	58,680	.035	102,690	.055	161,370
Rock riprap	50	Cubic yard	1.50	75			1.50	75
Tunnel (D=9.5 feet; L=14,000 feet):								
Excavation, all classes	50,120	Cubic yard	9.00	451,080			9.00	451,080
Steel rib supports	169,400	Pound	.08	13,552			.08	13,552
Steel liner plates	464,800	Pound	.08	37,184			.08	37,184
Concrete lining	12,495	Cubic yard	10.00	124,950	5.00	62,475	15.00	187,425
Timbering	137	M ft. b. m.	80.00	10,960			80.00	10,960
Drains	14,000	Foot	1.00	14,000	.50	7,000	1.50	21,000
Tunnel (D=8.75 feet; L=68,560 feet):								
Excavation, all classes	206,000	Cubic yard	15.00	3,090,000			15.00	3,090,000
Steel rib supports	757,600	Pound	.08	60,608			.08	60,608
Steel liner plates	2,159,700	Pound	.08	172,776			.08	172,776
Concrete lining	30,000	Cubic yard	16.50	495,000	5.00	150,000	21.50	645,000
Timbering	596	M ft. b. m.	80.00	47,680			80.00	47,680
Drains	55,000	Foot	1.50	82,500	1.00	55,000	2.50	137,500
66-inch needle valve	66,000	Pound	.025	1,650	.245	16,170	.27	17,820
79-inch paradox gate	81,000	Pound	.025	2,025	.21	17,010	.235	19,035
Hoist	3,000	Pound	.025	75	.245	735	.27	810
Miscellaneous metal	20,000	Pound	.025	500	.175	3,500	.20	4,000
Control house	(1)			2,000				2,000
Highway relocation	5	Mile	15,000.00	75,000			15,000.00	75,000
Right of way	825	Acre	50.00	41,250			50.00	41,250
Property damage	(1)					50,000		50,000
Subtotal				5,410,107		576,000		5,986,107
Contingencies, 15 percent								897,916
Total estimated field cost								6,884,023
Investigations and surveys								15,000
Engineering and inspection, 6 percent								413,041
Superintendence and accounts, 1½ percent								103,260
General expenses, 2½ percent								172,101
Total estimated cost								7,587,425
Howardsville Dam (total estimated cost)								2,845,071
Grand total								10,432,496

[1] ᵕump sum.

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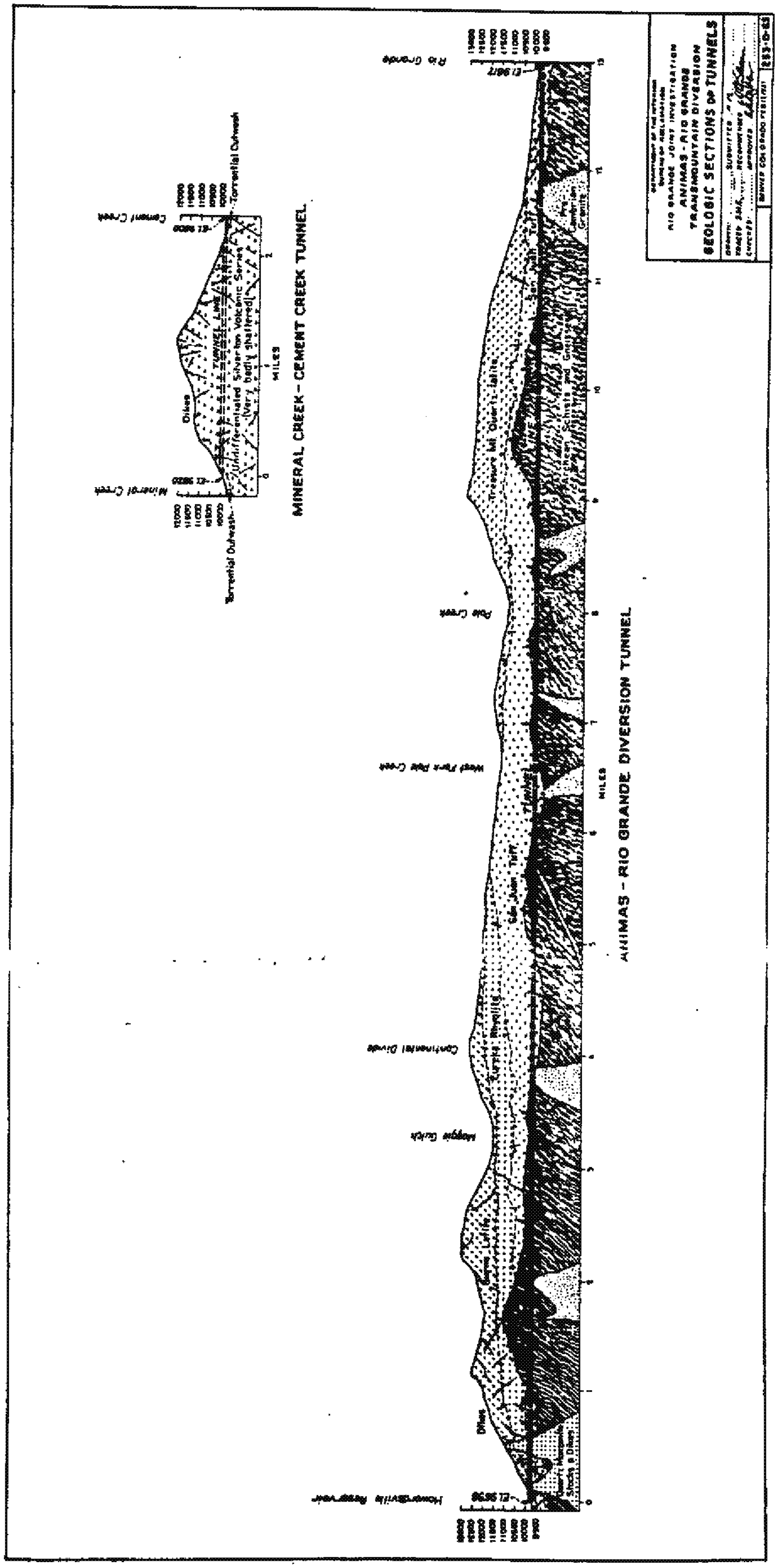

FIGURE 128

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Surveys

A topographic survey of the Howardsville Reservoir ... a scale of 200 feet to the inch, and triangulation for ... unnel line from Howardsville to the Rio Grande ... e carried out during August and the early part of September 1936. Detailed topography was not taken at the dam sites. Trial lines for the collection ditches were run by plane-table at elevation 9,600 and 9,800, the upper line being finally chosen after results of the tunnel survey became available. A trial canal line was run between Mineral Creek and Cement Creek, but the terrain encountered was so difficult that the tunnel between the two creeks was decided upon as the most feasible route for the canal. Topography was taken at each of the diversions from the various creeks.

Geology

Animas-Rio Grande tunnel.—With so little time and funds available for the investigation of this tunnel, the geologic investigation was necessarily limited to a minor field reconnaissance and an office study of available reports. Fortunately, the regional geology was but recently reviewed in a report by W. Cross and E. S. Larson (U. S. G. S. Bulletin No. 843, 1935).

The geologic history of the tunnel area starts with the pre-Cambrian period when the rocks of the time were metamorphosed into schists and gneisses. Then followed successively: Repeated intrusions by granite and ...ed magmas; marine sedimentation with the forma... of enormous thicknesses of sandstone, shales, and limestones in some places and local erosion in others; Cretaceous uplift with deep canyon erosion; volcanism with vast deposits and flows of tuffs, breccias, and agglomerates interspersed with periods of erosion. Repeated intrusions shattered, deformed, and altered host rocks in many localities and left innumerable adjacent zones of weakened materials, and finally uplifts and erosion.

Most of the main tunnel will be in Pre-Cambrian crystalline rock but volcanic tuff, flows, intrusions, breccias, and agglomerates will be encountered. The predominate type crystalline rock in this locality is a hard, black, amphibole schist, but undoubtedly areas of gneiss, granite, and other schists will be penetrated. Numerous dikes and other intrusives will be encountered. The series should offer no serious construction problem. The San Juan tuff, which immediately overlies the crystallines and may be penetrated for considerable distances, is formed of volcanic ejects and consists of dark andesite fragments and light colored volcanic ash, loosely consolidated. The tunnel will probably require timbering in this material. A few remnants of limestone and sandstone are found in Cunningham G..lch and the tunnel may encounter some of these ...ents, but little remains of them.

The greatest difficulty in construction will probably be encountered near the Howardsville Portal. Here, the rocks are a complex of flows, intrusives, tuffs, breccias, and agglomerates which have been deformed, fractured, altered, and intruded until it is difficult to follow any one formation for more than a few hundred feet. The series will be hard with softer altered zones and the shattered condition may give rise to undesirable water conditions. Support may be needed in sections.

Near the Rio Grande portal the tunnel will enter the Treasure Mountain quartz latite, a formation consisting of uniform latite and andesite flows with some interflow tuffs. Some lensed agglomerates will be encountered and may contain water. The flows are in general massive and competent and no undue difficulty is to be expected in the tunneling operations.

The geologic section shown on figure 128 was made from a regional study of the tunnel line. Because of the complex history, the section may be inaccurate in several sections, especially near the central portions. Only a few exposures of the underlying Archean crystallines have been found and the resultant interpretation of a predominantly crystalline tunnel may not be accurate.

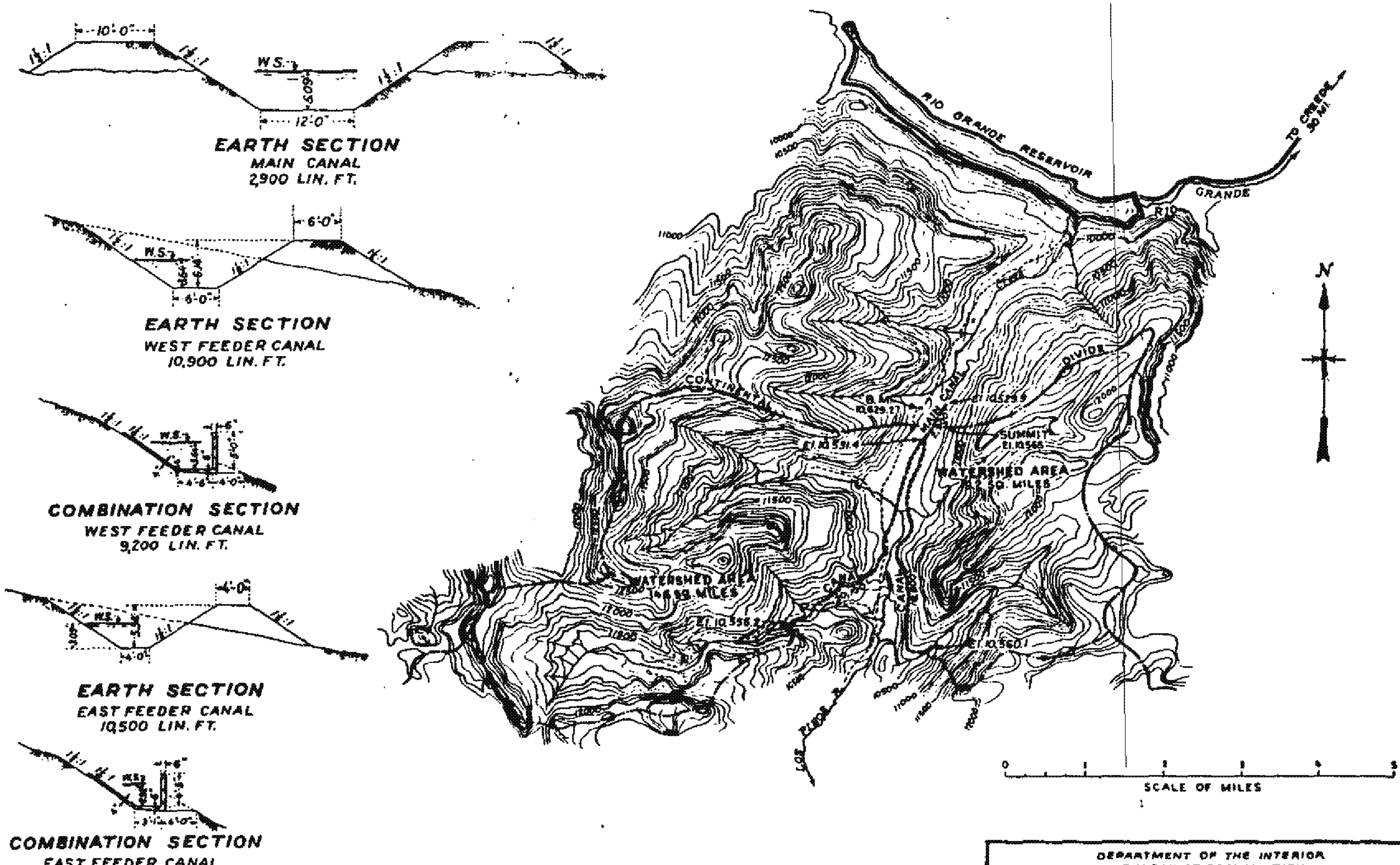
Many questionable zones will be penetrated: formation contacts, alteration of host rocks by intrusives, and loosely consolidated areas in the San Juan tuff or in any agglomerate or volcanic covered detritus. All such conditions will have their effect on the amount and rate of water to be encountered and on stability.

The porous San Juan tuff undoubtedly will contain water, held up as it is by the impervious basement of Pre-Cambrian rock. The elevation of these cyrstallines should be ascertained along the tunnel line by a careful geological investigation and by drilling where it is needed. The tunnel should be located continuously in the impervious Archean rocks, if possible.

Mineral Creek—Cement Creek tunnel.—A profile along the tunnel is shown on figure 128. Both portals should encounter bed rock within a relatively short distance. The bedrock is the Silverton volcanic series so extensively altered and fractured that it is impossible to determine the resultant relationship between the individual flows. Faults, folds, and other structural features are obscure. Such a condition allows only general observations as to the conditions to be expected in the tunnel. Some difficulty is to be expected in the shattered and altered zones through caving ground. Continuout trouble is not expected. Water conditions are nos expected to be severe as the source area is small and the general fractured condition of the rock will make for a general low water table through the area.

Howardsville reservoir and dam sites.—Geological work at this site is of only a preliminary character.

The basin is an erosional valley cut in the Eureka rhyolite and Burns latite flows of the Silverton volcanic



HYDRAULIC PROPERTIES

SECTION	A	V	Q	r	n	S
Main canal earth section	100.0	3.00	300	3.29	.025	.00052
West feeder canal earth section	41.7	3.00	125	2.18	.025	.00093
West feeder canal combination section	21.6	5.78	125	1.65	.014	.00148
East feeder canal earth section	26.7	3.00	80	1.77	.025	.00125
East feeder canal combination section	13.8	5.78	80	1.30	.014	.00202

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
WEMINUCHE PASS
TRANSMOUNTAIN DIVERSION
GENERAL MAP

REV. 8-1-37

DRAWN: .... SUBMITTED: ....
TRACED: S.M.E., C.M.A. RECOMMENDED: ....
CHECKED: .... APPROVED: ....

DENVER, COLORADO JULY 21, 1937 253-D-66

FIGURE 129

series. No evidence of an abnormal water table is found and spring and seep occurrences all indicate that any underground flow is directed normally down the r through the river detritus, or possibly in sections fractured flow bedrock. The sides of the basin a., n general, mantled with wash and fan materials in local transit to the stream. The flat basin bottom is composed of rounded and subangular pebbles and cobbles with sand and silt to form a firm but porous deposit. It is probably somewhat stratified.

Dam site no. 1, about 1 mile down stream from the highway bridge at Howardsville, is at the upper end of a steep walled gorge. Bedrock is very near the surface on both abutments and probably quite shallow in the foundation. The foundation and abutments of the dam are of the Burns latite, a dark gray, hard flow rock resembling andesite, underlain with Eureka rhyolite which, in turn, probably lies on the San Juan tuff, a compact mixture of angular andesite fragments and ash. The depth of river fill at this locality will probably not be excessive (10 ft.–20 ft.) as some sections of the canyon show rock across the bottom. All of the immediate rock is extremely broken and fractured so that the walls of the canyon appear cracked into small blocks. Weathering has widened these fissures.

Perhaps the most questionable and serious factor concerned is the severe fracturing of all of the foundation and abutment bedrock. Undoubtedly grouting will be re...ired which may reach such proportions as to render t undesirable.

.am site no. 2, 3,000 feet below the Howardsville bridge, the bedrock Burns latite is part of the same flow as encountered at the no. 1 dam site. However, the site at this position is out of the canyon section and the valley sides slope more uniformly to the river. The rock in all probability is equally as fractured as that at no. 1 with with less steep slopes, the joints have not had the same opportunity to expand and so an appearance of a tighter, less fractured rock is afforded. It is believed, however, that drilling will indicate its inherent fractured condition.

Bedrock is exposed only on the right abutment, about 40 feet above the railway grade. A mantle of glacial boulders and fragments covers the rest of the area together with large angular talus blocks and detritus derived from the immediate higher land and is apt to be 20 to 30 feet deep. The left abutment overburden is mainly outwash from a nearby gully probably 10 to 20 feet deep, modified by créep movement and incorporated glacial detritus. It is likely that all of this overburden would be removed during construction. The river at this point is flowing on coarse river gravels embedded in considerable sand and silt, with rock probably within 20 to 40 feet. Extensive grouting will be ired to eliminate possible abutment and foundation seepage which may otherwise prove to be excessive.

At dam site no. 3, located about 1,000 feet below the Howardsville Bridge, the entire area is mantled with various detritus.

The right abutment is a large alluvial fan made up of torrential debris carried down Brendel Gulch during floods. This detritus is a coarse mixture of angular boulders and fragments embedded in sand and silt. Probably 75 percent or more consists of large rock inclusions. It is believed to be fairly compact but its porosity and the manner in which it will act when saturated has not been determined. Bedrock, probably deep beneath the debris, will be the Burns quartz latite. The left abutment is mantled with outwash, composed of angular fragments and rock embedded in silt and sand, the whole being somewhat modified by soil creep. It is probable that bedrock is within 10 to 20 feet of the surface. Depth to bedrock in the channel is estimated at 50 feet.

Perhaps the most questionable feature at this dam site is the character of the right abutment outwash fan. Tests to determine its reaction to conditions similar to those that will be imposed by the dam should be made. The fan of the right abutment is as much in the process of formation today as at any time in the past, by frequent torrential floods. The depth of overburden will minimize the requirement for grouting of the bedrock.

The points in favor or against each of the possible dam sites are so widely varied that no comprehensive opinion can be formed without the advantage of a testing program. Geologically, the no. 1 site is to be preferred, provided that the severe fracturing of the bedrock has not so increased the porosity and decreased the stability as to lose the advantage normally gained by a bedrock foundation. Considerable exploratory work will be required at all of these sites before a selection can be made.

Weminuche Pass—Transmountain Diversion

The project contemplates the diversion of two creeks, one on each side of the Los Pinos River at elevation 10,550, to the central stream near the head of the pass with a combined drainage area of 23 square miles and thence through the divide by means of a long cut. The canal discharges into an unnamed creek which flows into the Rio Grande Reservoir. Figure 129 is a general map of the plan. The routes of both canals were covered by strip topography taken with a plane-table on a scale of 200 feet to the inch, with 5-foot contour interval.

Total run-off originating in the tributary watershed area was estimated by means of the altitude run-off curves used for the San Juan-Chama diversion project,

TABLE 13.—*Weminuche Pass transmountain diversion*

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total
Diversion structures (2):								
Diversion and care of creeks	(1)	2	$500.00	$1,000			$500.00	$1,000
Excavation, common	400	Cubic yard	.75	300			.75	300
Excavation, rock	400	Cubic yard	3.00	1,200			3.00	1,200
Backfill	100	Cubic yard	.25	25			.25	25
Puddling backfill	100	Cubic yard	.50	50			.50	50
Concrete, structure	206	Cubic yard	18.00	3,708	$3.75	$773	21.75	4,481
Radial gates, 2-3 by 5 feet, 1-8 by 5 feet, 1-6 by 5 feet	5,200	Pound	.05	260	.10	520	.15	780
Hoists	1,700	Pound	.05	85	.25	425	.30	510
Reinforcement steel	21,000	Pound	.02	420	.035	735	.055	1,155
Rock riprap	255	Cubic yard	1.50	383			1.50	383
Canals:								
Excavation, common	97,280	Cubic yard	.20	19,456			.20	19,456
Excavation, rock	38,990	Cubic yard	.80	31,192			.80	31,192
Backfill	100	Cubic yard	.25	25			.25	25
Trimming foundation	20,830	Square yard	.45	9,374			.45	9,374
Concrete, combination section	3,950	Cubic yard	13.00	51,350	3.75	14,813	16.75	66,163
Reinforcement steel	434,500	Pound	.02	8,690	.035	15,208	.055	23,898
Rock riprap	75	Cubic yard	1.50	113			1.50	113
Construction road	1.5	Mile	15,000.00	22,500			15,000.00	22,500
	4.5	Mile	5,000.00	22,500			5,000.00	22,500
Subtotal				172,631		32,474		205,105
Contingencies, 15 percent								30,766
Total estimated field cost								235,871
Investigations and surveys								5,000
Engineering and inspection, 6 percent								14,152
Superintending and accounts, 1½ percent								3,538
General expense, 2½ percent								5,897
Total estimated cost								264,456

[1] Lump sum.

somewhat modified to more nearly fit the trend indicated by the records of the Pine River at Bayfield. The results for the years 1916–35 are presented in figure 130. Filings have been made and ditches

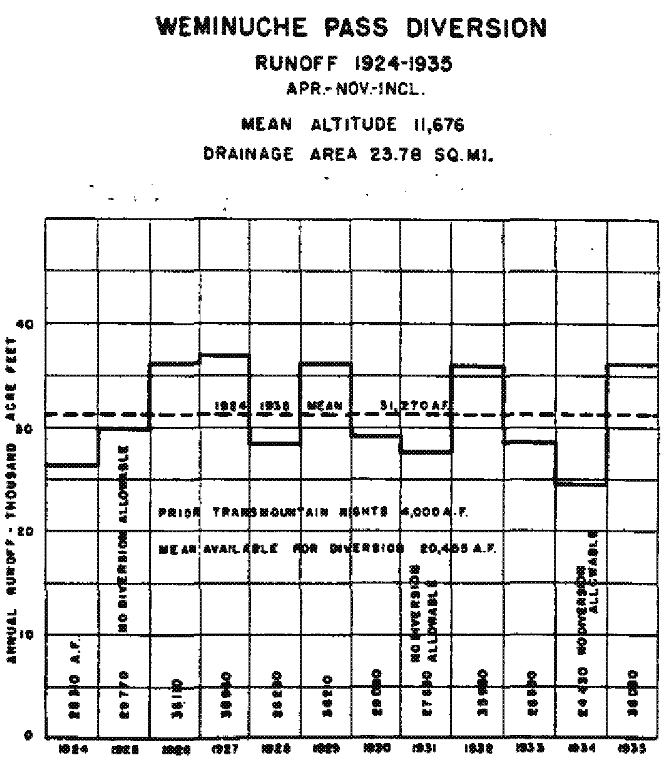


FIGURE 130

practically completed for a total of 20 second-feet of water to be diverted from two small creeks within this area at elevations just high enough to be taken over the Weminuche divide without a deep cut, but no decrees have yet been secured. It is estimated, from a comparison of areas tributary to these ditches, t' about 4,000 acre-feet, on the average, might be secu by such a diversion.

Diversions will be further limited in occasional years by the requirements for the Pine River project at Bayfield for which a reservoir of 125,000 acre-feet will soon be under construction to serve 69,000 acres of which about 35,000 acres are now being irrigated. A study of this project shows that while the reservoir would not have filled in 1925, 1931, and 1934, there would have been no serious shortages except in 1934.

The mean run-off from the intercepted area for 1924 to 1935 is estimated at 31,270 acre-feet. Allowing 4,000 acre-feet to care for prior rights for diversion through the pass and no water divertible in 1925, 1931, or 1934, by reason of the Pine River project demands, the 1924–35 average available for diversion is 20,455 acre-feet.

San Juan-South Fork Rio Grande Transmountain Diversion

General Plans

Early proposals for this diversion contemplated only a tunnel from Wolf Creek through the Continental

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Divide to the South Fork of the Rio Grande, a collection system to divert the West Fork of the San Juan River in' 'Beaver Creek, and both streams carried to the V reek portal by a ditch along the 9,000-foot conto.. The terrain between Beaver Creek and Wolf Creek at this elevation is a succession of precipitous cliffs, close examination of which in the field disclosed the impracticability of such a plan.

The plan adopted (fig. 131) provides for the diversion of the West Fork of the San Juan River to Beaver Creek in a canal approximately 2 miles long, of which 2,400 feet is bench flume. From Beaver Creek an 8-foot tunnel, 3.2 miles long and of 425 second-feet capacity would carry water southeasterly to meet a tunnel of the same size and 1.1 miles long from Wolf Creek. A 9-foot tunnel, 6.7 miles long and of 525 second-feet capacity will lead from the junction to the South Fork of the Rio Grande.

It will require 7 miles of difficult road construction to gain access to the West Fork diversion and the Beaver Creek portal. The South Fork portal is within a half mile of the main graveled highway over Wolf Creek summit, which also passes within 200 feet of the Wolf Creek portal. The latter is approximately 15 miles from the Creede branch of the Denver & Rio Grande Western Railroad Co.

Concrete aggregates are expected to be secured within a few miles of the three tunnel portals.

Si

Triangulation of the tunnel lines was carried out from the Hot Springs site to Wolf Creek portal and then to the South Fork portal. Strip topography was taken from Hot Springs to Beaver Creek. The Hot Springs and Beaver Creek reservoir sites were surveyed on a scale of 200 feet to the inch and their damsites on a scale of 50 feet to the inch. Detailed topography was also taken at each of the tunnel portals.

Geology

Near the close of the Cretaceous period, the great Rocky Mountains were uplifted from the sea, marine deposition ceased, and in the San Juan region the early part of the following Tertiary period appears to have been one of comparative quiet with continuous erosion. Beginning with about Miocene time, a long series of eruptions progressively filled in the valleys and, in time, buried the highest peaks with lavas. During interspersed erosion periods, drainage patterns were developed, at times with deep canyons subsequently refilled.

The oldest formation which will be encountered in the tunnel is the Conejos andesite, a series of alternating and ··s and related flows, containing breccias and agglomerate lenses of sand, gravel, and cobbles. Usually these lenses are well compacted with interstitial silts and clay, although a somewhat porous deposit is to be expected. Some lenses appear baked due to the heat of the overlying flows. This formation is about 800 feet thick where exposed as prominent cliffs near Beaver Creek.

Above the Conejos formation is a series of alternating flows and tuff beds called the Treasure Mountain quartz latites, mostly rhyolitic and latitic flows with minor amounts of breccias and agglomerates. The more massive members often stand out as bold vertical cliffs. In this locality the formation is about 1,200 feet thick.

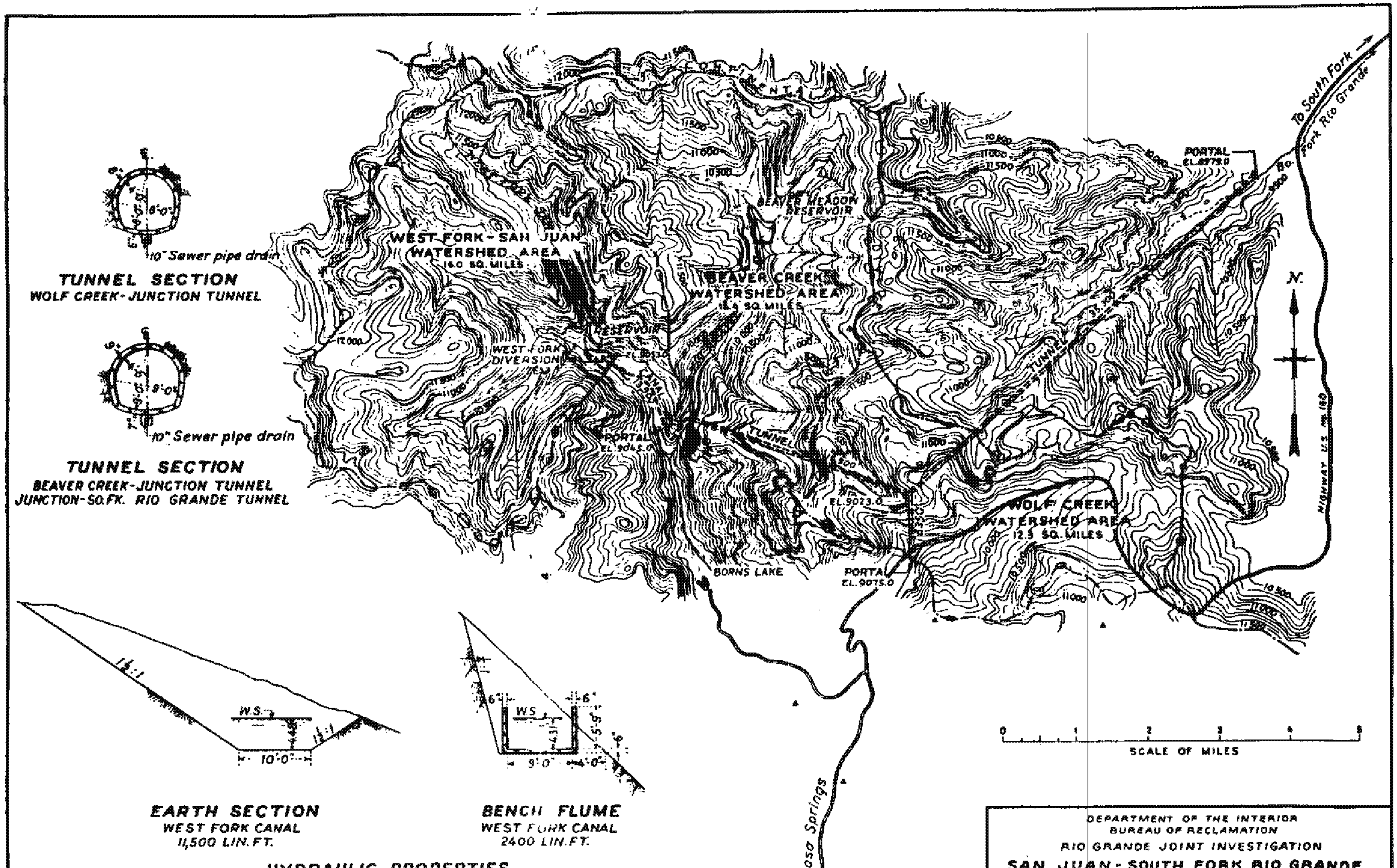
Overlying the Treasure Mountain series is the Sheep Mountain formation, consisting of thin discontinuous flows and chaotic breccias. Many of the brecciated flows appear to have been hot enough when broken to have welded together again. Little foreign agglomeratic material is present. This series is about 800 feet thick near Beaver Creek, where it is exposed in prominent cliffs.

The Alboroto quartz latite overlies the Sheep Mountain series. It consists of an enormous thickness of tuff beds and thick regular flows of quartz latite. The tuff beds are indurated and in many ways are similar to the flows, some of which are many hundreds of feet thick and appear to be dense and massive, with no outstanding breaks or fractures. In this locality, the formation is at least 1,600 feet thick.

Overlying the Alboroto formation are the Huerto andesites, the youngest flows to be encountered in the tunnel, composed of thin discontinuous andesite flows, 20 to 80 feet thick, and chaotic masses of breccia. With the brecciated masses is much fine cementing material so that a fairly resistant deposit is formed.

As indicated on the geologic section (fig. 132), the Beaver Creek Portal will begin in the Alboroto quartz latite. About one-half mile from the portal on the far side of the fault, it may penetrate the Sheep Mountain andesite, raised above its normal position by drag folding along the fault. On penetrating the fault zone it will be in the Treasure Mountain quartz latite for nearly 6 miles, although some of the central portions may fall in the lower Conejos andesite series. The last 3 miles, near the South Fork portal, will be in the Alboroto formation. The short tunnel from Wolf Creek to the angle in the main tunnel will start in the upper part of the Conejos andesite and near the junction may enter the Treasure Mountain series. It is doubtful, however, whether in the tunnel the two formations can be differentiated.

Structurally, all the flows encountered will be approximately horizontal, but local variations will be



HYDRAULIC PROPERTIES

SECTION	A	V	Q	r	n	S
West Fork Canal earth section	75.0	3.00	225	2.86	.025	00063
West Fork Canal bench flume	38.8	5.80	225	2.21	.014	00102
Beaver Creek-Junction Tunnel	58.1	7.32	425	2.76	.014	00117
Junction-So Fk Rio Grande Tunnel	64.6	7.97	515	2.67	.014	00150
Wolf Creek-Junction Tunnel	10.5	11.70	125	1.16	.014	00972

FIGURE 131

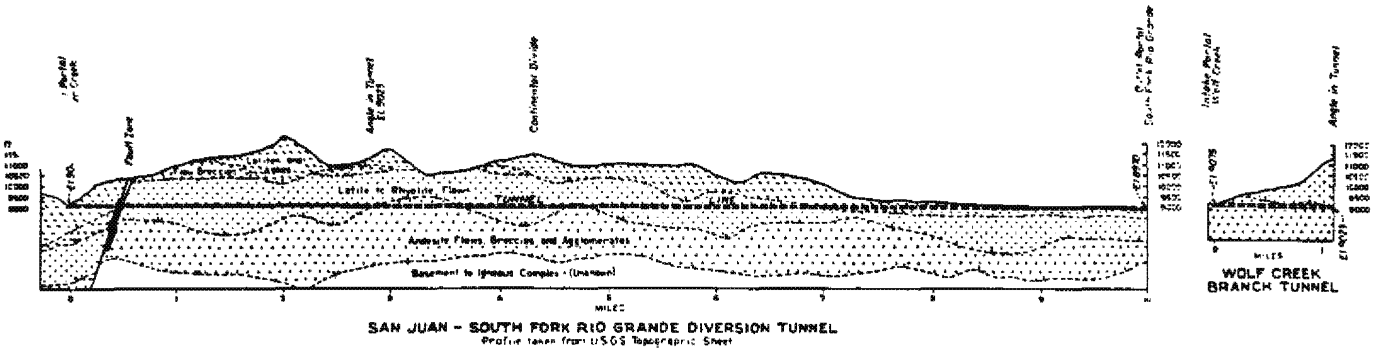


FIGURE 132

found with radical changes in the vicinity of the Beaver Creek fault. The only large fault indicated by present preliminary investigation will be penetrated by the tunnel not far from the present Beaver Creek portal. This is a large fault with a known vertical displacement of over 2,000 feet. It is entirely possible, but not expected, that other less severe displacements will be encountered. The faults seem now inactive.

Contacts between flows undoubtedly will contain local gravel or other detritus remnants incorporated between successive flows. As a generalization, these lensed inclusions may be more extensive between formation contacts than between intraformational flows. Such zones may cause soft caving ground.

It is probable that the regional water table is extremely erratic due to the variable permeabilities of th[illegible] members and the repeated changes in the drainage pattern. Some areas are likely to show water close to the surface while others will be dry for possibly thousands of feet. The area has, however, a high runoff and the total supply is great so that any opportunity to build up a high table would be taken. Under such a high table, if the tunnel happens to tap a fractured zone or other porous structure, the inflow may be great and of long duration. Areas that are open to the most suspicion are those in the Treasure Mountain and Conejos formations as well as in the fault zone. The Alboroto latites are, in general, massive and relatively impervious. Insofar as there is no regional under lying impervious basement as at the Silverton tunnel, large ground water basins will probably be rare and of local extent.

The tunnels will be in rock throughout but a section not far from the Rio Grande portal passes beneath a basin under which the rock cover will not be great.

It is believed that, on the whole, the rock will be adequately competent to support itself. Even the agglomerate lenses, where exposed, appear quite solid. Construction should be preceded by additional surveys, supplemented by some drilling.

Beaver Creek Reservoir and Dam Site

The bedrock in the basin is made up of a wide variety of volcanic materials, ranging from flows, agglomerates, and breccias to tuff. The complexity of the relationships is due to a fault running up and down the valley, a continuation of that penetrated by the tunnel.

The basin is, in general, heavily mantled with overburden materials, the bottom with river sorted gravels and sand, while talus and outwash materials cover the valley sides with varying thickness.

The reservoir basin has a normal tributary water table as indicated by spring and seep occurrences.

The ultimate bedrock at the dam site is probably the Huerto andesite, a volcanic flow formation, including

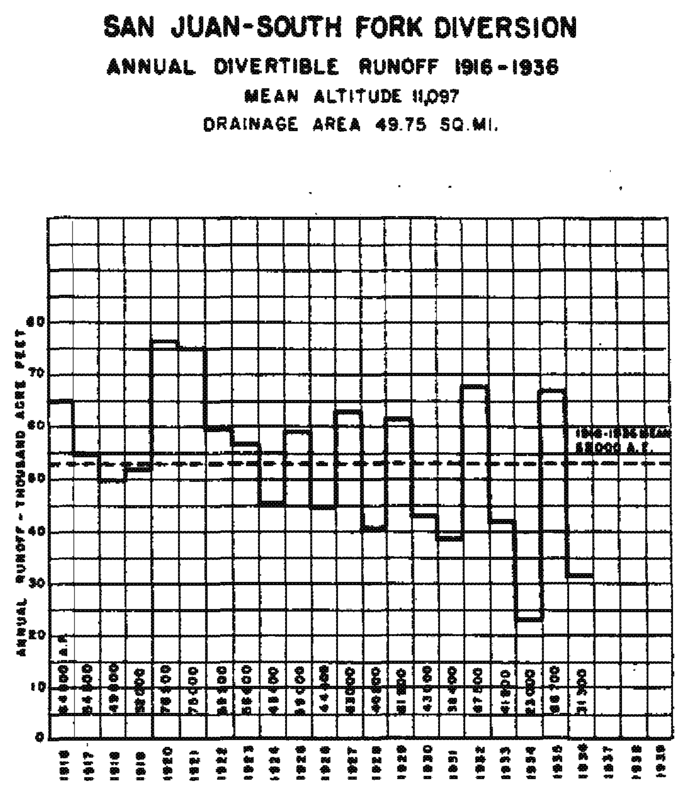


FIGURE 133

volcanic breccias and agglomerates. A fault passes up and downstream through the foundation, bringing older Potosi volcanics in juxtaposition to the above-mentioned Huerto andesite. Bedrock will not be economically within reach for either foundation or abutments.

The right abutment consists of slump rock and soil slowly creeping toward the stream bed. For 800 feet vertically above the bottom of the valley, one can see hundreds of irregularly tilted blocks of shattered rock. Near the proposed axis the slope of this creep material is 40° or more, indicating that the material will continue to move when conditions are favorable. The depth of this deposit is unknown with estimates ranging from 20 to 100 feet.

From a gully adjacent to the left abutment, torrential floods have washed large quantities of rock and soil to form an outwash fan of unknown depth. This deposit of debris was progressively built up faster than the main stream could carry it away, resulting in a choking of the valley to form the present reservoir basin. The choking of the stream has been an intermittent affair so that the central portions of the dam may be underlain with alternate wash and areas of more or less stratified deposits.

Perhaps the most serious problem concerns the ability of the overburdens to take the dam load and meet the permeability requirements. Nothing can be concluded in this regard without a complete test pit program. Another feature is the right abutment slide area probably still in motion down the slope. A third feature is possible leakage through the fault and the fractured bedrock. A drill program should ascertain the rock profile, the condition of the bedrock, ar porosity. No recent movement is indicated along fault line.

Hot Springs Reservoir and Dam Site

The reservoir basin is believed competent with a water table tributary to the stream. The valley is cut in the massive Alboroto quartz latite volcanic flows, little fractured. The sides of the valley are often bare but some areas are covered with a thin wash of soil and large angular rock. The basin is filled with similar material.

The river is flowing on bedrock and the abutments are for the most part bare. The flatter slopes back from the canyon edge are covered by a thin veneer (possibly 10 to 20 feet) of wash, composed of rock fragments embedded in some silt.

The rock on which the dam will rest is the Alboroto quartz latite, a series of thick massive flows and tuff beds. The flows are essentially horizontal, dipping only a few degrees to the north, without apparent faulting or fissuring. Minor grouting may be required.

Several hot springs issue from isolated joints in the rock, suggesting at least some deep water circulation possibly related to the Beaver Creek fault which, however, is located well out of the immediate dam area.

TABLE 14.—*San Juan-South Fork Rio Grande transmountain diversion estimate*

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
Diversions (3) West Fork, Beaver Creek, Wolf Creek:								
Diversion and care of creeks	(1)	3	$500.00	$1,500			$500.00	$1,500
Excavation, common	300	Cubic yard	.75	225			.75	225
Excavation, rock	950	Cubic yard	3.00	2,850			3.00	2,850
Backfill	250	Cubic yard	.25	63			.25	63
Puddling backfill	250	Cubic yard	.50	125			.50	125
Concrete, structure	385	Cubic yard	18.00	6,930	$3.75	$1,444	21.75	8,374
Reinforcement steel	34,000	Pound	.02	680	.035	1,190	.055	1,870
Rock riprap	200	Cubic yard	1.50	300			1.50	300
Canal: 10,500-foot earth canal, 2,400-foot bench flume:								
Excavation, common	45,700	Cubic yard	.25	11,425			.25	11,425
Excavation, rock	61,800	Cubic yard	.80	49,440			.80	49,440
Concrete, bench flume	985	Cubic yard	18.00	17,730	3.75	3,694	21.75	21,424
Reinforcement steel	88,700	Pound	.02	1,774	.035	3,105	.055	4,879
Tunnels: 5,850 feet, 8-foot diameter, 52,300 feet, 9-foot diameter:								
Excavation, all classes	190,000	Cubic yard	14.00	2,660,000			14.00	2,660,000
Steel rib supports	638,000	Pound	.08	51,040			.08	51,040
Timbering	533	M board measure	80.00	42,640			80.00	42,640
Concrete lining	47,800	Cubic yard	15.00	717,000	5.00	239,000	20.00	956,000
Steel liner plates	1,775,000	Pound	.08	142,000			.08	142,000
Drains	46,000	Foot	1.50	69,000	1.00	46,000	2.50	115,000
Construction road	7	Mile	15,000.00	105,000			15,000.00	105,000
Subtotals				3,879,722		294,433		4,174,155
Contingencies, 15 percent								626,123
Total estimated field cost								4,800,278
Investigations and surveys								10,000
Engineering and inspection, 6 percent								288,017
Superintendence and accounts, 1½ percent								72,004
General expense, 2½ percent								120,007
Total estimated cost								5,290,306

[1] Lump sum.

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Water Supply

Areas and mean altitudes of each individual area above the diversion point for the several plans considered were measured and run-off calculated from the altitude run-off curves already developed for the San Juan-Chama Diversion.

A reservoir at the Beaver Creek site of 4,500 acre-feet capacity requires a dam 100 feet high and 1,100 feet long with foundation conditions apparently very poor, although no explorations were made.

Above the diversion from the West Fork of the San Juan River, the Hot Springs Reservoir, with a capacity of 3,400 acre-feet, would require a dam 650 feet long and of 130 feet maximum height, with a cost roughly estimated at $1,000,000.

The reduction in canal and tunnel capacities, together with the small increase in water supply which these regulatory reservoirs would accomplish, is not commensurate with their cost. They are, therefore, omitted from the plan presented. The waters estimated to be divertible average 53,000 acre-feet annually, as shown on figure 133.

Conejos River Storage

The original program of investigation on the Conejos River contemplated only the drilling, prospecting, surveying, and estimate designs for a dam at site no. 1. This site had been previously investigated under the auspices of an association of water users on the Conejos River, but no foundation exploration had been done.

Conditions disclosed by initial drilling raised questions as to its feasibility. After consultation with interested parties, the scope of the investigation was broadened to include the prospecting, surveying, and estimate designs for other sites.

The location of all sites investigated is shown on figure 134. The extent of investigations at each is as follows:

Lower river

Dam site	Extent of investigations
Site no. 1	Six drill holes, two test pits, one drift, dam site survey. Rough estimate and design. Tipton Reservoir survey utilized.
Site no. 2	One drill hole in river bottom. Tipton Reservoir survey extended from no. 1.
Elk Creek site	Reconnaissance only.
Site no. 3	One drill hole on river bottom. No surveys. Geological reconnaissance.
Granite site	One drill hole, dam, and reservoir survey. Geological reconnaissance. Rough design and estimate.
Fox Creek site	Geological reconnaissance only.
Mogote site	One drill hole, three test pits, laboratory analysis of material. Dam, reservoir, and feeder canal surveys, estimates, and design.

Upper river

Site no. 4	One drill hole. Geological reconnaissance. No surveys.
Site no. 5	Three drill holes, dam site survey, geological reconnaissance.
Site no. 6	Reservoir and dam site survey. Geological examination. Design and estimates.

Dam Site No. 1 [1]

The reservoir is an erosional basin carved into a rock sequence of andesite flows, flow breccia, and agglomerate, dipping slightly downstream (1°–3°). In places erosion has penetrated to the granite floor on which the volcanics were extruded. Below the flow line, the sides of the basin are erratically covered with terrace gravels, wash, slump, and landslide materials. The water table is tributary to the stream as evidenced by normal ground water springs and seeps. This, together with consideration of the bedrock character, suggests that no significant seepage from the reservoir itself is to be expected.

The dam site is a narrows in which the enclosing bedrock is the same andesite complex found throughout the reservoir and no structural disturbances of folding or faulting were observed. The controlling factors to dam design are found not in the rock but in the character and relations of the various detrital overburdens. The right abutment is landslide debris, a heterogeneous aggregate of angular boulders, fragments, and crushed rock, together with some infiltrated surface silts. One drill hole and test pit indicates that the material is quite erratic both in composition and permeability. The slide debris is over 150 feet deep and rests on porous river gravels. It is believed that under present conditions the slide is quite stable, but this may not hold under the conditions imposed by the reservoir. The left abutment, as indicated by three drill holes, shows a narrow ridge of andesite extending to the river but flanked on both sides by deep wash and slump materials overlying terrace and river gravels. The ridge-like character of this abutment suggested that the rock is not in place but this suspicion was not upheld by one drill hole which penetrated rock for a depth of 146 feet. Drill holes show stratified river gravels or a loose, porous assemblage of gravel, cobbles, sand, and occasional boulders to be up to 200 feet deep in the river channel and they may be equally deep under the landslide and under the wash and slump deposits on the left slope. These gravels once extended higher than they do today, as evidenced by terrace remnants found 50 feet above the river. The landslide occurred over these gravels, when they were at river level, showing that the movement was not of recent occurrence.

[1] Figs. 135b and 136.

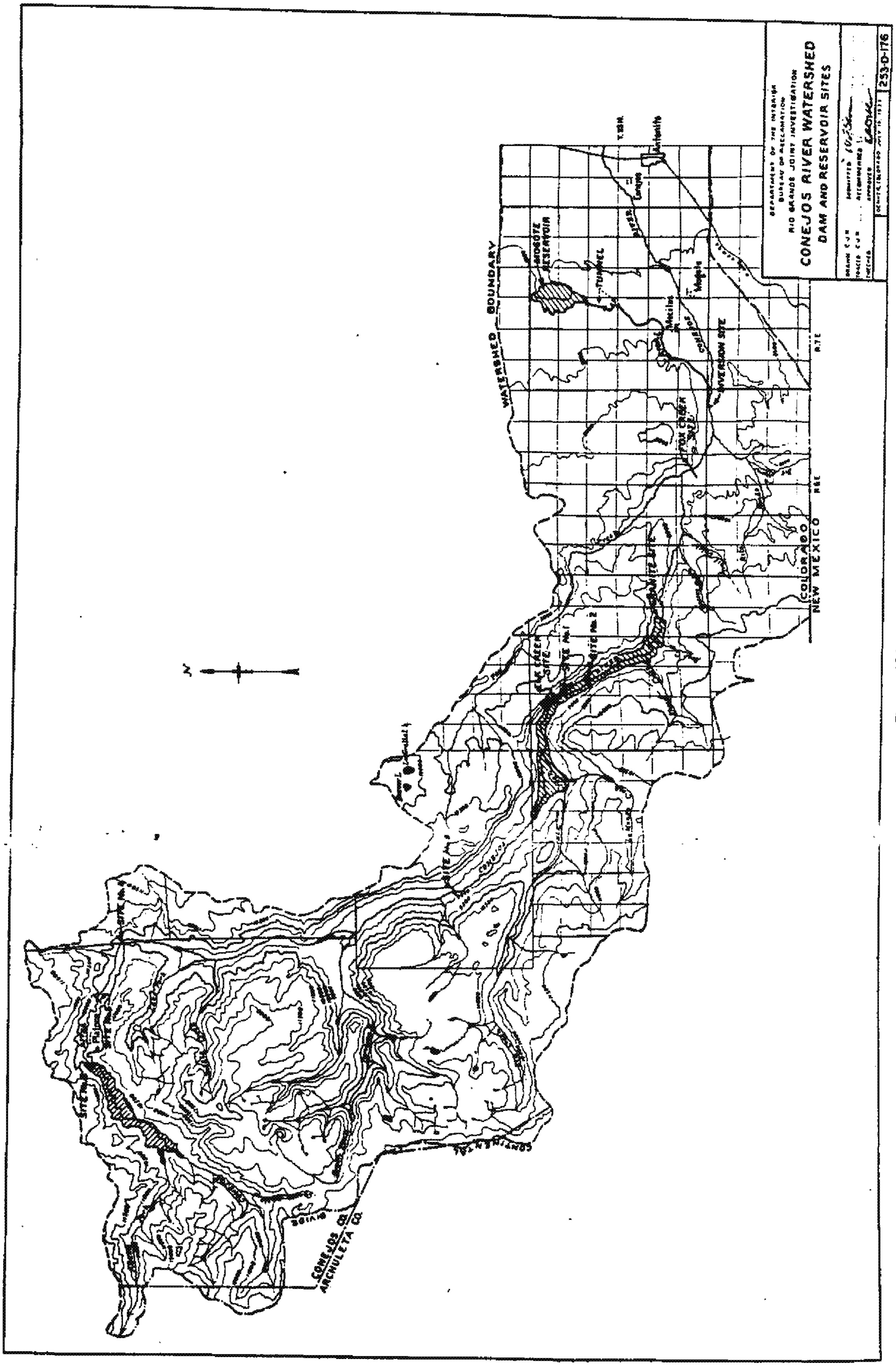

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
CONEJOS RIVER WATERSHED
DAM AND RESERVOIR SITES
253-D-176
WATERSHED BOUNDARY
MOGOTE RESERVOIR
TUNNEL
DIVERSION SITE
COLORADO
NEW MEXICO
CONEJOS CO.
ARCHULETA CO.
CONTINENTAL DIVIDE

FIGURE 134

Design and estimates.—The unfavorable foundation conditions demand extreme conservatism in the design of the dam. Construction of a cut-off to prevent percolation through the foundation is impractical. Reliance for safety must then be placed upon flat slopes, upstream blanketing and loose rock backing on the lower slope. Water losses beneath the dam may be estimated only after intensive and costly permeability investigations have been made. The results thereof may necessitate measures for control of percolation beyond those contemplated in the tentative design.

A dam 140 feet high to store 100,000 acre-feet is roughly estimated to cost $3,700,000.

Dam Site No. 2

This site was considered as a possible alternative to no. 1 dam site. Preliminary investigation did not indicate such superior merit as to warrant unequivocal acceptance. The reservoir basin is the same as that commanded by the no. 1 site and no new factors are introduced.

The dam site geology is in many ways parallel to the conditions found at the upper site. The bedrock is a complex of Conejos andesite, flow breccia, and agglomerate dipping downstream (1°–3°) and no faulting is in evidence. As at the no. 1 site, the most important factors involve the condition and relations of the various overburdens. The left abutment is a landslide of uncertain origin, composed of angular boulders, fragments, and crushed rock with much interstratified surface silts. It overlies river gravels which will be found to extend to considerable depth, possibly 100–150 feet. The right abutment shows bedrock close to the surface but conditions immediately up and down stream from the axis have not been determined. One hole, drilled to a depth of 90 feet, was entirely in river gravels which, in all probability, continue to over 150 feet. As at the upper site, terrace gravels, erratic wash, and talus deposits are found at various positions on the abutments.

The geological problems involve permeability of the left abutment slide and the underlying foundation. The stability of the landslide debris is open to question with regard to piping, settlement, or other transfer of material. As the site is geologically no better than the no. 1 site, with the dam more costly, it has been given no further consideration.

Elk Creek Site

This dam site, utilizing the Elk Creek storage basin, is located about 2 miles upstream from site no. 1. The dam must necessarily be a large one and, because of this, has not heretofore been seriously considered. Perhaps the main advantage of this site is the absence of landslide abutments giving access to the deep foundation gravels.

The dam site has by no means ideal geological conditions, but the simple relationships have not been altered by landslide or other structural disturbances. Both abutments are composed of Conejos andesite, flow breccia, and agglomerate, dipping 2° to 3° downstream. All rock is believed to be in place but is covered with various amounts of wash and talus interfingering with the bottom river gravels. The foundation gravels may prove to be 150 feet or more in depth.

Construction problems have to deal mainly with the control of foundation percolation.

Neglecting the excessive size of the required dam, this site is geologically preferable to the Conejos no. 1 or 2 sites.

Dam Site No. 3

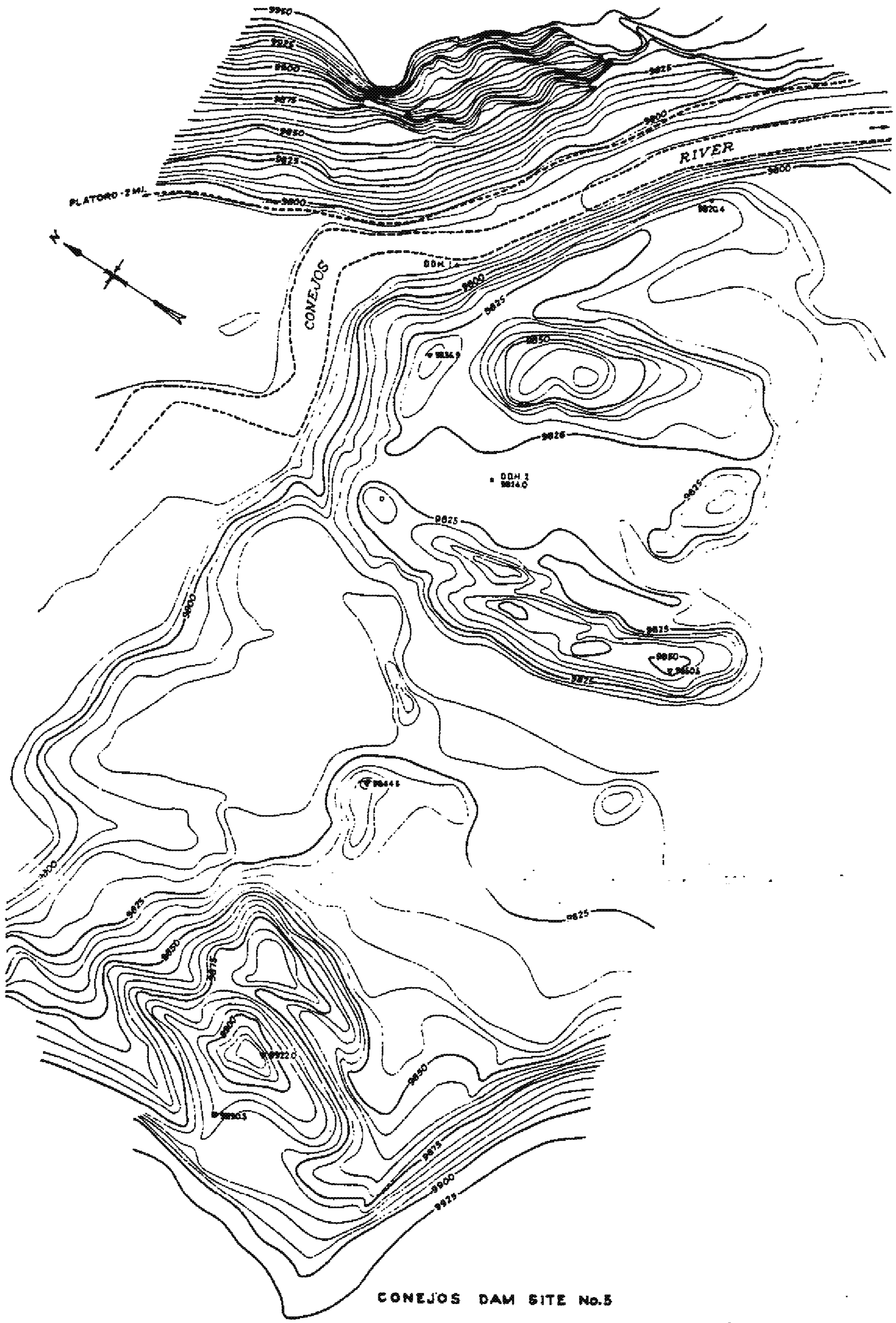
The reservoir utilizes the South Fork Basin and is probably the highest site on the river which can control South Fork run-off. Like no. 1 reservoir, the valley is an erosional basin in the Conejos andesite, flow breccia, and agglomerate complex, heavily mantled with detrital overburdens below the flow line. The bottom flats are covered with deep porous gravels and the sides with erratic landslide, wash, slump, and terrace deposits. The water table is tributary to the stream and no reservoir seepage is to be expected.

The dam site has many unattractive features. Rock will be deep in the foundation and abutments. Both abutments are of landslide material, composed largely of angular rock and rock fragments with some interstitial silts. One drill hole in the foundation penetrated boulders, gravel, and sand to a depth of 172 feet without reaching bedrock.

While the river bed gravels are quite permeable, they would be stable under earth-dam conditions. The slide materials on the other hand may be both permeable and unstable. The large volume of any dam constructed at this site, together with the unattractive foundation conditions, were responsible for the limited consideration given to this site.

Fox Creek Site

The San Juan Peneplain, comprising impervious andesitic flows, was here eroded to a flat surface lying well above the reservoir area on the right but dipping with a slope of 2 to 3° below the reservoir level in the left side. This original flat surface was covered with gravels and silts and topped with a thin flow of basalt (Los Pinos and Hinsdale formations). On tilting, stream erosion began progressively to strip off these less competent deposits, so that now the left rim of the reservoir has a retaining wall or hogback of compacted silts and gravel



CONEJOS DAM SITE No.5

FIGURE 135a

with a basalt cap. The water table is above the andesite on the right side. Ground waters probably flow the dipping andesite on the left side to form an .an flow in the main San Luis Valley. Under such .itions the reservoir seepage may prove to be large.

At the dam site the right abutment is of hard, impervious andesite overlain by erratic detrital talus and wash. The left end of the dam would rest on the northeast dipping, compacted silts, gravel and upper basalt, through which the water table falls. A block slide on this abutment has displaced a section of the capping basalts, lowering it to the present river level. Downstream from the axis this slide was disrupted to give rise to a landslide. The foundation along the axis is mantled with a depth of possibly 150 to 200 feet of recent, porous, stream gravels, cobbles, and sand.

The block slide, forming the left abutment, is shattered and instability is indicated by the present steep slopes and the soft character of the underlying materials. The deep foundation gravels are themselves quite permeable and probably feed directly to an underlying artesian member.

In view of the unfavorable geological conditions and the difficult remedial measures required, further consideration was deferred pending consideration of other, geologically more feasible, sites.

Granite Dam Site [1a]

Reservoir conditions are similar to no. 1 site and lateral seepage is to be expected. Granite bedrock is exposed in the present stream channel.

The most important feature at the dam site is the probability of a deeper stream gorge under the right abutment terrace. Drill hole no. 1 encountered the granite bedrock 30 feet below the present stream bed. Bedrock may prove to be well over 100 feet below the present river level, along the center of such a buried channel, the profile and location of which have not been determined. Overlying the bedrock are stratified sand, gravel, and boulders, which are remnants of terraces.

On the left abutment the granite is overlain by a series of agglomerate and ash, in turn covered by andesite flows and flow breccias. The ash layers appear quite compact. Normal talus debris mantles the abutment, increasing in depth from 5 to 25 feet up the slope. Permeability of the right abutment materials and the character of the left abutment contacts and ashes are important factors deserving further study if the site is to be seriously considered.

Storage capacity of 100,000 acre-feet at this site will require a dam with 210 feet maximum height and a crest length of 3,000 feet. Its cost is roughly estimated at $3,655,000.

[1a] Fig. 135c.

Dam Site No. 4

This site is located in a narrows below Fisher Gulch about 3½ miles below Platoro, Colo. Only a short geological reconnaissance was completed but the rock and overburden conditions have not proven satisfactory.

A high dam would given considerable storage but would flood numerous mining claims.

The reservoir basin involves many geological structures. Several faults cross the valley. The bottom flats are covered with river gravels and the flanks of the basin are erratically covered with landslide, talus, wash, terrace, and other detrital deposits. The ground water is tributary to the stream so that reservoir conditions can be considered satisfactory.

At the dam site, bedrock is the Conejos andesite formation of andesitic flows, flow breccias, ashes, and agglomerates, which on the right abutment dip steeply to the northeast (strike N. 40 W., dip 80 NE.). The dip on the left abutment is much flatter. The steep dip on the right abutment is probably due to a large fault running parallel to the river in the vicinity of Lake Fork. The left abutment shows a relatively thick mantle of talus rubble, overriding bottom terrace and recent gravels of unknown depth. The underlying rock may be quite shattered. The right abutment, on the other hand, is composed entirely of slump and landslide materials, showing much fine silty matrix so that it appears remarkably compact. One drill hole was churned to 75 feet without encountering bedrock.

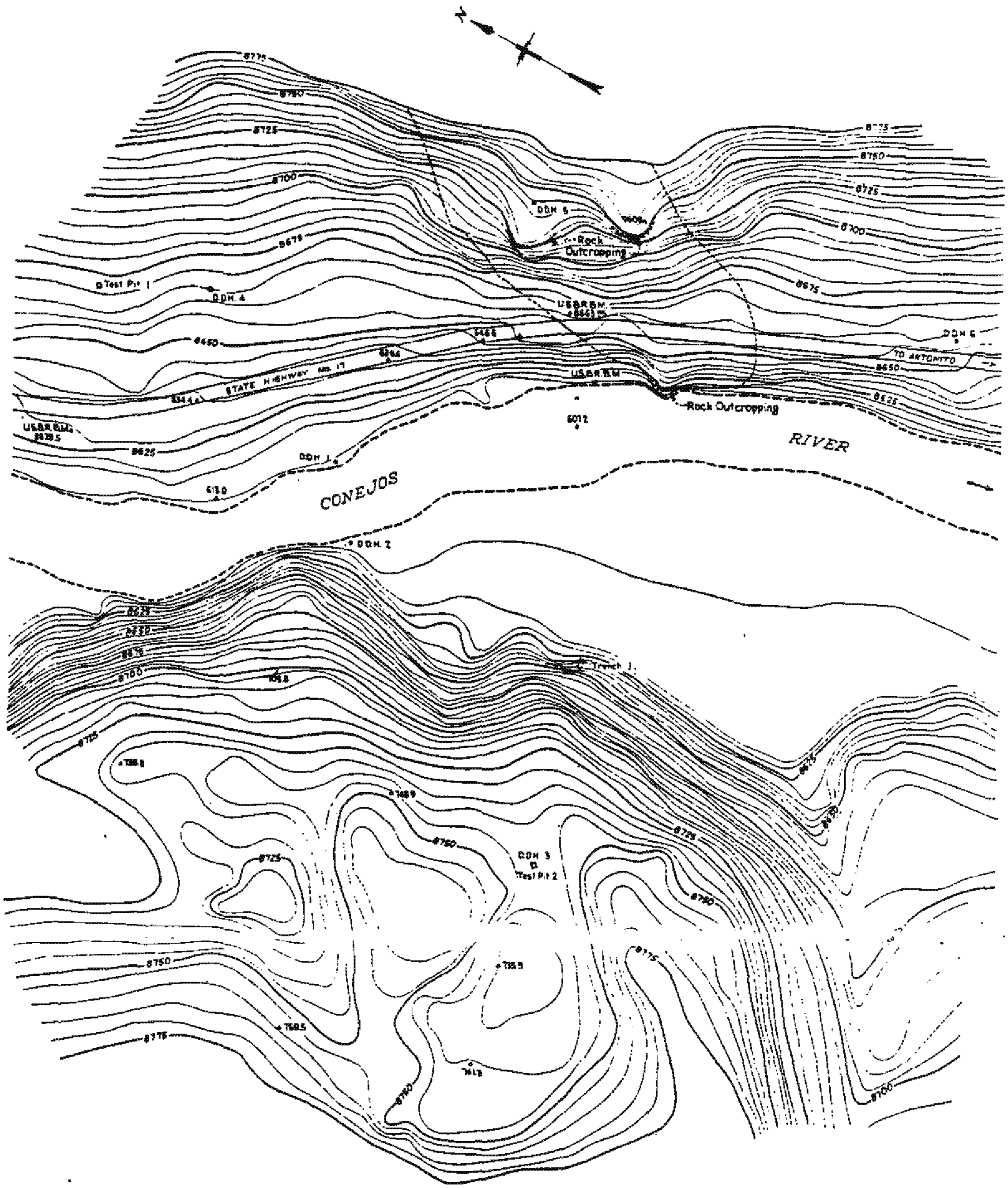
The 1912–35 mean annual run-off at this site was estimated at 55,000 acre-feet, of which not over 35,000 acre-feet could be stored without inteference with prior rights. Reconnaissance indicated that a dam more than 100 feet in maximum height and a crest length of about 1,000 feet would be required to store the available quantity. Its cost per acre-foot would greatly exceed the cost of no. 6 site. This fact, together with the more favorable geological conditions at no. 6 site, led to abandonment of explorations at an early stage.

Dam Site No. 5 [1]

Conejos dam site no. 5 is about 1 mile below Platoro, in the same reservoir basin controlled by the no. 4 site, but at the head of the steeper section. The site is attractive for a small dam (50 to 60 ft.).

The reservoir basin is eroded from a massive, horizontal, andesite flow, characteristic of this area. Much of the rock is severely fractured and igneous intrusive dikes as well as mineralized zones are common. The bottom is mantled with river gravels and the sides are erratically flanked with terrace gravels, wash, or talus deposits. Ground water is tributary to the stream and no reservoir loss is expected.

[1] Fig. 135a.



CONEJOS DAM SITE No. I

FIGURE 135b

The dam site utilizes a narrows where a low andesite ridge crosses the basin. This ridge is apparently due ·· superior erosional resistance. All the rock is rather erely fractured but as evidenced by pressure tests _ two drill holes, these planes are tight at depth and should allow little seepage. These fractures tend to localize in erratic shear zones. The site is quite free of detrital deposits with but 20 feet of gravels found in the river channel. A wedge of porous terrace gravel lies on the right abutment, which together with all such detrital materials, should be entirely excavated. Pockets of the same gravel may be found in the depressions along the ridge. Considerable blocky talus will be encountered against the left abutment face.

Construction problems vary largely with the size of the contemplated dam. A 50-foot structure will have small economical dam section, while a higher structure must include dikes along the rock ridge.

The low dam would provide in sufficient storage capacity; the higher would be expensive. The site was, therefore, abandoned in favor of no. 6 site.

No. 6 Site

The dam site is located about a mile upstream from Platoro which is 42.5 miles by gravelled highway from Monte Vista, the nearest railroad shipping point. The reservoir is entirely on Government land within a United States forest reserve.

ımary of data:

Storage capacity	32,000 acre-feet.
Spillway capacity	6,000 second-feet.
Outlet capacity (1,000 acre-foot level)	500 second-feet.
Elevation top of parapet	10,013.
Elevation top of dam	10,010.
Elevation of spillway crest	10,000.
Maximum water-surface	10,005.
Reservoir area at spillway level	710 acres.
Maximum height of dam	115 feet.
Estimated cost—dam and reservoir	$608,000.
Reservoir topography	Fig. 137.
General plan and sections	Fig. 138.
Preliminary estimate	Table 15.

Geology.—In many ways this site is geologically one of the most favorable sites to be found on the Conejos River. The reservoir basin is cut into a rock complex of massive andesite flows and flow breccias with numerous intruded sills and dikes. Two major faults cross the basin which are probably related in age to the severe fracturing of all the regional rock, a common feature in this area. The sides of the basin are erratically mantled with talus and wash, which interfingers with the bottom gravel deposits. The water table is tributary to the stream and no reservoir seepage loss is expected.

The dam site is in a canyon narrows eroded into a ··ˑck, massive andesite flow dipping slightly downım. Detrital deposits are shallow on the abutments and foundation. All the rock is excessively fractured and localized shear zones are common. One of these is along the location of the diversion tunnel and spillway so that excavation may prove somewhat difficult.

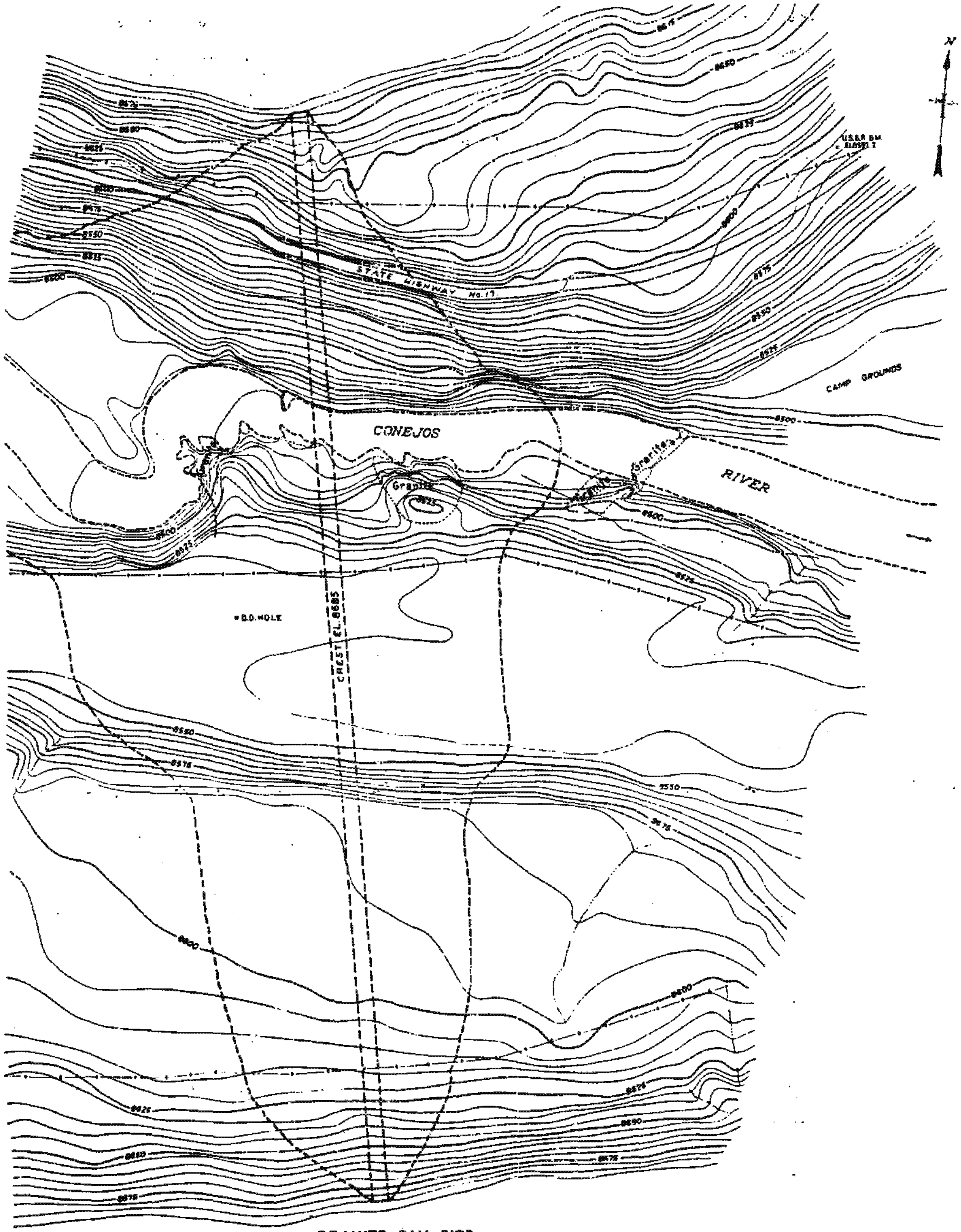
No drilling or test pits were considered necessary for preliminary designs, but extensive drilling will ultimately be required for the purpose of more closely determining the scope of grouting and stripping operations.

Dam.—Owing to the long haul for cement and the close proximity of sufficient embankment materials, this site appears to be best suited for the compacted embankment type of dam. It is estimated that there is sufficient material about three-fourths of a mile upstream from the site for embankment borrow quantities. There are ample sand and gravel deposits along the river within one-half mile upstream for the limited amount of concrete necessary for this dam.

Figure 138 shows the general plan and sections of the proposed dam and dike. The main dam is 540 feet long at the crest and attains a maximum height of 115 feet. The dike, some 400 feet to the left of the dam, is 400 feet long with a height of 38 feet. The typical embankment section has a 35-foot top width at elevation 10,010, a graveled roadway, and typical concrete parapets and curbs. The upstream slope is 3:1 with a 12-inch gravel blanket overlain by 3 feet of rock riprap. The downstream slope is 2½:1 with 2 feet of dumped rock for weather protection. It will be necessary to strip the vegetation from the site downstream from the axis and all of the material overlying the rock upstream from the axis. A considerable amount of this excavation can be used in the downstream portion of the embankment. Excavation is assumed to average 10 feet for the lower portions of the dam and 15 feet for the dike. The cofferdam is designed to be bulldozed back against the toe of the dam on a 5:1 slope. A concrete cutoff wall extends the entire length of the dam and dike.

Spillway.—A gate-operated spillway is inadvisable under the adverse climatic conditions and a side channel uncontrolled crest spillway was adopted. This spillway crest is 140 feet long and at elevation 10,000 discharges 6,000 second-feet with 5 feet of water over the crest. This spillway will be constructed entirely in sound rock and concrete-lined throughout. A concrete arch bridge will span the spillway channel.

Outlet works.—An 8.5-foot horseshoe concrete-lined tunnel will serve the purposes of river diversion during construction and later as an outlet. With the cofferdam constructed to elevation 9935 and the water surface at 9930 or 5 feet below the crest of the cofferdam, the tunnel will discharge 2,000 second-feet. After diversion one 72-inch diameter ring follower emergency gate and one 66-inch needle valve will be installed in the gate



GRANITE DAM SITE

FIGURE 185c

TABLE 15.—*Upper Conejos Dam, preliminary estimate, Jan. 30, 1937*

[Earth embankment: top of dam elevation 10,010; normal water surface elevation 10,000; maximum water surface elevation 10,005; maximum height of dam, 110 feet; drawing no. 253-D-76]

[Storage capacity, 32,000 acre-feet; spillway capacity, 6,000 second-feet; diversion capacity, 2,000 second-feet; required outlet capacity, 500 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion, and unwatering foundations	(1)	(1)	(1)	$3,000			(1)	$3,000
EARTHWORK								
Excavation, common:								
Stripping, dam foundation	15,300	Cubic yard	$0.30	4,590			$0.30	4,590
Stripping, borrow pits	40,000	Cubic yard	.30	12,000			.30	12,000
Dam foundation	22,255	Cubic yard	.30	6,677			.30	6,677
Toe drains and cut-off trenches	355	Cubic yard	.40	142			.40	142
Spillway, and tunnel inlet and outlet	1,000	Cubic yard	.40	400			.40	400
Roadway	1,830	Cubic yard	.35	641			.35	641
Borrow, and transportation to dam	353,100	Cubic yard	.30	105,930			.30	105,930
Excavation, rock:								
Cut-off wall	220	Cubic yard	4.00	880			4.00	880
Spillway, and tunnel inlet and outlet	28,700	Cubic yard	2.50	71,750			2.50	71,750
Roadway	3,670	Cubic yard	2.00	7,340			2.00	7,340
Outlet tunnel and shaft	3,400	Cubic yard	10.00	34,000			10.00	34,000
Embankment:								
Earth fill compacted	328,300	Cubic yard	.10	32,830			.10	32,830
Dumped rock on downstream slope	6,610	Cubic yard	.30	1,983			.30	1,983
Riprap rock on upstream slope	13,690	Cubic yard	.40	5,476			.40	5,476
Backfill about structures	1,100	Cubic yard	.50	550			.50	550
Gravel for roadway and spillway	1,900	Cubic yard	1.50	2,850			1.50	2,850
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 25 feet deep	6,000	Linear foot	1.00	6,000			1.00	6,000
Drain holes	1,400	Linear foot	1.00	1,400			1.00	1,400
Weep holes	350	Linear foot	1.00	350			1.00	350
Anchor bars and grouting in place	2,700	Linear foot	1.00	2,700	$0.10	$270	1.10	2,970
Pressure grouting: Foundation	15,000	Cubic foot	1.10	16,500	.90	13,500	2.00	30,000
Drain tile:								
12-inch diameter clay tile in gravel	325	Linear foot	.70	228	.45	146	1.15	374
8-inch diameter clay tile in gravel	775	Linear foot	.60	465	.30	233	.90	698
6-inch diameter clay tile in gravel	600	Linear foot	.50	300	.20	120	.70	420
4-inch split tile for spillway	300	Linear foot	.40	120	.15	45	.55	165
CONCRETE WORK								
Concr[illegible]								
[illegible] wall not formed	220	Cubic yard	10.00	2,200	3.60	792	13.60	2,992
[illegible] wall formed	450	Cubic yard	12.00	5,400	4.00	1,800	16.00	7,200
[illegible] and curb walls	370	Cubic yard	20.00	7,400	4.00	1,480	24.00	8,880
[illegible]ck and transition	125	Cubic yard	15.00	1,875	4.00	500	19.00	2,375
Below operating floor of gate chamber	175	Cubic yard	12.00	2,100	3.60	630	15.60	2,730
Tunnel, shaft, and gate chamber	1,100	Cubic yard	14.00	15,400	3.60	3,960	17.60	19,360
Spillway	1,950	Cubic yard	11.00	21,450	3.60	7,020	14.60	28,470
Control house	20	Cubic yard	20.00	400	4.00	80	24.00	480
Spillway bridge	200	Cubic yard	15.00	3,000	4.00	800	19.00	3,800
METALWORK								
Metal:								
Trash rack	25,000	Pound	.02	500	.08	2,000	.10	2,500
Reinforcement steel	284,000	Pound	.02	5,680	.03	8,520	.05	14,200
Spiral stairway	17,500	Pound	.03	525	.11	1,925	.14	2,450
Water stops	400	Linear foot	.30	120	.40	160	.70	280
72-inch ring-follower gate and control mechanism	51,000	Pound	.04	2,040	.24	12,240	.28	14,280
60-inch needle valve and control mechanism	58,000	Pound	.03	1,740	.22	12,760	.25	14,500
12-ton hand hoist	35,000	Pound	.02	700	.19	6,650	.21	7,350
Gas-electric generator set and equipment	(1)	(1)	(1)	200	(1)	800	(1)	1,000
Miscellaneous metalwork	2,000	Pound	.10	200	.10	200	.20	400
Grout and drain pipe	5,300	Pound	.05	265	.07	371	.12	636
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)	(1)		200		800	(1)	1,000
Transporting freight, except cement, for Government from Monte Vista, Colo., to the dam site (42.5 miles)	250	Ton	4.80	1,200				1,200
Highway construction	1	Mile		5,000				5,000
Clearing reservoir	100	Acre	25.00	2,500			25.00	2,500
Subtotal				399,197		77,802		476,999
Contingencies, 15 percent								71,550
Total estimated field cost								548,549
Investigations and surveys	(1)						(1)	5,000
Engineering and inspection, 6 percent								32,913
Superintendence and accounts, 1½ percent								8,228
General expense, 2½ percent								13,714
Total estimated cost								608,404
Cost per acre-foot storage								19.01

[1] Lump sum.

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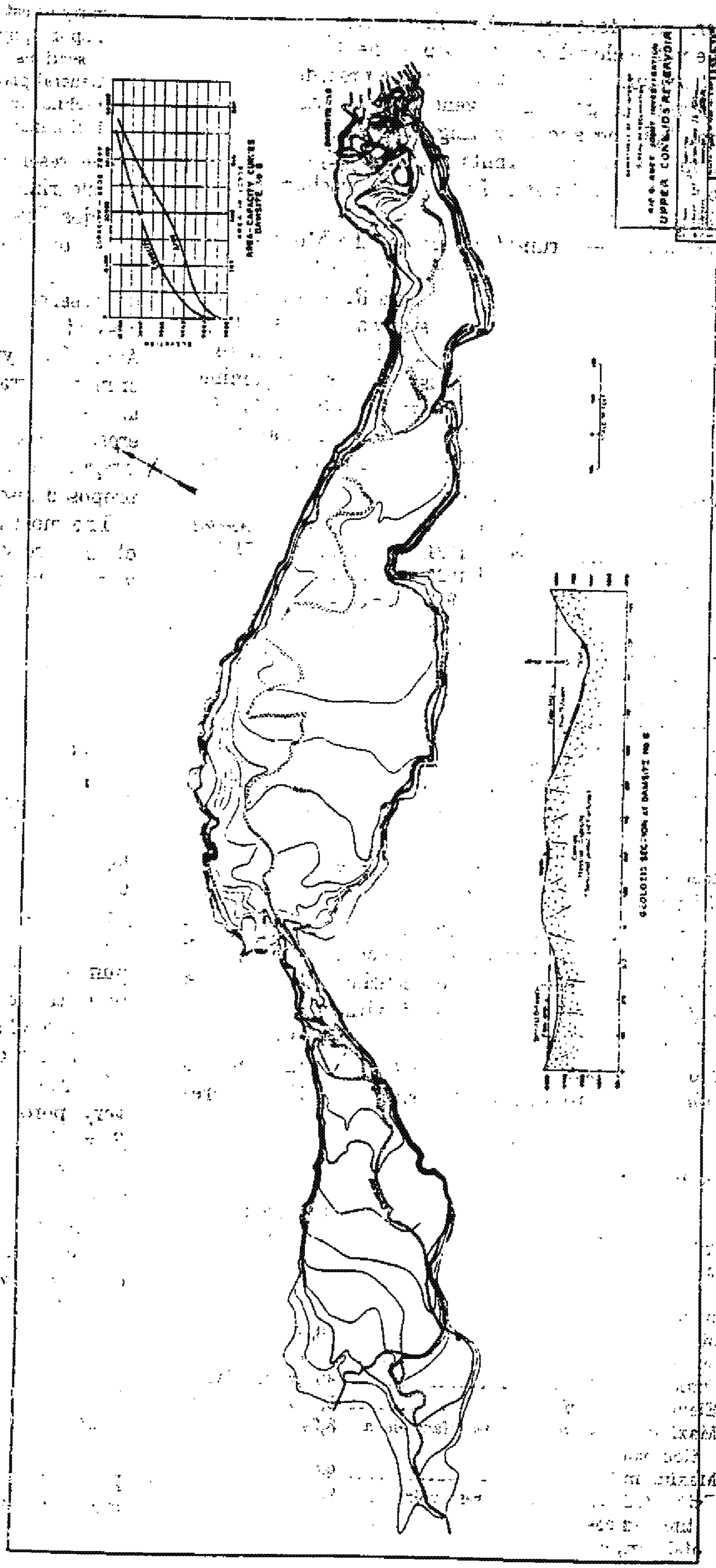

FIGURE 137

chamber. A 6-foot by 14-foot lined shaft will extend from the valve chamber to the top of the dam, where it [illegible] surmounted by a control house provided with a 1. [illegible] hoist. A gas engine generator set will be provided for lighting and operating purposes. The trash rack atop the tunnel permits a silting depth for the reservoir. The outlet end of the tunnel discharges into the stilling basin.

Water supply.—A run-off record for the Mogote station, 8 miles below no. 1 site, from 1912 to 1935, inclusive, is the only record on the Conejos River applicable to this study. Run-off at no. 6 site was estimated by the precipitation altitude method. Precipitation records at 10 stations in the San Luis Valley and adjoining watersheds, varying in elevation from 7,600 to 11,500 feet, are available but so widely scattered that their deviation from an average curve is quite great. The estimated run-off is as follows:

	Acre-feet		*Acre-feet*
1912	55,900	1924	51,100
1913	28,100	1925	42,000
1914	46,000	1926	44,700
1915	42,800	1927	62,000
1916	66,000	1928	34,400
1917	58,700	1929	61,100
1918	40,500	1930	36,800
1919	44,400	1931	27,100
1920	77,300	1932	64,200
192[illegible]	46,700	1933	39,100
	55,300	1934	18,700
	70,900	1935	55,500

Mean, 1912-35, inclusive, 48,700 acre-feet.

These estimates agree quite closely with results secured by modifying the altitude run-off curves used on the San Juan-Chama studies.

The reservoir capacity of 32,000 acre-feet represents the average amount storable, considering only the direct-flow uses on Conejos, and without regard for prior rights on Rio Grande, whether in Colorado, New Mexico, or Texas. In some years the amount so storable will fall to amounts not exceeding 20,000 acre-feet.

Mogote Reservoir

The dam is located approximately 5 miles northwest of Antonito, Colo., in section 4, T. 33 N., R. 8 E., N. M. P. M.

Summary of estimate data:

Storage capacity	30,000 acre-feet.
Spillway capacity	Emergency only.
Outlet capacity	400 second-feet.
Elevation, top of dam	8,045.
Maximum reservoir water-surface elevation, spillway level.	8,040.
Maximum height of dam	95 feet.
[illegible]timated cost, dam and reservoir	$394,000.
[illegible]timated cost of canal	$352,000.
[illegible]tal cost, reservoir and canal	$746,000.

Summary of estimate data—Continued.

Topography of reservoir and geological sections.	Fig. 139.
General plan and sections	Fig. 140.
Preliminary estimate of dam	Table 16.
Preliminary estimate of canal	Table 17.

The reservoir area at elevation 8,040 is 970 acres. No clearing will be required. Flood waters of the Conejos River are to be diverted into this basin by means of a feeder canal and short tunnel.

Geology.—The oldest rocks exposed in the vicinity of the reservoir basin are the Potosi series, a great thickness of dense, crystalline, volcanic flows of Miocene Age. Overlying this series is a thickness of 400 feet or more of gravels, sands, and silts. Capping the gravel and silt member is a thin basalt lava flow. Locally, erosion has cut through the basalt cap and carved irregular basins in the gravel and silt member. The proposed reservoir area is in such a basin.

The most important features involved in the utility of the reservoir basin are: (1) The great depth to the water table and (2) the permeability of the silts and gravels beneath the reservoir floor. A drill hole at the dam site, elevation 7,957, penetrated 252 feet of silts, sands, and gravels without encountering the water table. Over the reservoir floor with a minimum thickness of about 50 feet at the dam site is a fine rather compact silt. Laboratory tests on an undisturbed sample of the material indicate percolation rates of .6 feet per year under a unit head.

Under the silt is a series of stratified and unstratified layers of gravel, boulders, volcanic ash, and tuff. Part of this series is stream laid, while the unstratified members are probably torrential wash. Nearly all of the members below the silt layer are very porous. Water pumped into a drill hole drained rapidly away. Overlying the silt member around the rim of the reservoir is a layer of about 20 feet of coarse gravel and boulders. A cut near the dam site showed it to be well cemented with lime at this locality. At other points it may be very porous. Overlying the coarse gravel is a thin flow of black basalt, probably about 25 feet thick. Like all thin surface flows, it is badly jointed and fractured. The whole series dips slightly (about 5°) to the east.

From the available data it has been concluded that some leakage must be expected at this site. There are material differences of opinion on the extent of such leakage. It is unlikely, however, that such leakage will be of an extent that will preclude filling in most years, as Conejos River flows not locally needed for irrigation far exceed the reservoir capacity, except in rare years like 1931 or 1934. No opinion is here presented as to the extent of waters storable, considering all rights to the water of Rio Grande and its tributaries in Colorado, New Mexico, and Texas.

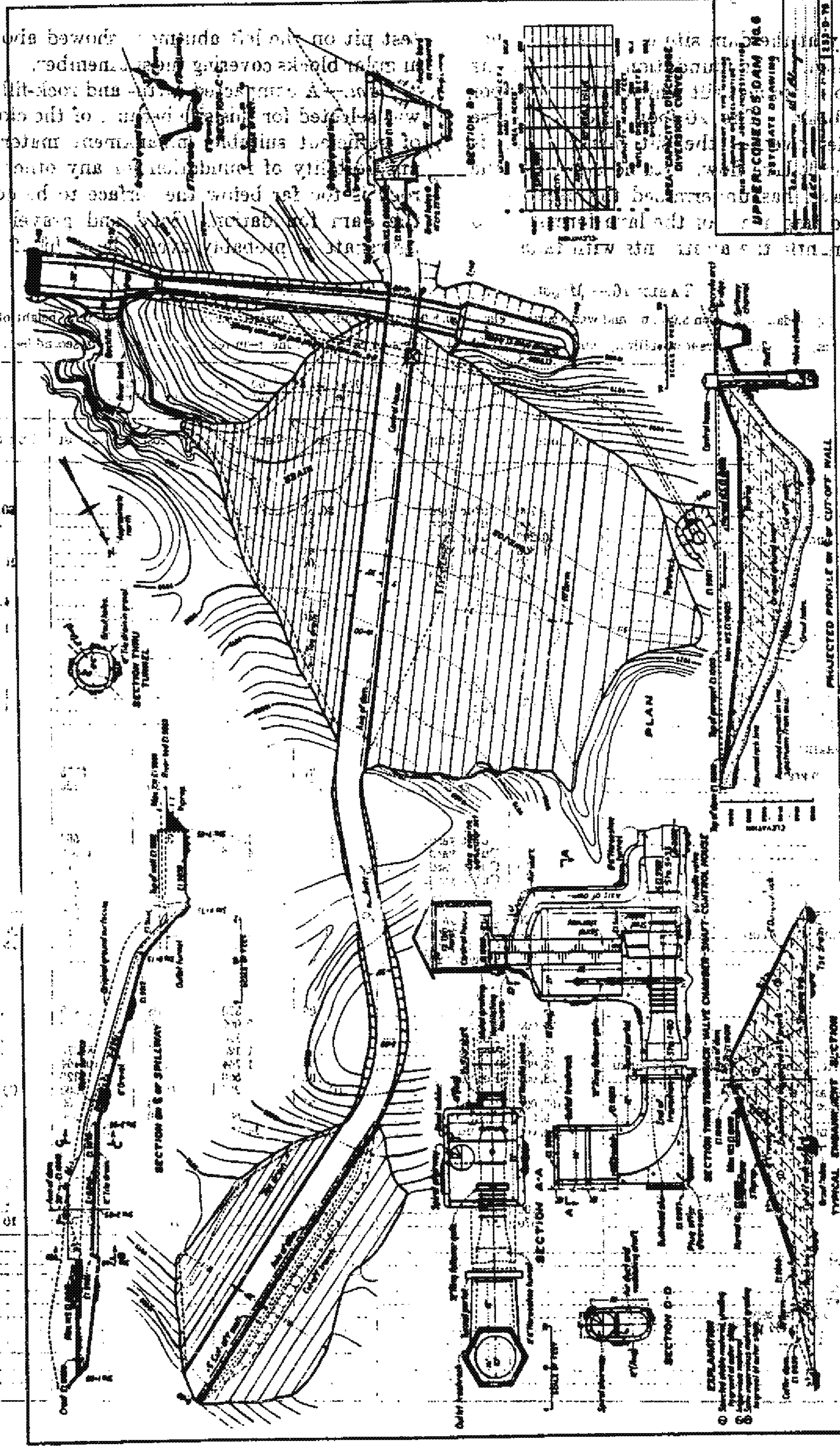
UPPER CONEJOS DAM
ESTIMATE DRAWING
PLAN
SECTION A-A
SECTION D-D
EXPLANATION
PROJECTED PROFILE ON ℄ OF CUT-OFF WALL
TYPICAL EMBANKMENT SECTION

FIGURE 138

The stratigraphy at the dam site is the same as that of the reservoir basin. The foundation and abutments of the yellow compact silt which covers the floor reservoir basin. The 20-foot layer of coarse gravel and boulder overlies the silt member and is overlain by the basalt lava flow. Rapid erosion of the softer silt and gravel has undermined the basalt cap, causing blocks and fragments of the lava formation to break away and mantle the abutments with talus. A test pit on the left abutment showed about 10 feet of angular blocks covering the silt member.

Dam.—A compacted earth- and rock-fill type of dam was selected for this site because of the close proximity of sufficient suitable embankment materials and the unsuitability of foundation for any other type. Bedrock is too far below the surface to be considered for the dam foundation. Sand and gravel for concrete aggregate is probably available within 2 miles of the

TABLE 16.—*Mogote Dam, preliminary estimate, August 1937*

[Earth embankment: top of dam, elevation 8,045; normal water surface, elevation, 8,040; maximum water surface, elevation, 8,040; maximum height of dam, 95 feet]

[Storage capacity, 30,000 acre-feet; spillway capacity, emergency only; diversion capacity, none; required outlet capacity, 400 second-feet]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
EARTHWORK								
Excavation, common:								
Stripping dam foundation	16,700	Cubic yard	$0.30	$5,010			$0.30	$5,010
Stripping borrow pits	13,000	Cubic yard	.30	3,900			.30	3,900
Toe drains and cut-off trenches	10,200	Cubic yard	.40	4,080			.40	4,080
Outlet works, open cut	4,300	Cubic yard	.40	1,720			.40	1,720
Outlet works, tunnel and gate chamber	2,050	Cubic yard	10.00	20,500			10.00	20,500
Borrow and transportation to dam	337,000	Cubic yard	.25	84,250			.25	84,250
Excavation, rock:								
Cut-off walls	350	Cubic yard	4.00	1,400			4.00	1,400
Borrow and transportation to dam	36,000	Cubic yard	.75	27,000			.75	27,000
Emergency spillway	1,700	Cubic yard	1.00	1,700			1.00	1,700
Embankment:								
Earth fill compacted	300,000	Cubic yard	.10	30,000			.10	30,000
Dumped rock on downstream slope	35,500	Cubic yard	.20	7,100			.20	7,100
Riprap rock on upstream slope	15,600	Cubic yard	.40	6,240			.40	6,240
Riprap rock in outlet channel	125	Cubic yard	1.00	125			1.00	125
Gravel for roadway	1,120	Cubic yard	1.25	1,400			1.25	1,400
Backfill about structures	300	Cubic yard	.50	150			.50	150
DRAINAGE								
[illegible] diameter clay tile in gravel	750	Linear foot	.70	525	$0.50	$375	1.20	900
[illegible] diameter clay tile in gravel	750	Linear foot	.60	450	.30	225	.90	675
CONCRETE WORK								
Concrete:								
Cut-off walls	150	Cubic yard	12.00	1,800	3.75	563	15.75	2,363
Parapets and curb walls	250	Cubic yard	17.10	4,275	4.15	1,038	21.25	5,313
Trash rack and transition	100	Cubic yard	14.35	1,435	4.15	415	18.50	1,850
Gate chamber below floor	50	Cubic yard	9.00	450	3.75	188	12.75	638
Gate chamber above floor	50	Cubic yard	18.00	900	4.50	225	22.50	1,125
Tunnel lining	740	Cubic yard	15.25	11,285	4.50	3,330	19.75	14,515
Stilling basin	120	Cubic yard	13.75	1,650	4.15	498	17.90	2,148
Control house substructure and portal	125	Cubic yard	16.25	2,031	4.15	519	20.40	2,550
Control house superstructure	25	Cubic yard	21.35	534	4.50	112	25.85	646
Special finishing concrete surfaces	425	Square yard	.60	255			.60	255
METALWORK								
Metal:								
Trash rack	18,500	Pound	.02	370	.08	1,480	.10	1,850
Reinforcement bars	100,000	Pound	.02	2,000	.035	3,500	.055	5,500
Pipe handrailing	1,100	Pound	.10	110	.10	110	.20	220
1 48-inch needle valve and control mechanism	37,600	Pound	.03	1,128	.22	8,272	.25	9,400
1 57-inch ring-follower gate, lining, and control mechanism	43,600	Pound	.04	1,744	.24	10,464	.28	12,208
1 8-ton hoist	28,000	Pounds	.02	560	.19	5,320	.21	5,880
Gas-electric generator set and equipment	(1)		(1)	200	(1)	800	(1)	1,000
400 feet of 57-inch I. D. steel pipe	107,000	Pound	.05	5,350	.10	10,700	.15	16,050
Miscellaneous	6,000	Pound	.10	600	.10	600	.20	1,200
Furnishing and placing liner plate	185,000	Pound	.08	14,800			.08	14,800
MISCELLANEOUS ITEMS								
Items:								
Control house except concrete	(1)		(1)	800	(1)	700	(1)	1,500
Transporting freight except cement for Government from Antonito, Colo., to dam site (6.25 miles)	200	Ton	1.00	200			1.00	200
Right-of-way	970	Acre			10.00	9,700	10.00	9,700
Subtotal				248,027		59,134		307,161
Contingencies, 15 percent								46,074
Total estimated field cost								353,235
Investigations and surveys								5,000
Engineering and inspection, 6 percent								21,194
Superintendence and accounts, 1½ percent								5,298
General expense 2½ percent								8,831
Total estimated cost								393,558
Cost per acre-foot of storage								13.12

[1] Lump sum.

5—38——36

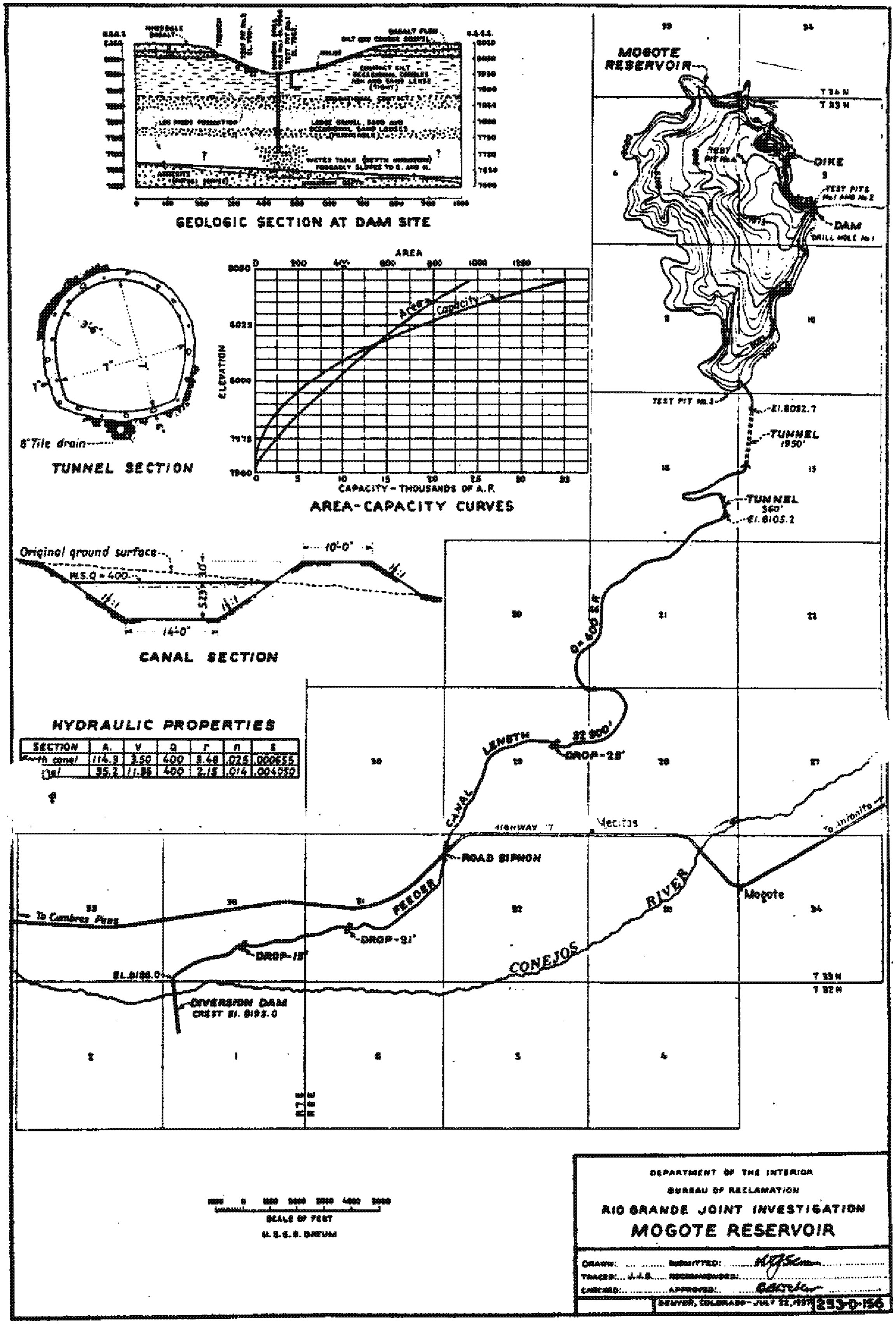
GEOLOGIC SECTION AT DAM SITE
TUNNEL SECTION
8" Tile drain
AREA
ELEVATION
CAPACITY - THOUSANDS OF A.F.
AREA-CAPACITY CURVES
Original ground surface
W.S.Q = 400
14'-0"
10'-0"
CANAL SECTION
HYDRAULIC PROPERTIES
MOGOTE RESERVOIR
DIKE
DAM
TEST PIT No.3
El. 8092.7
TUNNEL 1950'
TUNNEL 560'
El. 8105.2
Q = 400 S.F.
LENGTH 32,900'
DROP-25'
CANAL
HIGHWAY 17
ROAD SIPHON
FEEDER
Mogote
RIVER
CONEJOS
To Cumbres Pass
DROP-15'
DROP-21'
El. 8188.0
DIVERSION DAM
CREST El. 8193.0
T 33 N
T 32 N
SCALE OF FEET
U.S.G.S. DATUM
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
MOGOTE RESERVOIR
DENVER, COLORADO
253-D-156

FIGURE 139

site, although no pits have been dug. Embankment materials can be obtained in the reservoir area, just above the dam site.

The proposed rolled-earth and rock-fill dam has a crest length of 645 feet and attains a maximum height of 95 feet above the stream bed.

The embankment has a crest width of 35 feet at elevation 8,045 and carries a graveled roadway with typical concrete parapets and curbs. The upstream face, protected with a 3-foot layer of dumped rock riprap has a 3:1 slope. The downstream face is formed by a rock-fill of increasing thickness from crest to toe, that has an outer slope of 2¼:1 to elevation 7,992, a 6:1 slope down to elevation 7,970, and 1½:1 slope terminating at the foundation level. Beneath the rock-fill, which has a minimum thickness of 5 feet at the crest, is the rolled semi-impervious section which has a slope of 2¼:1. An inverted filter will be incorporated in base of the rock-fill. A cut-off trench 15 feet deep is placed under the impervious section of the dam. Stripping of vegetation for the entire area of the dam is provided.

A dike approximately 300 feet long and 25 feet in maximum height will be required in the saddle about 1,800 feet to the northwest of the dam. This dike is similar to the dam in section, except that rock-fill at downstream toe is decreased. An emergency spillway consisting of an open cut channel in the basalt cap rock 1,800 feet northwest of the left abutment of the dam was provided in the plan. This channel will be 25 feet in bottom width with ¼:1 side slopes. The bottom of the channel will be at elevation 8,035 with a fuse plug built to maximum water surface. The channel is near the right abutment of the dike and spills downstream from the dike into the saddle. The outlet works consist of a concrete-lined tunnel under the left abutment of the dam. The tunnel has an internal diameter of 5 feet upstream from the gate chamber and the downstream section is 9 feet in diameter. The gate chamber, containing one 57-inch ring follower emergency gate, is placed under the axis of the dam. A 57-inch steel pipe conduit through the 9-foot diameter tunnel connects the emergency gate chamber with the 48-inch needle valve in the valve house at the downstream portal of the tunnel. A stilling basin is provided to prevent erosion from the needle valve discharge.

Provisions are made in the estimate for steel liner plate for the tunnel. The outlet works will provide a discharge capacity of 400 second-feet with the reservoir half full or a water surface at elevation 8,018.

Mogote Creek is a small intermittent stream that discharges into Conejos River. Owing to the small

TABLE 17.—*Mogote Canal estimate*

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
Diversion:								
Diversion and care of river	(1)			$5,000				$5,000
Excavation, common	16,000	Cubic yard	$0.50	8,000			$0.50	8,000
Excavation, structure	1,100	Cubic yard	1.00	1,100			1.00	1,100
Embankment	600	Cubic yard	.75	450			.75	450
Backfill	300	Cubic yard	.25	75			.25	75
Riprap	1,200	Cubic yard	1.50	1,800			1.50	1,800
Concrete	2,000	Cubic yard	18.00	36,000	$3.75	$7,500	21.75	43,500
Reinforcement steel	265,000	Pound	.02	5,300	.035	9,275	.055	14,575
Slide gates and hoists	10,000	Pound	.05	500	.25	2,500	.30	3,000
Radial gate and hoist	1,500	Pound	.05	75	.15	225	.20	300
Canal:								
Excavation, common	147,000	Cubic yard	.15	22,050			.15	22,050
Excavation, rock	15,000	Cubic yard	.75	11,250			.75	11,250
Excavation, structure	315	Cubic yard	.75	236			.75	236
Backfill	700	Cubic yard	.25	175			.25	175
Riprap	3,800	Cubic yard	1.50	5,700			1.50	5,700
Concrete, structure	370	Cubic yard	18.00	6,660	3.75	1,388	21.75	8,048
Reinforcement steel	47,600	Pound	.02	952	.035	1,666	.055	2,618
Turnouts		10	200.00	2,000	50.00	500	250.00	2,500
Farm bridges		15	200.00	3,000			200.00	3,000
Tunnels, 7-foot diameter; L=560 and 1,950 feet:								
Excavation, all classes	5,375	Cubic yard	15.00	80,625			15.00	80,625
Concrete lining	1,355	Cubic yard	18.00	24,390	5.00	6,775	25.00	31,165
Steel rib supports	87,100	Pound	.08	6,968			.08	6,968
Timber	75.3	M ft. b. m.	80.00	6,024			80.00	6,024
Drains	2,510	Linear foot	1.00	2,510	.50	1,255	1.50	3,765
Right-of-way	100	Acre foot			50.00	5,000	50.00	5,000
Property damages	(1)					5,000		5,000
Fencing right-of-way	12.5	Mile	350.00	4,375			350.00	4,375
Subtotal				235,215		41,084		276,299
Contingencies, 15 percent								41,445
Total estimated field cost								317,744
Investigations and surveys								3,000
Engineering and inspection, 6 percent								19,065
Superintendence and accounts, 1½ percent								4,766
General expense, 2½ percent								7,944
Total estimated cost								352,519

[1] Lump sum.

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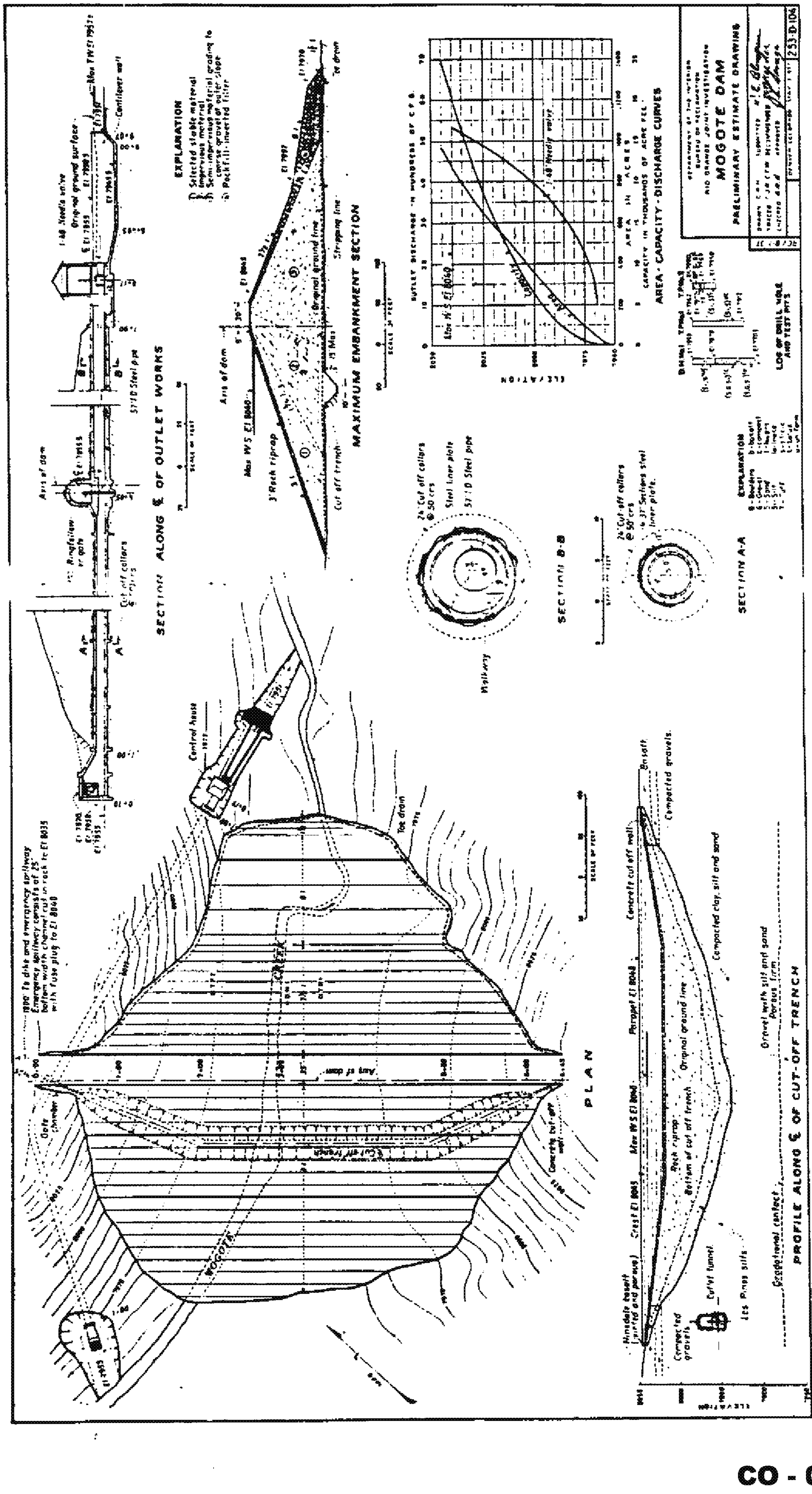
SECTION ALONG ℄ OF OUTLET WORKS
MAXIMUM EMBANKMENT SECTION
AREA - CAPACITY - DISCHARGE CURVES
SECTION B-B
SECTION A-A
MOGOTE DAM
PRELIMINARY ESTIMATE DRAWING
PLAN
PROFILE ALONG ℄ OF CUT-OFF TRENCH

FIGURE 140

flows in the creek no special provisions are necessary for diversion during construction as the outlet tunnel will easily handle any anticipated stream flow.

This dam can probably be constructed in one season. There are no improvements within the reservoir area. No clearing will be necessary. The reservoir area is mainly used for grazing and the cost of right-of-way should not exceed $10 per acre. No construction camp or permanent building will be required owing to the short distance by dirt road to Antonito, where it is assumed that suitable housing facilities for construction workmen and the dam caretaker can be obtained.

Feeder Canal.—A canal of 400 second-foot capacity was surveyed, diverting from the Conejos River in section 1, T. 32 N., R. 7 E., N. M. P. M., to fill Mogote Reservoir. The canal is 39,500 feet long with two tunnels 560 feet and 1,950 feet long. Strip topography of the entire route was secured and an estimate prepared as shown in table 14B.

The diversion dam in Conejos River is one of the major items of cost, and is 2 miles upstream from the elevation required, in order to secure a gravity diversion from a stabilized section of the river channel. Three drops then became necessary to absorb the excess fall from the diversion dam. No feasible route could be found to avoid the two tunnel locations.

Wagon Wheel Gap Reservoir

Summary of data:

Storage capacity	1,000,000 acre-feet.
Spillway capacity	10,000 second-feet.
Regulated outlet capacity	5,000 second-feet.
Elevation top of dam	8,780.
Elevation of parapets	8,783.
Normal reservoir water-surface elevation.	8,773.
Maximum reservoir water-surface elevation.	8,780.
River level	8,440.
Maximum height of dam to bedrock	430 feet.
Total estimated cost of dam	[1] $11,301,861.
Preliminary estimate	Table 17.
Reservoir topography	Fig. 141.
General plan and sections	Fig. 142.

In accordance with agreements covering the program of the investigations, the plan and estimate is for a reservoir of 1,000,000 acre-feet, and no water supply studies have been made.

General Data

Wagon Wheel Gap dam site is located on the Rio Grande about 9 miles southeast of Creede, Colo., in Mineral County. It is 32 miles from Del Norte, Colo. The Creede branch of the Denver & Rio Grande Western Railroad runs directly through the dam site and nearly the full length of the reservoir. The reservoir was surveyed and mapped by Shrive B. Collins in April 1909. The topography and area map is no. 5802, filed by Chas. W. Comstock, May 6, 1909, at the office of the State engineer of Colorado. An assumed datum was used for that map and survey with zero elevation apparently at river level. A flow line survey traversed the 300-foot level. The initial point of this survey and three of the points on the axis of the dam were tied into the 1936 surveys. The zero elevation of the original survey corresponds within .5 foot of United States Geological Survey elevation 8,440.

Planetable topography of dam and spillway site on a scale of 1 inch=50 feet, with contour interval of 5 feet, was secured by the Bureau of Reclamation in 1936.

Reservoir Geology

Basement rocks of the region are pre-Cambrian granites and gneisses, above which in the order of their deposition are the following formations, all of which are exposed somewhere in the immediate region.

1. Conejos andesite.
2. Treasure Mountain quartz latite.
3. Sheep Mountain andesite.
4. Alboroto quartz latite.
5. Huerto andesite.
6. Piedra rhyolite.
7. Creede sedimentaries.
8. Fisher latite.

Erosion periods of varying length and intensity followed each eruption, so that each succeeding flow filled the eroded valleys and canyons. The Creede sedimentaries and Fisher latites, being the latest deposits, are now the predominate formations in the reservoir area and at the dam site. The present topography is the result of an extremely long erosional period following the Piedra eruptions during which uplift in Pleistocene and recent times rejuvenated the streams to etch the present-day relief. The history of this section of the Rio Grande during Tertiary times is complex. Flows time and again must have dammed or changed its course. After the uplift, the river for some undetermined reason did not entrench itself in the neighboring Creede sedimentaries, but became caught in the Fisher Latite to form the present canyon, a canyon that is not at all the result of faulting or other structural disturbances. Glaciers reached no farther than about 3 miles upstream from the flow line of the reservoir, but outwash from that period is observable as terrace remnants in the reservoir basin and as recent gravels in the foundation.

No indication of unsatisfactory reservoir conditions have been found. Normal seep and spring occurrences indicate a water table tributary to the river. The basin is heavily mantled with terrace and recent river gravels to a depth of at least 50 to 100 feet. Side wash, fan,

[1] Exclusive of power plant and reconstruction of railroad.

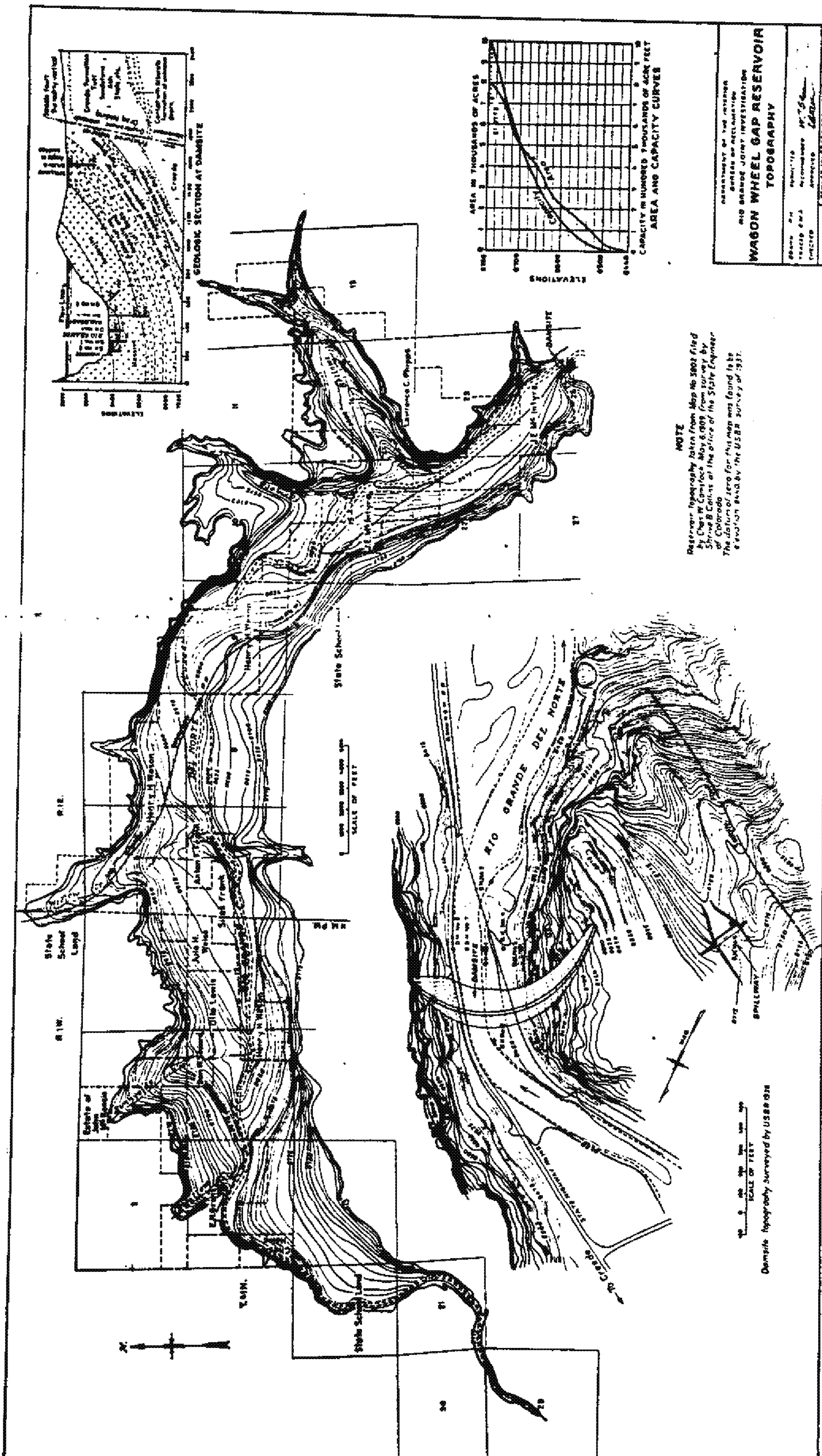
WAGON WHEEL GAP RESERVOIR
TOPOGRAPHY
AREA AND CAPACITY CURVES
GEOLOGIC SECTION AT DAMSITE
RIO GRANDE DEL NORTE
SPILLWAY
SCALE OF FEET
NOTE

FIGURE 141

slough, and other detrital deposits are now progressively covering the bottom gravels.

The immediate bedrock is Creede sedimentary tuffs, shales, and sandstones. In turn, this rests on an older valley floor of volcanic flows. In the vicinity of the dam site a massive latite (Fisher) flow rests on the Creede shales to form a bottle neck, across which the river flows and which forms the barrier responsible for the formation of the flat basin itself.

Considering the volcanic rock character and the compact Creede sedimentaries filling the older Rio Grande Channel as well as mantling the basin, little, if any, reservoir seepage can occur.

Dam Site Geology [4]

The rock forming the foundation and abutments is the Fisher andesite or latite, a dark, fine-grained flow rock with numerous larger crystals or phenocrysts of feldspar, biotite, and hornblende. It is massive, hard, and competent. Some jointing and minor fracturing is noted but water tests in the drill holes showed that these planes are tight at depth. Flow lines are evident and occasionally a soft, thin, interbedded ash layer is found. The latter inclusions become more prevalent at depth or toward the spillway saddle.

The walls of the canyon are unusually sheer, but some local areas at the base are mantled with talus detritus composed of angular rock and fragments with little interstitial silt, which, together with the bottom gravels must be entirely excavated. Some local pockets on the right abutment near the spillway contain a veneer (3-5 feet) of wash material.

Beneath the present river bed, the V-shaped canyon formerly cut in the bedrock is filled to a maximum depth of 80 feet with a roughly stratified mixture of boulders, cobbles, gravel, and sand in a loose, porous deposit. Boulders became more prominent with depth. Beneath the gravel, the rock is somewhat shattered and broken for depths of 5 to 10 feet but then becomes hard, dense, watertight and competent.

A drill hole 305 feet deep (246 feet in rock) failed to penetrate through the latite. Creede sedimentaries probably underlie, but there is a remote possibility that at this particular location the Creede may be entirely eroded and the latite resting directly on one of the other basement flows.

In either event the thickness of rock beneath the foundation should be sufficient to withstand any pressures imposed upon it by the dam. The Creede formation itself, wherever observed, appears compact and adequately impervious.

Neither abutment offers problems of consequence.

All of the Fisher andesite flows show some development of joints and an obvious flow structure. The joints appear to be tight and when free from weathering influences should offer no difficulty. These joints do not extend laterally over great distances, but appear to be a poorly developed columnar type, running at all directions, but always perpendicular to the cooling surfaces.

On the other hand, the horizontal flow lines extend uniformly over large distances. These are planes parallel to the cooling surfaces (top and bottom) which, rather than cleavages, are marked changes in the textural quality of the andesite. They are believed to originate, during the extrusion and subsequent cooling, by temperature differences. Often they mark boundaries between thin ashy inclusions. Such planes are almost invariably tight and no seepage can be expected from this source. All observed fractures were clean and are believed to be susceptible to grouting, if and when any seepage is found.

The andesite, on the whole, dips slightly upstream and more steeply into the canyon. To the northeast the dip varies widely, becoming steeper toward the right where it is measured at 60°. At the top of the right abutment the strike is N. 30° W., dip 30° NE. while on the top of the left abutment it has flattened to strike N. 30° W., dip 5°-10° NE.

A fault parallels the river through the saddle on the right abutment, the downthrown block on the river side, bringing the andesite into juxtaposition to the normally underlying Creede sedimentaries.

It is believed that this faulting has induced much of the folding that is noted in the andesite flows at the dam site. That the dip steepens progressively against the fault is suggestive, while unquestioned drag folding of the Creede sedimentaries has been noted on the other side. However, some of the folding may be of original flow origin. There is no evidence of recent movement.

There is little doubt as to the tight character of the andesite at the dam and little suspicion of the saddle sedimentaries is held in view of their compact character and the excessive distance the water must travel.

Dam

The dam site is very well adapted to a concrete arch type of dam. Studies and estimates were made for a concrete gravity dam as well as for other sections of arch dams. There is an ample supply of sand and gravel deposits of good quality both upstream or downstream from the dam site.

Figure 142 shows the general plan and sections of the proposed dam and spillway. The main dam will be 1,200 feet long at the crest and attains a maximum height of 430 feet above the foundation. The arch section as shown on the drawing has a 20-foot crest at elevation 8,780, with typical concrete curbs and 3-foot

[4] See geologic section, fig. 141.

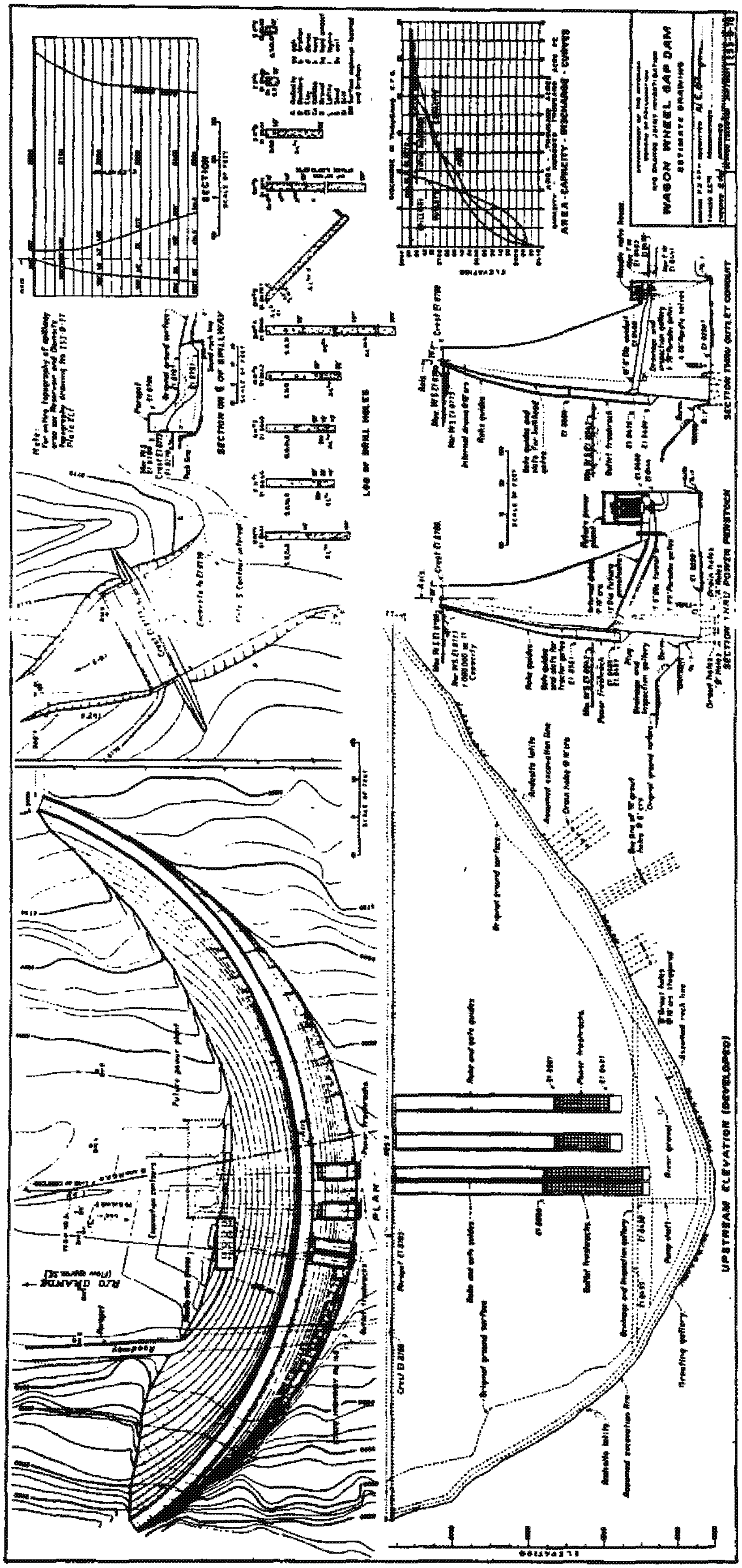

FIGURE 142

parapets. The upstream and downstream face of the dam is curved in section as well as in plan. The dam is designed as a constant angle arch type as closely as the topography will permit.

One line of grout holes at 5-foot centers 50–125 feet deep and several lines of grout holes at 10-foot centers, staggered, 40 feet deep, are contemplated. One line of drain holes at 10-foot centers, 75 feet deep, connect with a drainage and grouting gallery.

Spillway

A straight uncontrolled overflow type of spillway will be located in a saddle approximately 560 feet from the right abutment. This spillway crest at elevation 8,773 is 140 feet long. With the water at its maximum elevation of 8,780 or 7 feet over the crest, the discharge will be 10,000 second-feet. The spillway will be constructed entirely on sound rock and concrete lining does not appear to be necessary below the apron, as the outlet capacity provided will enable full control of practically all floods without the use of the spillway. A channel with a 50-foot bottom width will be excavated in rock for a short distance below the apron and discharge into a natural channel leading to the river approximately 1,500 feet downstream from the dam.

Outlet Works

The outlet works consists of two 10.5 foot diameter steel lined conduits placed at elevation 8,475 branching into four 79-inch diameter conduits at the downstream side of the dam. Four 79-inch diameter paradox gates and four 66-inch needle valves will be located at the downstream slope of the dam in a needle-valve house. The gates and valves will be installed as shown on the drawing. It is planned to install a gas engine electric generator set for lighting and operation purposes.

With the water-surface elevation 8,542 in the reservoir (the 50,000 acre-foot level) the outlet works will discharge the required 5,000 second-feet.

Miscellaneous Cost Items

During May 1937, survey parties relocated the highway, took strip topography throughout and prepared an estimate of cost. A major item is the construction of a high bridge across the river near the upper end of the reservoir. State highway officials have given welcome advice on the relocation. Including a branch road from the upper end of the reservoir to Creede, a total of 21 miles of road will be rebuilt. The road was estimated with a 23-foot base, 6-inch gravel surfacing, maximum 6 percent grade and 20° curves. The route selected starts about one-fourth of a mile below the dam site, climbs to the saddle on the right abutment with a uniform gradient, then follows the right bank of the reservoir to the upper end approximately on a water grade. From Creede the new route leaves the town at the present location of the Lake City road but climbs to a 9,000-foot elevation within a short distance and maintains that elevation until it joins the route on the south side of the reservoir.

An alternative route along the north or left side of the reservoir was considered but discarded because of the excessive curvature, steeper grades and higher elevations required. For several miles the route would be at elevations of over 10,000 feet which would be exceptionally difficult to keep open in the winter months. The route would be a few miles shorter from Creede to a point below the dam but longer in time required for travel from Creede.

There are 8,500 acres of land to be submerged in the reservoir; its ownership and estimated value is as follows:

	Acres	Estimated value
Private lands	[1] 7,547	$377,350
State school lands	[2] 203	6,090
U. S. Fisheries Bureau	30	
U. S. National Forest	820	
Total	8,500	383,440

[1] $50 per acre.
[2] $30 per acre.

Property damage, which covers several farm buildings, about 100 tourist cabins and miscellaneous structures, is estimated at $150,000; telephone lines, 20 miles at $1,500, $30,000; removal of Federal fish hatchery, $50,000.

Information furnished by State officials is to the effect that the Denver & Rio Grande Western Railroad Co. has agreed if the reservoir is built, to petition the Public Utilities Commission of Colorado and the Interstate Commerce Commission for the abandonment of that part of the railroad from Wagon Wheel Gap to Creede, which is the present end of the line. If such is done and the petition is granted, there will be no additional cost to the reservoir. The cost of reconstruction has not been determined but it would probably be fully $2,000,000. An item of $25,000 for salvaging the present roadbed has been included in this estimate. There is also included an item of $75,000 for the construction of a secondary road from Creede along the left side of the reservoir to give access to points now reached from the bottom of the basin.

Diversion During Construction

It is estimated that river diversion and unwatering of foundations will cost about $100,000. River diversion during construction can be handled in two ways—a 12-foot diameter unlined horseshoe tunnel 1,000 feet long can be driven through the rock under the right abutment of the dam; or inlet and outlet flumes

TABLE 17.—*Wagon Wheel Gap Dam preliminary estimate, Aug. 1, 1937*

Concrete arch: Top of dam, elevation 8,780; spillway crest, elevation 8,773; normal water surface, elevation, 8,773; maximum height of dam, 430 feet; drawing no. 253-D-78]

[Storage capacity, 1,000,000 acre-feet; spillway capacity, 10,000 second-feet; required outlet capacity, 5,000 second-feet; at elevation 8,542 (50,000 acre-feet)]

Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
	Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
RIVER WORK								
Diversion, and unwatering foundations	(1)		(1)	$100,000			(1)	$100,000
EARTHWORK								
Excavation, common:								
Dam foundation	185,000	Cubic yard	$1.00	185,000			$1.00	185,000
Spillway	9,000	Cubic yard	1.25	11,250			1.25	11,250
Excavation, rock:								
Dam foundation	221,000	Cubic yard	3.00	663,000			3.00	663,000
Spillway	6,000	Cubic yard	3.50	21,000			3.50	21,000
Embankment: Backfill about structures	4,000	Cubic yard	.75	3,000			.75	3,000
GROUTING AND DRAINAGE								
Drilling:								
Grout holes not over 25 feet deep	500	Linear foot	1.00	500			1.00	500
Grout holes 25 to 50 feet deep	6,000	Linear foot	2.00	12,000			2.00	12,000
Grout holes 50 to 100 feet deep	11,200	Linear foot	2.50	28,000			2.50	28,000
Grout holes over 100 feet deep	18,800	Linear foot	3.00	56,400			3.00	56,400
Drain holes	12,200	Linear foot	2.50	30,500			2.50	30,500
Pressure grouting:								
Foundation	45,000	Cubic foot	1.00	45,000	$1.00	$45,000	2.00	90,000
Contraction joints	5,300	Cubic foot	2.00	10,600	1.35	7,155	3.35	17,755
Drain tile: 5-inch porous-concrete drain tile	24,000	Linear foot	.60	14,400	.07	1,680	.67	16,080
CONCRETE WORK								
Concrete:								
Dam	88[illegible],500	Cubic yard	3.25	2,877,875	3.25	2,877,875	6.50	5,755,75[illegible]
Parapets and curbs	400	Cubic yard	18.00	7,200	4.00	1,600	22.00	8,800
Spillway	1,600	Cubic yard	4.00	6,400	3.25	5,200	7.25	11,600
Trash racks	3,150	Cubic yard	12.00	37,800	4.00	12,600	16.00	50,400
Outlet superstructure	700	Cubic yard	20.00	14,000	4.00	2,800	24.00	16,800
Outlet substructure	6,500	Cubic yard	5.75	37,375	3.75	24,375	9.50	61,750
Training walls, spillway	160	Cubic yard	7.25	1,160	3.75	600	11.00	1,760
Cut-off walls, spillway	400	Cubic yard	5.75	2,300	3.75	1,500	9.50	3,800
Cooling plant	(1)		(1)	100,000			(1)	100,000
Special concrete finishing	2,500	Square yard	.60	1,500			.60	1,500
METALWORK								
al:								
Trash rack	125,000	Pound	.015	1,875	.06	7,500	.075	9,375
Reinforcement bars	500,000	Pound	.02	10,000	.03	15,000	.05	25,000
Grout and water stops	16,500	Linear foot	.25	4,125	.40	6,600	.65	10,725
Bulkhead gates, frames, and guides	35,000	Pound	.015	525	.09	3,150	.105	3,675
Outlet conduits	370,000	Pound	.025	9,250	.075	27,750	.10	37,000
4 66-inch needle valves and operating mechanism	264,000	Pound	.025	6,600	.245	64,680	.27	71,280
4 79-inch paradox gates	324,000	Pound	.025	8,100	.21	68,040	.235	76,140
Pipe handrailing	2,000	Pound	.10	200	.10	200	.20	400
Miscellaneous metalwork	41,000	Pound	.10	4,100	.10	4,100	.20	8,200
Pipe and fittings for foundation grouting	79,000	Pound	.05	3,950	.07	5,530	.12	9,450
Pipe and fittings for contraction joint grouting	140,000	Pound	.10	14,000	.10	14,000	.20	28,000
Hoist	(1)		(1)	3,000			(1)	3,000
MISCELLANEOUS ITEMS								
Items:								
Gate tender's house	(1)		(1)	3,000			(1)	3,000
Clearing reservoir	300	Acre	25.00	7,500			25.00	7,500
Gas-electric generator set and equipment	(1)		(1)	400	(1)	1,600	(1)	2,000
Construction camp	(1)		(1)		(1)	60,000	(1)	60,000
Highway relocation (21 miles)	(1)		(1)	692,272	(1)	68,741	(1)	761,013
Right-of-way	7,547	Acre			50.00	377,350	50.00	377,350
Right-of-way (school land)	203	Acre			30.00	6,090	30.00	6,090
Property damage	(1)				(1)	200,000	(1)	200,000
Telephone and utility lines	20	Mile			1,500.00	30,000	1,500.00	30,000
Removal of United States fish hatchery	(1)				(1)	50,000	(1)	50,000
Building secondary road	15	Mile	4,000.00	60,000	1,000.00	15,000	5,000.00	75,000
Salvaging railroad (9 miles)	(1)				(1)	25,000	(1)	25,000
Subtotal				5,095,157		4,030,716		9,125,873
Contingencies, 15 percent								1,368,881
Total estimated field cost								10,494,754
Investigations and surveys	(1)							20,000
Engineering and inspection, 5 percent								524,738
Superintendence and accounts, 1 percent								104,948
General expense, 1½ percent								157,421
Total estimated cost								11,301,861
Cost per acre-foot storage								11.30

[1] Lump sum.

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connecting with a conduit placed in the base of the dam can be used for the diversion of stream flow. Either installation will cost approximately the same, i. e., $50,000. The sum of $25,000 is included for plugging the tunnel or conduit system, and pumping and unwatering of foundations was estimated at $25,000. It will be necessary to coordinate river diversion with the construction schedule.

Construction Schedule

It will require approximately 3 years to complete this dam. The first year would see construction of the river diversion system and the major portion of the dam excavation. Construction of the main dam can be started early in the beginning of the second year. The spillway excavation and concrete structure can also be completed in that year. In the third year, concrete pouring, finishing work on the structures, and installation of the outlet gates and valves can be completed.

Power Development

Provisions will be made for a future power installation by placing two 19-foot diameter tunnels (closed with plugs) through the dam for a later installation of two 13-foot diameter penstocks, and guides for future tractor gates and trash racks will be constructed on the face of the dam. No power items, other than those necessary for present construction, were included in this estimate.

The period 1911 to 1933, inclusive, was used in making the study of possible power production at Wagon Wheel Gap Reservoir.

The operation schedule for the reservoir was obtained from a study made by R. J. Tipton, consulting engineer for San Luis Valley interests. Mr. Tipton's schedule was for all the reservoirs on the Rio Grande above Wagon Wheel Gap. For this study his results have been modified to the extent that the capacity of Wagon Wheel Gap Reservoir alone has been used, assuming that the 150,000 acre-feet of storage capacity upstream would be ideally operated to regulate inflow to Wagon Wheel Gap Reservoir.

The power installation proposed consists of two 25,000-kilowatt generators with penstocks of 3,000-second-foot capacity at rated head of 250 feet. All irrigation releases and spills were assumed to be available for power generation up to the penstock capacity. As the lowest head to be encountered during the period covered by the study was in excess of 250 feet, a constant over-all efficiency was assumed for the power installation of 80 percent. At lower heads this efficiency could not be realized, but no modification was necessary for this study.

No correction for evaporation was made in this study, as allowance for evaporation from Wagon Wheel Gap Reservoir was made by Mr. Tipton in the gross demand upon the reservoir.

The reservoir releases and spills given in Mr. Tipton's tabulations have been used directly, except that the November-March period used in Mr. Tipton's study was broken down into months in this study whenever there were releases from the reservoir. The apparent discrepancies in power produced by the releases usable for power in the summary table are due to this breakdown into monthly values.

Table 18 is a summary of the detailed study of possible power production at Wagon Wheel Gap Reservoir. The study was carried through September of 1933, as that was as far as Mr. Tipton's study was based upon recorded discharge.

Power produced must be considered as secondary power only since the plant, as a rule, can only be operated during the irrigation season.

At an estimated cost of $54 per kilowatt of installed capacity, the total cost of power installation at the dam will be $2,700,000.

Power Market

A study of the trend of population growth in the San Luis Valley indicates a population of about 50,000 in 1950. At present, per-capita consumption of power probably does not exceed 500 kilowatt-hours annually. Very few of the farms are electrified. Development of power at Wagon Wheel Gap may make feasible the operation of numerous pumping plants in the valley designed to recover a part of the great amount of water now stored beneath the valley floor. For such a load the plant at Wagon Wheel Gap is ideally fitted. It may also have some value for use as a peak-load plant when operated in conjunction with existing power plants. A market for the entire output of the plant within the immediate future is not now in prospect.

Flood Damage

Flood damage on the Rio Grande in Colorado between Creede and Alamosa has been limited. Occasionally the head gates and diversion dams of some of the canals have been damaged and prolonged high water in the river at Alamosa has raised the ground waters beneath that city high enough to flood cellars and overload the sewage system.

Below Alamosa, the flooding of larger areas of farm land near the mouth of La Jara Creek and the Conejos River has occurred frequently but the resulting benefits to meadows and pastures have sometimes been as great as the damage to other areas.

The construction of Wagon Wheel Gap Reservoir cannot be expected to alleviate flood conditions to any great extent unless a considerable amount of its capacity is set aside for flood regulation alone.

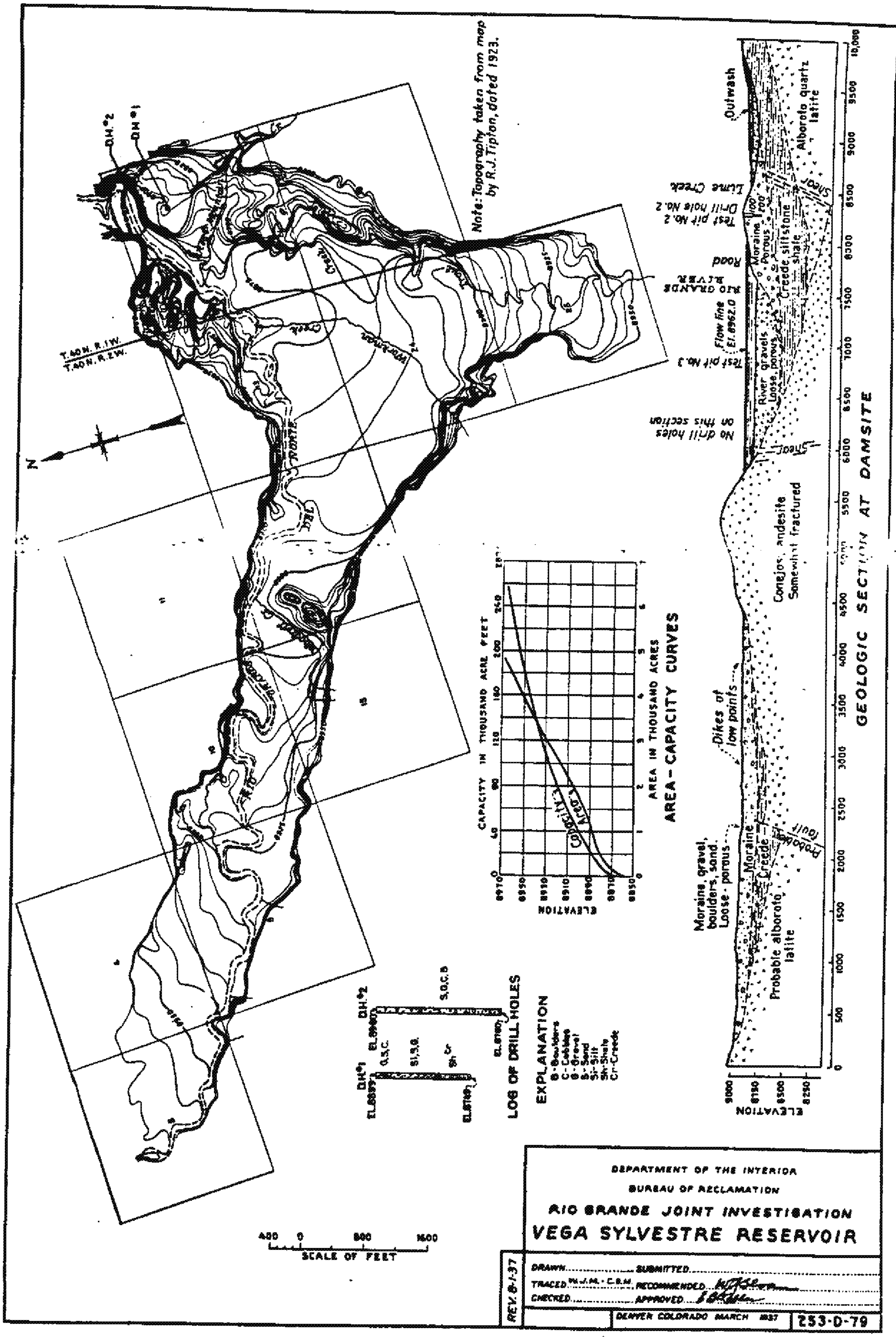
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RIO GRANDE JOINT INVESTIGATION
VEGA SYLVESTRE RESERVOIR
DENVER COLORADO MARCH 1937
253-D-79
REV. 8-1-37
Note: Topography taken from map by R.J. Tipton, dated 1923.
GEOLOGIC SECTION AT DAMSITE
AREA-CAPACITY CURVES
CAPACITY IN THOUSAND ACRE FEET
AREA IN THOUSAND ACRES
ELEVATION
LOG OF DRILL HOLES
EXPLANATION
B-Boulders
C-Cobbles
G-Gravel
S-Sand
Si-Silt
Sh-Shale
Cr-Creede
SCALE OF FEET
T.40N. R.1W.
T.40N. R.2W.
Outwash
Alboroto quartz latite
Lime Creek
Drill hole No. 2
Test pit No. 2
Road
RIO GRANDE RIVER
Flow line El. 8962.0
Test pit No. 3
No drill holes on this section
River gravels Loose, porous
Conejos andesite Somewhat fractured
Dikes at low points
Moraine gravel, boulders, sand. Loose - porous
Probable alboroto latite
Probable fault

FIGURE 143

TABLE 18.—*Summary of power production at Wagon Wheel Gap with 150,000 acre-feet of upstream storage*

Year	Reservoir releases in 1,000 acre-feet					Mean reservoir contents for year in 1,000 acre-feet	Power output in 1,000,000 kilowatt-hours	
	To supply irrigation demand [1]	Surplus after reservoir is full [2]	Total	Usable for power generation	Waste		Per 1,000 acre-feet release	Total
1910	432	161	593	593	0	976	0.270	160.9
1911	279	230	509	509	0	1,003	.272	130.0
1912	398	229	627	610	17	1,003	.272	174.2
1913	419	18	437	437	0	990	.271	118.4
1914	413	67	480	477	3	1,003	.272	129.7
1915	425	52	477	477	0	1,003	.272	129.7
1916	310	205	515	515	0	1,003	.272	134.1
1917	316	282	598	526	72	1,003	.272	149.0
1918	437	0	437	437	0	988	.271	118.6
1919	353	62	415	415	0	1,003	.272	112.9
1920	271	345	616	552	64	1,003	.272	149.1
1921	331	383	714	609	105	1,003	.272	157.9
1922	275	347	622	604	18	1,003	.272	173.2
1923	322	145	467	467	0	1,003	.272	127.1
1924	364	230	594	594	0	995	.271	161.4
1925	387	0	387	387	0	1,003	.272	105.3
1926	393	22	415	415	0	1,003	.272	112.7
1927	293	250	543	543	0	1,003	.272	137.2
1928	395	97	492	492	0	991	.271	144.0
1929	281	161	442	442	0	1,003	.272	113.6
1930	460	0	460	460	0	984	.270	131.3
1931	512	0	512	512	0	792	.250	130.5
1932	248	0	248	248	0	907	.263	65.1
1933 [3]	434	0	434	434	0	891	.261	113.8
Total	8,748	3,286	12,034	11,755	279	23,559	....	3,179.7
Mean	364.5	136.9	501.4	489.8	11.6	981.6	.270	132.5

[1] Release required to make up total demand at Del Norte of 600,000 acre-feet.
[2] Released through turbines and usable for power.
[3] January to September, inclusive, only.

Based on reservoir operation study by [illegible]. J. Tipton.

Vega Sylvester Reservoir

Summary of data:

- Storage capacity — 240,000 acre-feet.
- Spillway capacity — 15,000 second-feet.
- Regulated Outlet capacity at 45-foot head. — 5,000 second-feet.
- Top of dam, elevation — 8,970.
- Maximum water surface, elevation — 8,962.
- Height of dam above stream bed — 125 feet.
- Total estimated cost, dam and reservoir. — $4,825,879 maximum.
- Reservoir topography and geologic section. — Fig. 143.
- General plan and sections — Fig. 144.
- Preliminary estimate — Table 19.

General

The Vega Sylvester Reservoir is generally considered an alternative for the Wagon Wheel Gap Reservoir which, although not so effective in control of the Rio Grande, would provide a large measure of storage control at much less cost than the Wagon Wheel Gap Reservoir. It is about 17 miles above that site, also on the main stream, but with several important tributaries entering between. The drainage area is 530 square miles, mostly at high altitudes. San Luis Valley interests had tentatively decided upon a storage capacity of 240,000 acre-feet as best suited to valley needs and the designs submitted are for that capacity. The Bureau of Reclamation, in accordance with the program of work for this investigation, has not made a study of waters storable nor of the possible utilization of storage releases.

The proposed dam is located about 11 miles southwest of Creede, Colo., the nearest railroad point, in Mineral County, Colo. Colorado State Highway No. 149 from Creede to Lake City passes through portions of the reservoir. Approximately 7 miles of this highway would have to be reconstructed and a small mileage of secondary roads would also be affected.

The State engineer furnished maps of the reservoir and dam site, together with logs of several holes heretofore drilled.

Much of the basin is a mountain meadow used for pasture and wild hay, but its chief value is for recreational and fishing purposes.

Geology

The dam for Vega Sylvester Reservoir is only about 4 miles above the flow line of Wagon Wheel Gap Reservoir. Regional geology as described for that area is equally applicable to this with the exception that the only extrusive formation found in the basin itself is the earliest Conejos andesite, and the later Creede alluvium. Subsequent to the deposition of the Creede formation, Wisconsin glaciers occupied the new valley and deposited large quantities of loose detritus in the form of moraines and outwash. Continued recent erosion has somewhat modified these deposits, forming terraces in the outwash and channels across the moraines.

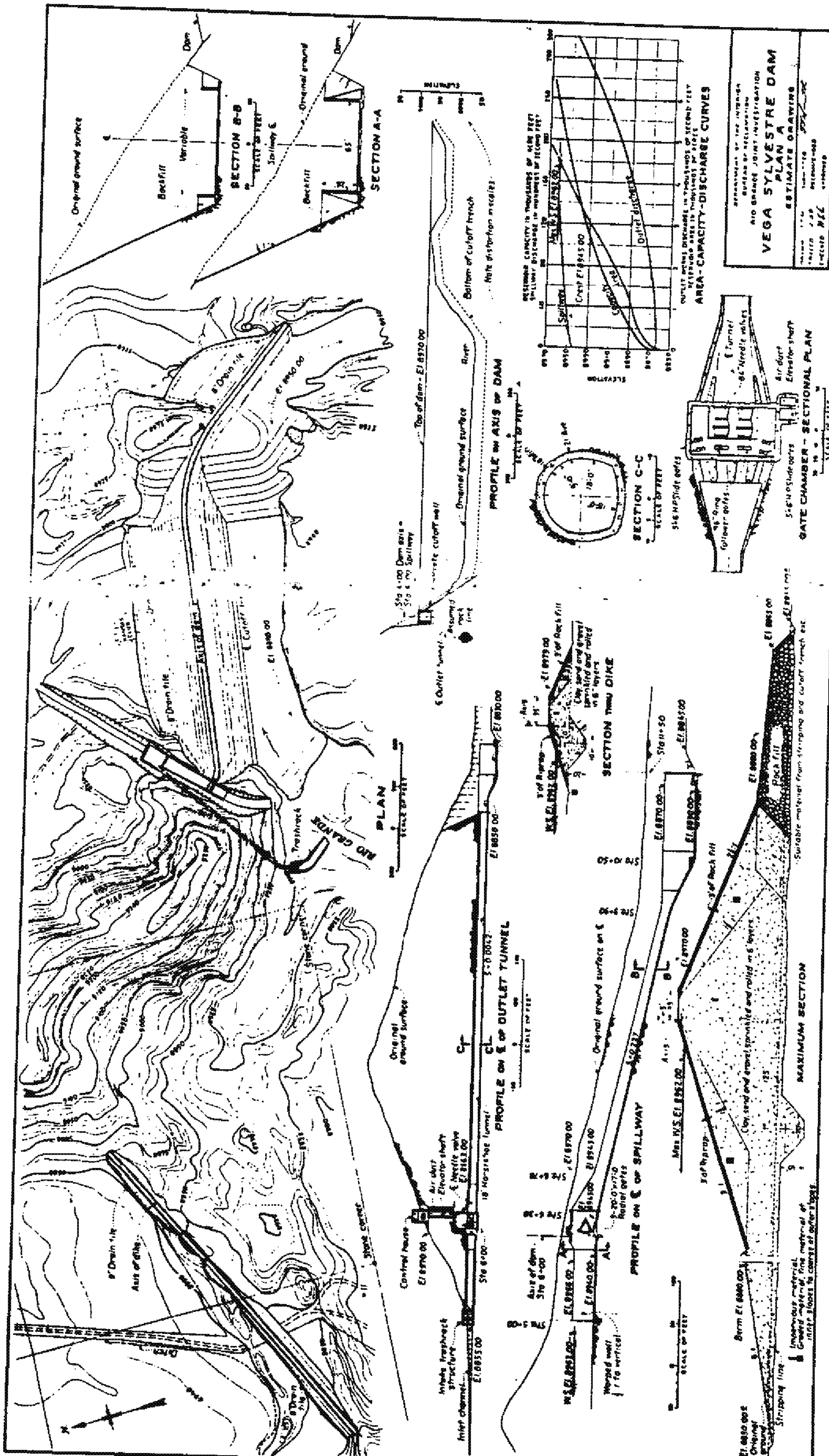
VEGA SYLVESTRE DAM
PLAN A
ESTIMATE DRAWING
AREA-CAPACITY-DISCHARGE CURVES
SECTION B-B
SECTION A-A
PROFILE ON AXIS OF DAM
SECTION C-C
GATE CHAMBER - SECTIONAL PLAN
PLAN
RIO GRANDE
PROFILE ON ℄ OF OUTLET TUNNEL
SECTION THRU DIKE
PROFILE ON ℄ OF SPILLWAY
MAXIMUM SECTION

FIGURE 144

The basin is a normal erosional feature, carved from a rather complex but ordinarily impervious rock complex. (Conejos andesite, Creede siltstones.) The horizontal Creede siltstones are heavily mantled with river gravels and with glacial terrace gravels, largely derived from moraine and other glacial debris. All these detrital materials are extremely porous and unconsolidated, so that considerable ground storage can be expected.

There is no reason to suspect an unsatisfactory reservoir basin above the dam site. Normal spring and seep occurrences indicate a water table tributary to the river with remote chance for an inclined or perched condition.

The ancestral Rio Grande Valley was carved from substantially horizontal volcanic flows. The Creede sedimentaries were likewise deposited essentially horizontal.

It is known that considerable faulting crosses the valley at approximately right angles to the river, below and possibly above the dam site. Effects of these movements are undoubtedly reflected in the fractured and displaced state of sections of the left abutment andesite. On the whole, the central knob is horizontal but detailed work will be required to interpret local irregularities.

Although the block faulting is believed to have occurred after Creede deposition, it is doubtful whether this will have any detrimental effect on its impervious character, especially as the fault zones do not follow the river but cut obliquely across.

The Creede tuffs, ashes, shales, sandstones, and conglomerates are abundantly exposed below the dam site. In general, toward the center of the valley the deposits are shaly, well stratified and apparently part of a lake deposit. Marginal facies are sometimes sandstone or even conglomerate. Numerous travertine or hot spring deposits are found, one of which outcrops shortly above the dam site. The Creede sedimentaries when ever encountered can be considered adequately impervious and competent.

The rock forming the left abutment is believed to be the so-called "Conejos" andesite of the Tertiary volcanic series. It is a dark, fine-grained flow rock with visible crystals of feldspar, biotite, and pyroxene. In areas, it is somewhat porphyritic. It is uniformly hard but is somewhat fractured; the latter condition is sometimes accentuated in shear zones. This flow is one of the oldest members of a long series of extrusives.

On the extreme left, the saddle across which the Lake City, Creede road passes must serve as a natural dam. This depression is filled by a parallel series of lateral or terminal moraines which rise to such a height as to require the addition of only low additional dikes. The moraines are similar to those on the right abutment. A pit exposed a heterogeneous assemblage of poorly compacted boulders, cobbles, gravel, and sand. The material caved and raveled easily, necessitating careful timbering. In all probability it is quite porous. It is said that when irrigation occurs on the neighboring flats, ponds form in several of the lower glacial depressions. The depth to a cut-off is unknown and either Creede siltstone or andesite may form the underlying basement. The valley floor downstream from these moraines is flat and in all probability is heavily mantled with loose porous terrace gravels topped by a thin veneer of soil.

On the right abutment, rock is so deep that it cannot practicably be reached with a cut-off. Support and impervious properties must rely upon the character of the glacial moraine which is composed of assemblages of unstratified boulders, cobbles, gravel, sand, and minor silt. A test pit penetrating the right abutment material indicated a moderately firm deposit for the first 25 feet with a gradational change into looser, porous gravels to a depth of 100 feet. Continued with a drill hole, the same material was encountered to 200 feet. Water was encountered at 97 feet, or 13 feet above the river. A characteristic thin clay-silt coating is found covering the cobbles and pebbles, a feature not found in the terrace and river gravels. These morainal deposits are remarkably uniform in character both horizontally and vertically. Lensed structures are generally lacking and if it were not for the surface topographic expressions, identification would be difficult. As a rule, moraine material is somewhat compact and relatively impermeable but these deposits are different. It is evident that they are very porous, only slightly better than loose river gravels. With a 4-foot depth of water in pit no. 2, the continuous outflow was 33 gallons per minute.

The terrace gravels are believed to be largely derived from glacial detritus as the stream reworked these deposits and spread them out as stratified river gravels. In this process much of any original silt content was lost, but large boulders were not moved so that the resulting deposits are extremely loose and porous. Pit no. 1 in this gravel would not stand unsupported for more than 3 feet. At 15 feet, the hole had to be abandoned. These gravels are now found above the present stream bed as terrace flats and remnants.

In the river bed, loose porous gravels will be encountered for at least 100 feet beneath the river and may continue to 150 or 200 feet. Drilling prior to that by the Bureau suggested that the clay content becomes predominant with depth. This conclusion is not borne out by the Bureau's examination and must be discounted until justified by the results of further drilling. Neither drill hole no. 1 nor no. 2 shows any evidence of this condition, although it must be recognized that their positions are not ideally located for this determi

TABLE 19.—*Vega-Sylvestre Dam, preliminary estimate, plan A, December 1936*

[Normal water surface elevation, 8,962; spillway capacity, 15,000 cubic foot-seconds; outlet capacity, 5,000 cubic foot-seconds; storage capacity, 240,000 acre-feet]

[Type: Earth fill; top of dam, elevation 8,970; spillway crest, elevation 8,945; maximum height, 125 feet]

Item no.	Item	Quantity		Material and labor furnished by the contractor		Material furnished by the Government		Summary	
		Amount	Unit	Unit cost	Total cost	Unit cost	Total cost	Unit cost	Total cost
1	Diversion and care of river during construction and unwatering foundations	(1)			$20,000				$20,000
2	Excavation, stripping borrow pits	$260,000	Cubic yard	$0.30	78,000			$0.30	78,000
3	Excavation, common, stripping for embankment	350,000	Cubic yard	.30	105,000			.30	105,000
4	Excavation, common, for spillway and for tunnel inlet and outlet	158,000	Cubic yard	.30	47,400			.30	47,400
5	Excavation, rock for spillway and for tunnel inlet and outlet	241,000	Cubic yard	1.00	241,000			1.00	241,000
6	Excavation all classes in outlet tunnel and elevator shaft	26,000	Cubic yard	8.00	208,000			8.00	208,000
7	Excavation, common, for embankment toe drains and for cut-off trenches	230,000	Cubic yard	.25	57,500			.25	57,500
8	Excavation, rock, for cut-off wall footings and for embankment toe drains	250	Cubic yard	5.00	1,250			5.00	1,250
9	Excavation, common, in borrow pits and transportation to embankments	5,050,000	Cubic yard	.25	1,262,250			.25	1,262,250
10	Excavation, rock, in borrow pits and transportation to embankments	12,000	Cubic yard	.75	9,000			.75	9,000
11	Backfill	20,000	Cubic yard	.50	10,000			.50	10,000
12	Earth fill in embankments	4,500,000	Cubic yard	.10	450,000			.10	450,000
12	Rock fill on downstream slope of embankments	300,000	Cubic yard	.30	90,000			.30	90,000
14	Riprap on upstream slope of embankments	90,000	Cubic yard	.50	45,000			.50	45,000
15	Dumped riprap in spillway channel	2,000	Cubic yard	1.00	2,000			1.00	2,000
16	Constructing 12-inch diameter sewer-pipe drains, with uncemented joints, embedded in gravel	1,600	Linear foot	.70	1,120	$0.70	$1,120	1.40	2,240
17	Constructing 8-inch diameter sewer-pipe drains, with uncemented joints, embedded in gravel	6,200	Linear foot	.60	3,720	.60	3,720	1.20	7,440
18	Constructing 6-inch diameter sewer-pipe drains, with uncemented joints, embedded in gravel	800	Linear foot	.50	400	.50	400	1.00	800
19	Drilling weep holes	1,000	Linear foot	1.00	1,000			1.00	1,000
20	Drilling grout holes not more than 25 feet deep	20,000	Linear foot	1.00	20,000			1.00	20,000
21	Drilling grout holes more than 25 feet deep and not more than 50 feet deep	500	Linear foot	1.75	875			1.75	875
22	Drilling grout holes more than 50 feet deep and not more more than 100 feet deep	1,000	Linear foot	2.50	2,500			2.50	2,500
23	Installing grout pipe and fittings	7,000	Pound	.10	700	.10	700	.20	1,400
24	Pressure grouting	22,000	Cubic foot	1.00	22,000	.60	13,200	1.60	35,200
25	Drilling holes for anchor bars and grouting bars in place	1,000	Linear foot	1.00	1,000	.50	500	1.50	1,500
26	Concrete in cut-off wall	200	Cubic yard	12.00	2,400	7.00	1,400	19.00	3,800
27	Concrete in trash-rack structure and transition	470	Cubic yard	17.50	8,225	7.50	3,525	25.00	11,750
28	Concrete in tunnel lining	4,500	Cubic yard	13.00	58,500	7.00	31,500	20.00	90,000
29	Concrete in gate chamber and elevator shaft	5,500	Cubic yard	15.00	82,500	7.50	41,250	22.50	123,750
30	Concrete in floors of spillway and outlet works channel	3,450	Cubic yard	10.00	34,500	7.00	24,150	17.00	58,650
31	Concrete in spillway and outlet works channel, except floors	4,300	Cubic yard	12.00	51,600	7.00	30,100	19.00	81,700
32	Concrete in outlet works operating house	330	Cubic yard	20.00	6,600	7.50	2,475	27.50	9,075
33	Concrete in parapet and curb walls	1,300	Cubic yard	14.00	18,200	7.50	9,750	21.50	27,950
34	Placing reinforcement bars	2,200,000	Pound	.025	55,000	.035	77,000	.06	132,000
35	Installing metal sealing strips	1,500	Linear foot	.30	450	.30	450	.60	900
36	Furnishing and installing steel tunnel-liner plates and supports	100,000	Pound	.10	10,000			.10	10,000
37	Special finishing of concrete surfaces	6,900	Square yard	.60	4,140			.60	4,140
38	Construction of outlet works operating house, except concrete	(1)			500		2,500		3,000
39	Installing trash-rack metalwork	140,000	Pound	.03	4,200	.07	9,800	.10	14,000
40	Installing high-pressure hydraulically operated slide gates and metal conduit linings	320,000	Pound	.03	9,600	.12	38,400	.15	48,000
41	Installing high-pressure hydraulically operated ring-follower gates and metal conduit linings	346,000	Pound	.04	13,840	.15	51,900	.19	65,740
42	Installing control apparatus for high-pressure gates	12,000	Pound	.10	1,200	.35	4,200	.45	5,400
43	Installing needle valves	368,400	Pound	.04	14,736	.23	84,732	.27	99,468
44	Installing radial gates and operating mechanisms	70,000	Pound	.03	2,100	.10	7,000	.13	9,100
45	Installing freight elevator	(1)					13,500		13,500
46	Installing cranes, hoist, and blower	60,000	Pound	.04	2,400	.20	12,000	.24	14,400
47	Installing metal stairway, walkway, and grating	10,000	Pound	.10	1,000	.12	1,200	.22	2,200
48	Installing pipe handrails	5,000	Pound	.10	500	.15	750	.25	1,250
49	Installing miscellaneous metalwork	30,000	Pound	.10	3,000	.10	3,000	.20	6,000
50	Installing electrical equipment	(1)			2,000		12,500		14,500
51	Construction camp and permanent buildings	(1)					40,000		40,000
	Subtotals				3,066,906		522,722		3,589,628
	Contingencies, 15 percent								538,444
	Total estimated construction field costs								4,128,072
	Investigation and surveys (estimated to date)								5,000
	Engineering and inspection, 6 percent								247,684
	Superintendence and accounts, 1½ percent								61,921
	General expense, 2½ percent								103,202
	Total estimated cost								4,545,879
	Right-of-way		5,000 acre			35.00			175,000
	Relocation of road		7 mile			15,000.00			105,000
	Total								4,825,879

[1] Lump sum.

NOTE.—Cost per acre-foot, $20.11.

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nation. It is possible that some of the material listed as "heavy with clay", in the past drilling, was in reality the Creede formation. Artesian conditions point toward this belief.

Most of the holes in past drilling on the lower axis encountered artesian water. The origin of this is not clear due to the uncertainty of the character of the materials that were penetrated and when and where the flow was first encountered.

Hole no. 1 on the upper axis encountered Creede formation at 101 feet. It is significant that the water table remained at 42 feet until a depth of 101 feet was reached. Later a slow rise was noted, fed in all probability from an aquifer in the Creede silts. However, no gravel zones were encountered in the Creede formation. It is suggested that if the hole had been deeper some such member would have been encountered.

Such a conclusion suggests that Creede formation may have been penetrated at the lower axis. Flow from these holes was measured at 2-3 gallons per minute. The artesian pressure at the river is small, estimated about 2-5 pounds per square inch.

Geologically, the dam site must be classified as a poor one as it requires excessive corrective measures to overcome unsatisfactory characteristics. Much more prospecting must be done before the limitations of safe and economical design can be determined.

Design Problems

In all, five different designs and estimates have been made to utilize the dam site, beginning with a dam across the river bottom on the lowest axis and successively swinging the axis upstream in a radial direction from the left abutment, in order to utilize the terrace upstream from the shortest axis. If there were no uncertainties concerning ability to drive sheet piling and its efficacy as a cutoff, the lower axis would probably be the best but recent experience has cast doubt upon the advisability of placing reliance on piling as a cutoff and opinions as to its practical use differ widely.

The most serious factor in any design is the amount of flow occurring under the dam and right abutment during reservoir operation. Information to aid in solving this problem is not sufficient in scope and could not be secured without the expenditure of several times the amount allotted for this study. Design of a safe dam is possible with present information but whether the reservoir will leak so badly as to materially impair the effectiveness of the reservoir, cannot be predicted.

The selection of a dam site in this locality is controlled by the relative values for foundation purposes, of the materials in the river bed, the terrace and the moraine on the right abutment. While these materials are all porous, they differ to some degree. The moraine material does contain a small amount of clay and is probably the least porous. The gravels in the river bed come next in porosity as they contain some sand but little, if any, clay. The reworked moraine material in the terrace is believed to contain very little sand or clay. Because of the many unsolved features, it is not considered advisable to recommend any one particular plan. Plan A herein described in some detail, is intended only as an approach to a final solution. This plan presents a scheme to secure a deep cutoff in the stable river gravels and avoid, so far as possible, dependency on the reworked moraine material. A blanket is carried upstream to increase percolation distances.

The plan contemplates a rolled earthfill and rockfill dam located in the wide portion of the river bottom where the overlying beds of resorted glacial and recent river gravels have been largely eroded. The upper portion of the upstream slope of the dam has a 3:1 slope protected with 3 feet of riprap while the lower portion consists of a long blanket with variable slopes. The downstream slope varies from 2½:1 in the upper portion with variable slopes approximating 12:1 in the lower portion. The upper portion of the rock fill is 3 feet thick and the lower portion varies in thickness to a maximum of about 35 feet. The central and earth blanket portions of the dam are composed of impervious material grading into pervious material at the outer slopes. The cutoff trench has a bottom width of 20 feet and 1:1 side slopes with a depth of approximately 30 feet. A concrete cut-off wall will be constructed in the bottom of the trench at the left abutment where rock is encountered. The rock at the left abutment will be grouted beneath the cut-off wall and elsewhere, as required.

Left Ridge Dike

A long low dike is required at a low section in the reservoir west of the dam. Rapid seepage of irrigation water at this point indicates high porosity and it is very questionable whether leakage through the foundation materials under the dike could be reduced materially at a reasonable cost. A cut-off trench with a 10-foot bottom width and 20-foot depth is provided and is considered the maximum size of trench justified by the height of the dike.

Spillway

The spillway is located on the left abutment in the andesite rock. Outflow is controlled by three 20- by 17-foot radial gates having a discharge capacity of 15,000 second-feet. The channel is concrete-lined throughout and terminates in a combination stilling basin for the spillway and the outlet works. A long tlet channel will be required to connect with the ver channel.

Outlet and Diversion

The outlet and diversion tunnel is located in the left abutment. The 18-foot diameter horseshoe tunnel extends from the trash-rack structure to the spillway stilling basin except for a section at the gate chamber which is widened to provide for four outlet conduits. The two outer conduits are controlled by two sets of 5- by 6-foot hydraulically operated slide gates and the two inner conduits are controlled by 84-inch needle valves and 96-inch ring follower gates. A diversion requirement of 4,000 second-feet is provided with the gates installed and the needle valves omitted until storage is begun.

Construction Materials

Test pits have shown a sufficient supply of suitable materials for construction of the earth embankment available at a distance of approximately three-quarters of a mile below the dam site on the right bank. The spillway and outlet tunnel excavation will provide the major portion of rock embankment for the riprap and rock fill portions of the dam. It is believed that sand and gravel aggregate for concrete is available near the dam site but no pits have been prospected.

Right-of-Way

The area flooded by the reservoir is a mountain meadow used for pasture only, but in addition, has a recreational value for fishing. There are few buildings in the area. Seven miles of the Creede-Lake City highway will need to be relocated on more difficult terrain than the present location.

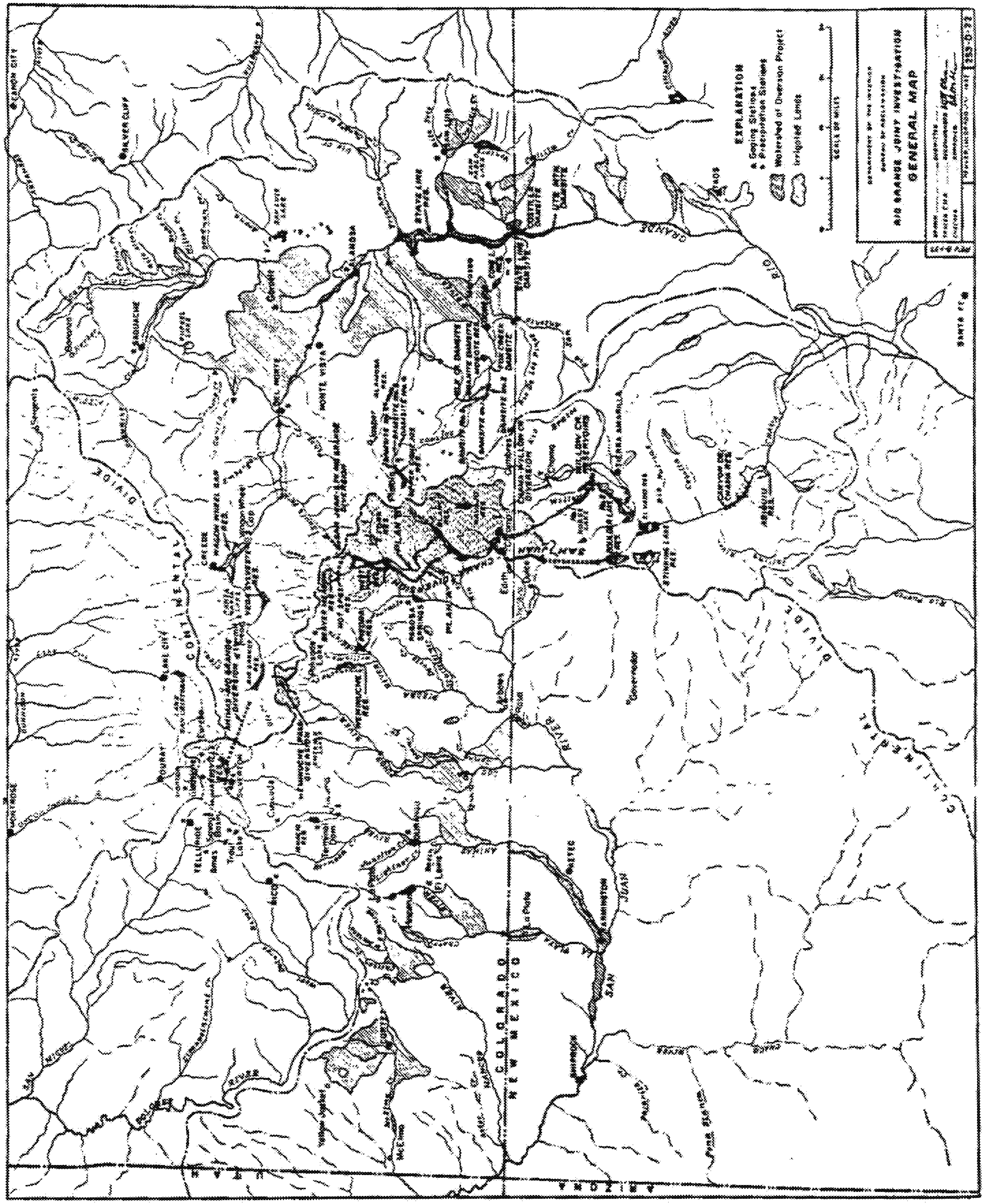

Figure 60

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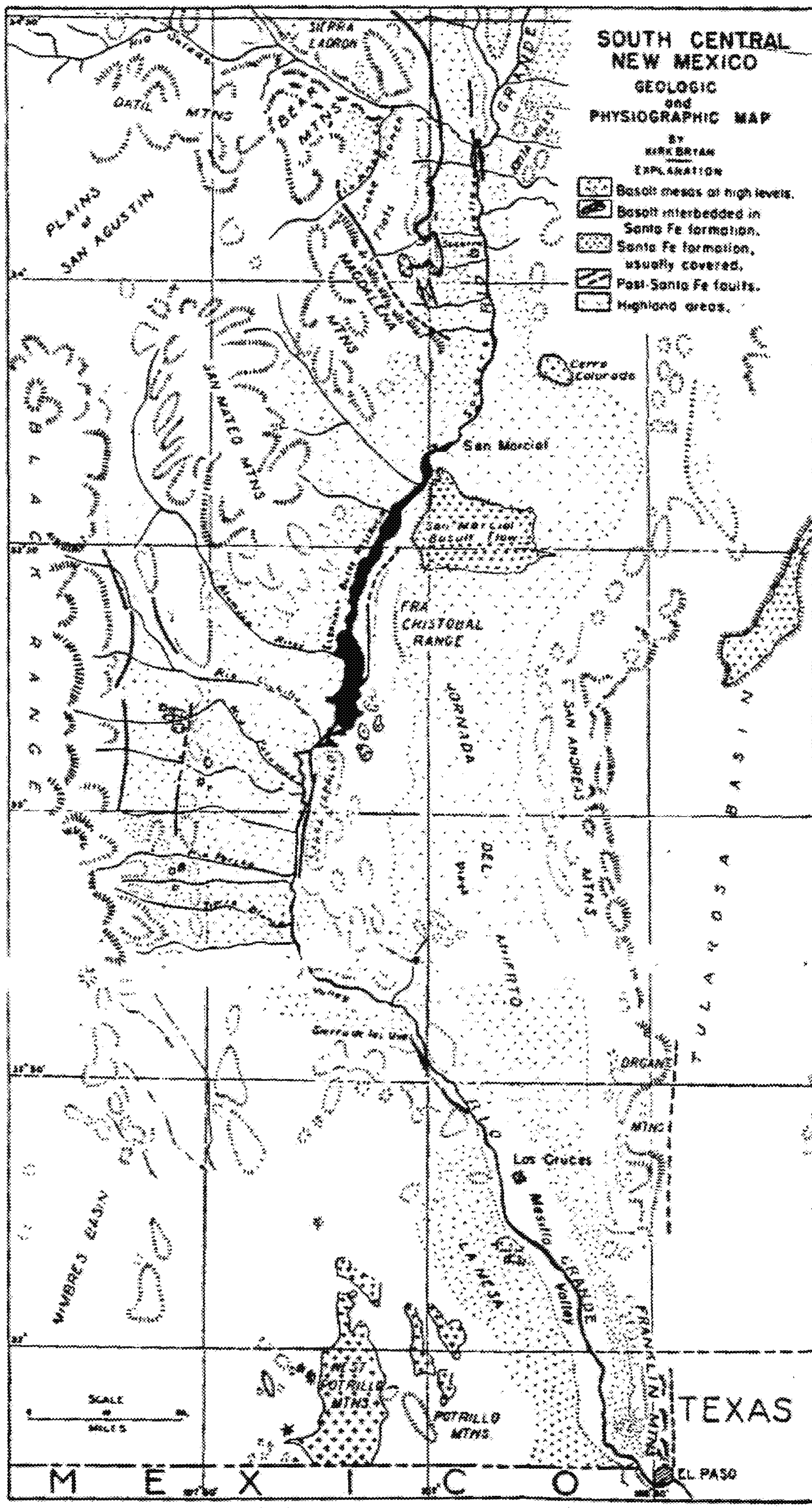

FIGURE 50.—Geologic and physiographic map of south-central New Mexico.

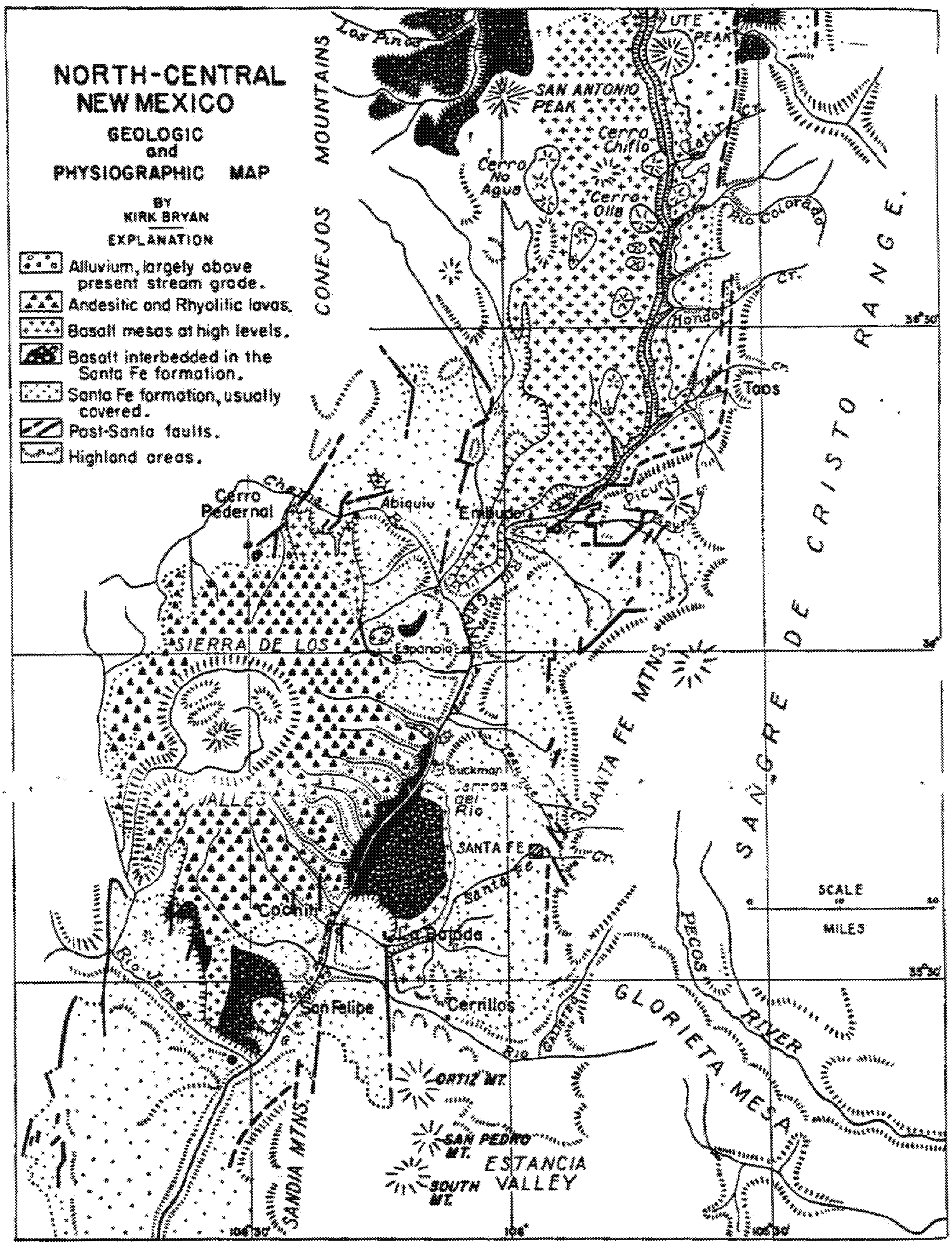

FIGURE 46.—Geologic and physiographic map of north-central New Mexico.

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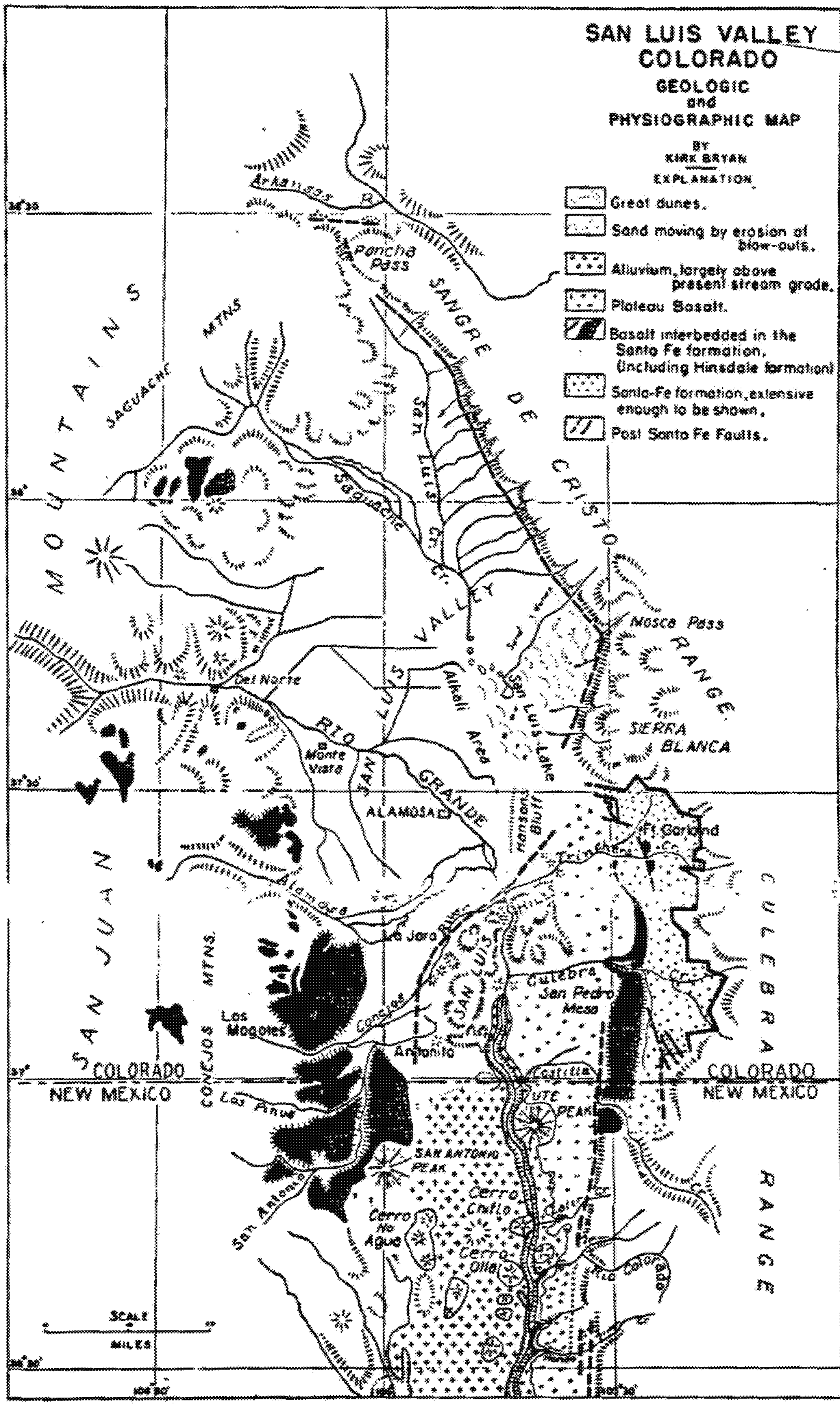

Figure 47.—Geologic and physiographic map of the San Luis Valley, Colo.

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Tab 4

REPORT

of the

RIO GRANDE COMPACT COMMISSION 2001

6

TO THE GOVERNORS OF
Colorado, New Mexico and Texas

Errata Sheet for the 2000 Report of the Rio Grande Compact Commission

On page 31 make the following changes:

1. For "Actual Spill," add footnote number 4 that reads, "Adopted March 22, 2001, made effective January 1, 2001.

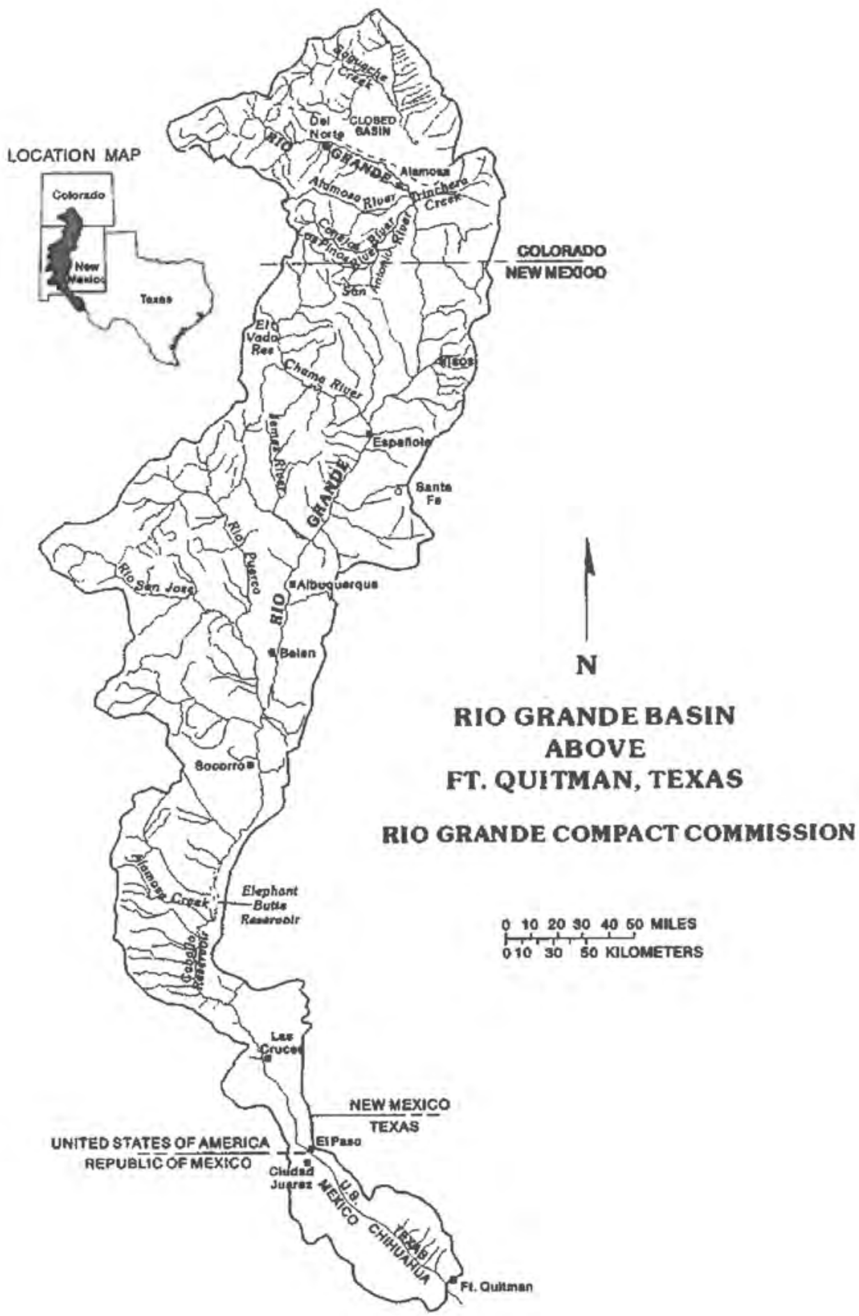
2. Change paragraph "b" from 2,040,000 acre-feet to 1,998,400, from 2,015,000 acre-feet to 1,973,400. Change "1988 acre-capacity table" to "1999 area-capacity table."

Errata Sheet for the 2000 Report of the Rio Grande Compact Commission

On page 31 make the following changes:

1. For "Actual Spill," add footnote number 4 that reads, "Adopted March 22, 2001, made effective January 1, 2001.

2. Change paragraph "b" from 2,040,000 acre-feet to 1,998,400, from 2,015,000 acre-feet to 1,973,400. Change "1988 acre-capacity table" to "1999 area-capacity table."



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RIO GRANDE COMPACT COMMISSION
COLORADO TEXAS NEW MEXICO

March 21, 2002

The Honorable Gary Johnson
Governor of the State of New Mexico
Santa Fe, New Mexico

The Honorable Rick Perry
Governor of the State of Texas
Austin, Texas

The Honorable Bill Owens
Governor of the State of Colorado
Denver, Colorado

Honorable Governors:

The 63rd Annual Meeting of the Rio Grande Compact Commission was held in Santa Fe, New Mexico, on March 21, 2002.

The Commission reviewed its prior reports and the current reports of the Secretary and the Engineer Advisers relative to streamflow at Compact gaging stations and storage in reservoirs in 2001. The Commission found that:

(a) Deliveries of water at the Colorado-New Mexico state line by Colorado amounted to 300,300 acre-feet in 2001 and the scheduled delivery for the year was 313,700 acre-feet.
(b) Deliveries of water into Elephant Butte Reservoir by New Mexico, as measured by the Elephant Butte Effective Supply, amounted to 416,400 acre-feet in 2001 and the scheduled delivery for the year was 494,900 acre-feet.
(c) The actual release of usable water from Project Storage was 788,000 acre-feet.

The Commission agreed to the accounting of accrued credits for 2001, as follows:

(1) The Commissioners found that the accrued credit for deliveries by Colorado at the Colorado-New Mexico State Line was 10,100 acre-feet on January 1, 2002.
(2) The Commissioners found that the accrued credit for deliveries by New Mexico at Elephant Butte Dam was 155,700 acre-feet on January 1, 2002.
(3) The Commissioners found that the accrued departure from normal release from Project Storage as of January 1, 2002 was a credit of 77,900 acre-feet.

The Commission reviewed the cost of operation and found that the expenses of the administration of the Rio Grande Compact were $169,296 in the fiscal year ending June 30, 2001. The United States bore $57,439 of this total: the balance of $111,857 was borne equally by the three States party to the Compact.

Respectfully,

Thomas C. Turney, Commissioner for New Mexico

Joe G. Hanson, Commissioner for Texas

Harold D. Simpson, Commissioner for Colorado

REPORT OF THE ENGINEER ADVISERS TO THE RIO GRANDE COMPACT COMMISSIONERS

February 22, 2002

COMPACT ACCOUNTING

The Engineer Advisers to the Rio Grande Compact Commissioners have reviewed the streamflow and reservoir storage records and other pertinent data and have determined the scheduled and actual deliveries, and release of Usable Water during calendar year 2001. The Engineer Advisers adjusted accrued credit balances as of January 1, 2001, to reflect correction of errors in Bureau of Reclamation (Reclamation) Elephant Butte Reservoir evaporation data and delayed application by Reclamation of revised equations for sediment accumulation in Abiquiu, Cochiti, and Jemez Canyon Reservoirs as further described below.

As determined by the Engineer Advisers, the corrected balances as of January 1, 2001, scheduled and actual deliveries, and release of usable water for the year 2001 are as follows:

(a) Deliveries by Colorado at the Stateline:

Balance as of January 1, 2001	27,000 acre-feet
Scheduled delivery	313,700 acre-feet
Actual delivery at Lobatos plus 10,000 acre-feet	300,300 acre-feet
Reduction of credit on account of evaporation	3,500 acre-feet
Accrued credit January 1, 2002	10,100 acre-feet

(b) Deliveries by New Mexico at Elephant Butte Dam:

Balance as of January 1, 2001	269,100 acre-feet
Scheduled delivery	494,900 acre-feet
Actual delivery	416,400 acre-feet
Reduction of credit on account of evaporation	34,900 acre-feet
Accrued credit January 1, 2002	155,700 acre-feet

(c) Project Storage and releases:

Accrued departure (credit) as of January 1, 2001	75,900 acre-feet
Actual release of usable water	788,000 acre-feet
Accrued departure (credit) as of January 1, 2002	77,900 acre-feet

Usable water in Project Storage exceeded 400,000 acre-feet for the entire year.

The Engineers Advisers met in Santa Fe from February 20 through February 22 to prepare the 2001 Compact water accounting and to discuss continuing and new issues in preparation for the 2002 meeting of the Rio Grande Compact Commission (Commission). The Engineer Advisers requested and received the participation of Reclamation, the U.S. Army Corps of Engineers (Corps), and the U.S. Fish and Wildlife Service (Service) in part of that meeting to discuss in detail their specific water-related activities in the basin.

CONTINUING ISSUES

This section of the report addresses issues previously addressed by the Engineer Advisers or the Commission. It reflects information obtained by the Engineer Advisers subsequent to the 2001 Commission meeting, including information obtained in the reports of federal agencies at the 2002 Engineer Advisers meeting.

Sedimentation in Upper and Middle Rio Grande Reservoirs in New Mexico

Sediment surveys were conducted in 1998 for Abiquiu, Cochiti and Jemez Canyon Reservoirs, which are primarily flood control reservoirs owned and operated by the Corps. Based on the sediment surveys, Reclamation subsequently revised the sediment accumulation equations and area-capacity tables for use in daily operations and water accounting models. The area-capacity tables derived from the 1998 surveys were made effective January 1, 1999. Reclamation's 1999 water accounting reflected the revised area-capacity tables but did not reflect the revised sediment accumulation equations. Reclamation and the Engineer Advisers agreed at the 2000 meeting of the Engineer Advisers, and again at the 2001 meeting, that Reclamation was to apply the new sediment accumulation equations retroactively to January 1, 1999.

Instead, Reclamation used the old sediment accumulation equations in the 1999 and 2000 accounting, which estimated excess sediment accumulation in Abiquiu, Cochiti and Jemez Canyon Reservoirs. In December 2000, Reclamation corrected the excess sediment accumulation calculations resulting from continued use of the old equations and coordinated with the Corps to release approximately 5,000 acre-feet of excess native Rio Grande storage, some of which carried over into January 2001.

Associated corrections were required to Reclamation's native Rio Grande and San Juan-Chama water accounting for the three reservoirs for 1999 and 2000. Reclamation made those corrections in early 2002. These reservoir storage accounting corrections in turn resulted in a reduction in New Mexico's accrued credit as of January 1, 2001, of 1,600 acre feet as calculated by the Engineer Advisers. This reduction was incorporated into the 2001 accounting.

URGWOM Accounting Model

The Commission approved a resolution in 2001 that provided approval for Reclamation's use of the Upper Rio Grande Water Operations Model (URGWOM) accounting module, subject to the following conditions: (1) that Reclamation provide the Compact states with timely access to the URGWOM accounting model and its associated data and results, (2) that Reclamation work with the Engineer Advisers to perform a review and documentation of the procedures for Compact accounting documentation of Rio Grande and San Juan-Chama Project water, and (3) that Reclamation work with the Engineer Advisers to quantify evaporation accounting errors for the period from 1993 through 1998 for accumulated credits of New Mexico and Colorado. It is the opinion of the Engineer Advisers that Reclamation has fulfilled those conditions, or has made satisfactory progress towards their fulfillment, as discussed below.

The URGWOM model team established an FTP (file-transport protocol) website in 2001 and placed updated model input data on the website approximately weekly. The states may access the data and use it to operate a copy of the URGWOM model to analyze the water accounting produced by Reclamation.

The Engineer Advisers and Reclamation met in person or held conference calls on several occasions in 2001 and planned their comprehensive documentation of Rio Grande Compact accounting procedures. The Engineer Advisers compiled the historic Engineer Adviser Reports, Commission meeting minutes, and Commission resolutions, and prepared complete sets for each state and Reclamation. Reclamation completed an internal file search for Compact accounting documents and indicated that these documents soon will be provided to the three states. The Engineer Advisers and Reclamation also prepared a proposed Memorandum of Understanding (MOU) between the Commission and Reclamation that formally describes the duties, roles, and responsibilities of each party in the water accounting, reporting, and documentation of the waters of the Rio Grande Basin above Fort Quitman, Texas, in accordance with the Compact. The Engineer Advisers recommend Commission approval and adoption of the MOU. The proposed MOU provides that the Engineer Advisers and Reclamation will prepare a manual describing the historic and current accounting procedures and that Reclamation and the Engineer Advisers will formally review the accounting and reporting procedures for potential modifications and enhancements every five years, or more frequently if necessary.

Reclamation reported in 1999 that its internal review of evaporation data at Elephant Butte Reservoir for the period 1993 through 1998 found arithmetic and transcription errors. The accounting procedures use gross calculated evaporation rates and precipitation on the reservoir surface, in accordance with the Rules and Regulations for Administration of the Compact, to adjust the amounts of Colorado's and New Mexico's credit water in storage in Elephant Butte Reservoir for evaporative losses. Consequently, the calculation of credit water and Usable Water in Project Storage, as reported in the Reports of the Commission, was in error for the periods 1993 to 1995 and 1997 to 1999. No credit water was in storage in 1996 due to Actual Spill in 1995. Reclamation and the Engineer Advisers quantified the errors, which were determined to be partially offsetting, and found that the impact to Compact accounting was significant only for 1997. The Engineer Advisers found the resulting required correction to be a reduction of 100 acre-feet in New Mexico's accrued credit status at the end of 2000. This correction was incorporated into the 2001 accounting provided at the beginning of this report.

During presentation by Reclamation of its 2001 accounting the Engineer Advisers found that

the URGWOM accounting module continued to calculate the accumulation of sediments in Jemez Canyon Reservoir during the months that the reservoir had no water in storage. The Engineer Advisers requested Reclamation make the necessary changes to its sediment accumulation equations so that the modeled accumulation of sediment and depletion of available storage space is stopped when reservoirs contain no stored water.

Sedimentation in Rio Grande Project Reservoirs

Sediment surveys were conducted in 1999 and 2000 for Elephant Butte and Caballo Reservoirs. Based on the sediment surveys, Reclamation revised the area-capacity tables for the two reservoirs effective January 1, 2001. Decreased project storage capacity due to sedimentation since the last survey in 1988 was 41,652 acre-feet (top of conservation pool) for Elephant Butte Reservoir and 4,838 acre-feet (top of conservation pool) for Caballo Reservoir. The Commission adopted changes at its March, 2001 meeting, effective January 1, 2001, to the Rules and Regulations for Administration of the Compact (Paragraph b of the section entitled "Actual Spill") to reflect the decrease in storage capacity in Elephant Butte and Caballo Reservoirs. The remarks for Elephant Butte and Caballo Reservoirs will be revised in the 2001 annual report of the Commission to reflect the reduction in storage capacity in the section entitled "Storage in Reservoirs, Reservoirs in Rio Grande Basin in New Mexico".

Compliance by Federal Agencies with State Water Law and Regulations

The Commission approved a resolution in 2001 that requested the Corps, Reclamation and Service to comply with state law by obtaining permits from the appropriate state agencies for any water related actions that result in new or additional river depletions. The Engineer Advisers discussed with the Corps, Reclamation and Service permitting and water rights issues related to creation or restoration of wetlands and riverine or riparian habitat and related environmental projects in 2001 and again in 2002. In 2001, Federal agency representatives acknowledged the need to comply with applicable state water laws regarding these projects. New Mexico reports Federal agencies are inconsistent in submitting applications for permits to comply with New Mexico's requirements to obtain permits for riparian and riverine habitat restoration projects that increase consumption of water. Federal agencies are planning or constructing numerous habitat restoration projects.

Elephant Butte Pilot Channel Project

The Commission approved resolutions in 2000 and 2001 requesting Reclamation to continuously extend and maintain a constructed pilot channel from San Marcial through the sediment delta to the active reservoir pool in Elephant Butte Reservoir as the reservoir recedes. Reclamation has not succeeded in constructing and maintaining such a channel to the reservoir pool. New Mexico asserts that maintaining an active river channel from San Marcial through the sediment delta to Elephant Butte Reservoir is crucial to New Mexico's ability to make Compact deliveries.

The pilot channel as designed incorporates side channel weirs, constructed as areas of low constructed height in the pilot channel spoil bank levees. The side channel weirs and other channel features were requirements of the Endangered Species Act (ESA) Section 7 consultation between Reclamation and the Service regarding the construction of the pilot channel. In addition, Reclamation has also constructed culverts and side channel weirs through the spoil bank levee that is the west bank of the Rio Grande just downstream of the current terminus of the Low Flow Conveyance Channel. These features were requirements of ESA Section 7 consultation between Reclamation and the Service regarding construction of a previous pilot channel in that reach.

New Mexico asserts the culverts and side channel weirs are de facto surface water points-of-diversion that divert water from the pilot channel and spread it out over the Elephant Butte Reservoir sediment delta, which until recently was inundated but now is exposed. New Mexico asserts that these unpermitted diversions result in significant depletions and losses of water, impairing New Mexico's Compact deliveries and making less water available for Rio Grande Project use. New Mexico and Reclamation agreed that more discussion is needed as this project progresses.

The pilot channel failed sometime during the snowmelt runoff period from late April through May 2001, resulting in the spreading of water into the sediment delta with high attendant evaporative losses. The location of the failure was at a side channel weir constructed at a bend in the channel. Sinuosity of the channel through the sediment delta is another pilot channel feature required of Reclamation through the ESA consultation.

Reclamation temporarily halted construction of the pilot channel during the spring runoff period of 2001. Reclamation resumed construction of the pilot channel in October 2001. At the 2002 meeting of the Engineer Advisers, Reclamation estimated that the pilot channel would be extended to Nogal Canyon, the originally planned project downstream terminus, sometime by the fall of 2002. By that time the upstream edge of the reservoir pool will be approximately five miles downstream, based on current projections by Reclamation. Reclamation reported that they have initiated design and permitting work associated with a new phase of the project to extend the pilot channel past Nogal Canyon. The New Mexico Engineer Adviser inquired of Reclamation what its response would be if New Mexico proposed to contract with a private sector construction firm to construct portions of the pilot channel. Reclamation's Albuquerque Area Office Manager said he would welcome such assistance.

Reclamation's oral and computer graphic presentation of the pilot channel construction at the Engineer Advisers meeting contained little detail. The Engineer Advisers requested a more substantive presentation from Reclamation, including maps showing progress in constructing the channel, at the 2002 Commission meeting.

Endangered Species Act Section 7 Consultations

The Commission approved resolutions in 2000 and 2001 requesting that the Federal agencies involved in ongoing ESA Section 7 river operations consultations with the Service bring them to prompt conclusion as required by law.

The river operations consultation was successfully concluded with the issuance of the June 29, 2001, Programmatic Biological Opinion on the Effects of Actions Associated with the U.S. Bureau of Reclamation's, U.S. Army Corps of Engineers' and Non-Federal Entities' Discretionary Actions Related to Water Management on the Middle Rio Grande, New Mexico (Programmatic Biological Opinion) that was a companion to the Conservation Water Agreement between the State of New Mexico and the United States (discussed below) executed that same date.

Low Flow Conveyance Channel Design, Construction, Operation and Maintenance

Reclamation staff affirmed the need for its proposed project to relocate the river channel, and the intervening Low Flow Conveyance Channel, to the west side of the valley floor downstream from San Marcial. The need is critical due to the problems associated with the elevated channel floor caused by sedimentation in the river channel and the resulting diminishing channel capacity, which is less than the two-year frequency flood event. An uncontrolled breech of the river channel will occur if the channel is not relocated to the lower elevation flood plain area from its current elevated location on the east margin of the flood plain. Reclamation staff informed the Engineer Advisers that Reclamation submitted a Biological Assessment regarding the realignment project to the Service in May 2001, with copies to the Engineer Advisers, and is currently continuing its consultation with the Service. The elapsed time to date since the submittal of the Biological Assessment substantially exceeds the time allowed by federal regulation for completion of such consultations unless the Service and Reclamation have agreed to extend it for a specific time period or the Director of the Service has taken action to extend it in order to obtain additional data. Reclamation is consulting on the bottom-up realignment alternative with an initial Low Flow Conveyance Channel (LFCC) capacity of 500 cubic feet per second (cfs).

The Commission's April 11, 2001, resolution addressing this project documents that Reclamation informed the Commission at its regular annual meeting on March 22, 2001, that the Final Environmental Impact Statement (EIS) for this project was expected to be completed by the summer of 2001. The resolution also requested that the replacement LFCC be constructed with a 2000 cfs capacity and further requested that Reclamation keep the Commission informed through the Engineer Advisers of any additional difficulties in implementing the project and provide a quarterly update on project activities, problems, and results. Reclamation staff informed the Engineer Advisers at the 2002 meeting that the Final EIS would not be completed until conclusion of its ESA Section 7 consultation with the Service. The Engineer Advisers have not received progress reports from Reclamation over the last year.

Reclamation informed the Engineer Advisers of ESA conflicts with the planned relocation of the LFCC. An area of concentrated Southwestern willow flycatcher nests now exists in the proposed location of the relocated Low Flow Conveyance Channel. Water from the current Low Flow Conveyance Channel outfall, located many miles upstream of the reservoir pool, now flows overland through this nesting area. Reclamation said the current plan is to construct the new LFCC to this area, allow the channel discharge to flow overland two to three miles through the nesting area, and then recollect the water into a second segment of constructed LFCC. The Engineer Advisers questioned the efficiency and usefulness of this plan. The Engineer Advisers also questioned the lower planned capacity of 500 cfs, as opposed to the capacity of 2000 cfs requested by the Commission's resolution. Reclamation staff responded that since it does not have current plans to divert water from the river to the LFCC, the higher capacity is not warranted and that LFCC capacity is needed only for drainage. The alternatives currently being formulated for analysis as part of the Upper Rio Grande Water Operations Review and EIS are based on the existing authorities of Reclamation, which include a Low Flow Conveyance Channel capacity of 2000 cfs.

Reclamation also stated that budget to construct this project is not currently available or planned.

Water Resource Development Act Section 729 Comprehensive Planning Study

The Corps provided an update on the on-going Section 729 authority, which authorizes the Corps to perform Basin wide Rio Grande studies. The Corps has conducted public meetings and met with the Engineer Advisers regarding potential projects that might be implemented. The Engineer Advisers recommended to the Corps that the Corps concentrate on the improvement of channel capacities of the Rio Grande from Cochiti Reservoir to Elephant Butte Reservoir based on information provided relating to the continuing decreasing channel capacity of the Rio Grande.

New Mexico reported to the Engineer Advisers that it has entered into a cost sharing agreement with the Corps under its Section 729 authority to initiate a water resources investigation in the reach of the Rio Grande between San Acacia and Elephant Butte Reservoir. This study includes groundwater observation wells and surface water staff gages throughout the reach to characterize the shallow groundwater system and surface water/groundwater interactions. New Mexico is currently working on an Environmental Assessment, access agreements with landowners, and Scopes of Work for the project.

YEAR 2001 OPERATIONS

Middle Rio Grande Endangered Species Conservation Pool Operations

The Commission approved a resolution in 2001 that established the Middle Rio Grande Endangered Species Conservation Pool (Conservation Pool). By adoption of that Resolution, the Commission gave its advice and consent to a deviation from normal operations of the Corps Middle Rio Grande Project Reservoirs, as specified by the Flood Control Act of 1960 (Public Law 86-645), to allow for Conservation Pool operations for a term of not more than three years. The Resolution also reserved for the State of Texas the right to rescind its approval of the Resolution on March 21, 2002 and again on March 20, 2003, if Texas were to determine that it has been or will be harmed by the departure from normal operations of the reservoirs.

A Conservation Water Agreement (CWA) was executed on June 29, 2001 between the State of New Mexico and the United States that set limitations and conditions on the storage and release operations of the Conservation Pool. The CWA will expire December 31, 2003. Up to 100,000 acre-feet of native Rio Grande water may be captured and released from Abiquiu and Jemez Canyon Reservoirs during 2001 through 2003 for Rio Grande Compact management and federal ESA purposes. A maximum of 30,000 acre-feet of Conservation Pool water, plus any carryover amounts unused in previous years, may be used in any one calendar year.

A total of 58,814 acre-feet was captured in the Conservation Pool during 2001, with 51,188 acre-feet captured in Abiquiu Reservoir and 7,627 acre-feet captured in Jemez Canyon Reservoir. The bulk of this storage was captured during the peak snowmelt runoff month of May. Releases from the Conservation Pool commenced on July 2, 2001 and continued through the end of October at a combined rate of approximately 100 cfs from both reservoirs. Due to a structural problem with the bulkhead guides at Jemez Canyon Reservoir it became necessary to drain that reservoir completely in October. Releases from the Conservation Pool in 2001 totaled 25,624 acre-feet. Evaporative and unidentified losses totaled 6,246 acre-feet, leaving 26,945 acre-feet in storage at the end of 2001, all in Abiquiu Reservoir.

The water accounting of the Conservation Pool was performed in accordance with the Rules and Regulations of the Compact.

Supplemental Water Program Operations

The supplemental water program is intended to provide additional water for endangered species needs. Reclamation's draft report identifies five aspects of the program as defined in the March 2001 Final Rio Grande Supplemental Water Programmatic Environmental Assessment, including San Juan-Chama water leases, concurrence with waiver requests for delayed delivery of San Juan-Chama Project water from Heron Reservoir to project contractors, LFCC water management options, off-channel interim storage of water at refuges, and use of groundwater wells. Reclamation leased 9,255 acre-feet of San Juan-Chama water from six contractors in 2001 and released 4,990 acre-feet of allocated but uncontracted San Juan-Chama water from Heron Reservoir for a total of 14,245 acre-feet. All of this water was provided to the Middle Rio Grande Conservancy District (MRGCD) prior to the end of April, 2000, in partial repayment of the 20,900 acre-feet of water Reclamation owed to MRGCD as specified in the August 2, 2000 Agreed Order Resolving Plaintiffs' Motion for Preliminary Injunction in *Minnow v. Martinez* (now *Minnow v. Keys*).

Reclamation operated pumps at four locations during 2001 to pump an estimated (by Reclamation) 25,000 acre-feet of water from the LFCC to the Rio Grande. Reclamation applied for a permit and received an emergency authorization from the New Mexico Office of the State Engineer for this pumping operation. New Mexico advised that Reclamation did not install flow meters on the pumps as required by the authorization.

Conservation Pool water was used to assist in meeting minimum and target flows below San Acacia Diversion Dam and at the San Marcial gaging station. Flows below San Acacia Diversion Dam were consistently at or above 100 cfs, and therefore consistently exceeded the 50 cfs target flow established by the June 29, 2001, Programmatic Biological Opinion. Flows at the San Marcial gage also consistently exceeded the applicable minimum and target flows, which vary with time of year. Reclamation staff indicated that they were assisted by the MRGCD in meeting the minimum and target flows.

Jemez Canyon Reservoir Sediment Control Pool

The agreements between the New Mexico Interstate Stream Commission (NMISC) and the Corps and between the NMISC and the City of Albuquerque governing the existence and operation of the Jemez Reservoir sediment control pool expired as of December 31, 2000 and the ownership of the remaining San Juan-Chama Project water (approximately 4,500 acre-feet at the end of 2000) in the sediment control pool reverted back to the City of Albuquerque as of January 1, 2001. This water was released in June and July 2001 at the request of the City. The Corps currently anticipates that the reservoir will thereafter be operated as a normally dry flood control facility following the expiration of the CWA at the end of 2003.

REPORTS OF THE FEDERAL AGENCIES

Representatives of Reclamation, Corps, Service, and U.S. Geological Survey presented reports to the Engineer Advisers on February 21, 2001. The Engineer Advisers specifically requested in writing prior to the meeting discussion by Reclamation and the Service of the impacts of the ESA on Reclamation's productivity and effectiveness in carrying out its traditional river maintenance, water conveyance, and water salvage activities and ways those impacts might be mitigated. The Engineer Advisers subsequently have invited the Regional Directors of Reclamation and the Service to attend the 2002 Commission meeting for discussion of these issues.

Upper Rio Grande Basin Water Operations Review and EIS

Reclamation, Corps and NMISC signed a Memorandum of Agreement in January 2000 to conduct the review and EIS. This project is a five-year effort that will evaluate alternatives for more efficient operations of Federal water storage and flood control facilities under existing authorities to meet the increasing demands on the upper Rio Grande. Compliance with the National Environmental Policy Act (NEPA) and the ESA will be provided. The agencies are currently holding a series of public meetings throughout the planning region to present and obtain public comment regarding alternatives that they propose to evaluate in the EIS.

Caballo Dam Structural Repairs

Reclamation informed the Engineer Advisers that repairs to Caballo Dam associated with concrete cracking of the spillway structure center pier and design deficiencies in the radial gate structures are almost complete. The temporary restriction, which results in a temporary reduction in Project Storage capacity of 93,244 acre-feet in Caballo Reservoir operating levels, was imposed in December 2000 and is still in place. Reclamation indicated that the construction would be completed and the restriction will be lifted in the near future.

Rio Grande Project Storage Projections

Reclamation discussed their Rio Grande Project water allocations for 2002. Reclamation indicated that an initial allocation was made on December 17, 2001 that included a 20.8 percent reduction in full supply. Reclamation revised this allocation on January 29, 2002 to reflect a 12.8 percent reduction. Reclamation advised the Engineer Advisers that they anticipate revising this allocation near the end of February to reflect approximately a 6 percent reduction in available supply and anticipated that by the end of March 2002 a full water supply will be available to Rio Grande Project water users. The Engineer Advisers expressed concern with this allocation procedure since it did not reflect any inflow estimates for the year while including evaporation projections. Such a procedure is inconsistent and leads to misconceptions of the amount of available Project water. The Engineer Advisers requested Reclamation, which made no commitment, to revise their procedures to use all available information, including projected inflows, to provide the basis of the annual Rio Grande Project water allotment.

Reclamation presented projections of reservoir operations for Elephant Butte and Caballo Reservoirs based on February 1, 2002, snowmelt runoff forecasts for March-July 2002. The projections indicate that Elephant Butte Reservoir storage would be drawn down to approximately 334,000 acre-feet by the fall of 2002. This level of Elephant Butte Reservoir storage would be the lowest since 1978. Approximately 166,000 acre-feet of this storage is accrued credit of New Mexico and Colorado. Reclamation stated that if current conditions persist that the 2003 irrigation allotment from Project Storage would be less than a full allotment.

Upper Rio Grande Water Operations Model

The RiverWare simulation software that is the basis of URGWOM now operates on a personal computer platform. That is pertinent to historic concerns of Commission members that the software previously only operated on a UNIX workstation. Reclamation personnel demonstrated the model showing simulated hydrographs above Elephant Butte Reservoir. This demonstration showed that low peak flow runoff that is projected to occur at Lobatos and Otowi likely will not allow any additional storage of water for the Conservation Pool in 2002.

Middle Rio Grande Project Channel Maintenance

Reclamation personnel provided an extensive presentation regarding the status of Reclamation's channel maintenance program. In summary, Reclamation representatives said that the river channel is in a failed condition in many locations due to inadequate funding, restrictions and conditions on maintenance work imposed for compliance with the ESA, and delays in completion of consultations with the Service for compliance with Section 7 of the ESA. Reclamation described the impending failure of the river levees as the result of river channel migration into the levee toe at numerous locations and severely restricted channel capacity. Reclamation stated that current channel flow capacity is reduced from the historic capacity of 22,000 cfs to a current capacity of 3,800 cfs with a projected future capacity in five years of 2,000 cfs. Reclamation has identified 25 critical sites on the river where the mean annual flood cannot be safely passed without threat of a levee failure. The probable damage from levee failure is high because sedimentation has elevated the river channel above the adjacent valley floor throughout the Middle Rio Grande. Reclamation showed graphic simulations of flooded areas resulting from levee toe erosion failures and provided rough estimates of additional depletions of water associated with levee failures at current problem areas. Reclamation personnel stated that ESA restrictions prevent adequately stabilizing the channel to keep it from endangering the levee. Additionally, the number of sites that Reclamation is able to address in any one year has dropped by one-half (from ten to five per year) since 1995 and is projected to decline further through 2005. The conclusion of the presentation was that this failed condition will worsen because the failed sites that require maintenance are growing in number, the costs and complexity of maintenance needs at each site are generally greater, and the budget for this work is flat, resulting in a steadily increasing number of sites of impending levee failure.

The Engineer Advisers discussed with Reclamation the delays associated with Section 7 consultation in addressing historic channel failures and current channel problems. These delays have been reduced, perhaps partially due to the programmatic compliance efforts, from the 18 months required to complete NEPA and ESA compliance activities. It appears NEPA and ESA compliance delays recently have been short for projects to restore endangered species habitat but the same expeditious treatment has not yet occurred for work at critical maintenance sites.

Reduction in effectiveness and productivity of Reclamation's channel maintenance responsibilities is an impact that should be addressed in the Rio Grande silvery minnow critical habitat rule EIS now being prepared by the Service. Failure of the levee and channel, in addition to causing damaging flooding, could also severely impact conveyance of flows through the Middle Rio Grande to Elephant Butte Reservoir, increase depletions of water in the Middle Rio Grande, and impair water supplies for water users below Elephant Butte Dam. The Engineer Advisers recommend that the Commission formally request that the Service and Reclamation describe these impacts explicitly and report to the Commission the plans of these two federal agencies to mitigate and minimize these impacts. An uncontrolled breach of the levee system could potentially dewater a significant portion of the river channel resulting in the mortality of the endangered Rio Grande silvery minnow.

Los Lunas Habitat Restoration Project

This project consists of habitat restoration for the Rio Grande silvery minnow and the Southwestern willow flycatcher of approximately 40 acres near Los Lunas, New Mexico. The project would provide for overbank flooding at flows above 2500 cfs and the creation of low velocity riverine habitat in side channels by removal of jetty jacks and lowering of the river banks in the area. Section 7 consultation concurrence was received from the Service one week after submittal of the Biological Assessment for this project. Net depletions aspects of this project were discussed. Reclamation's Albuquerque Area Office Manager said Reclamation may not have the resources to offset its additional depletions of water associated with its ESA compliance actions and projects.

Santa Ana Habitat Restoration Project

This restoration project, located at the confluence of the Jemez River with the Rio Grande, involves realignment and widening of the river channel and stabilization of the river channel grade with "gradient restoration facilities" installed by Reclamation, and by the Corps under a separate but related effort.

Rio Grande Silvery Minnow

Reclamation staff reported briefly on monitoring of the Rio Grande silvery minnow status that it has funded. Current monitoring shows increased numbers throughout the Middle Rio Grande compared to the previous year but numbers are much lower than in 1995, which was followed by the very dry year of 1996.

The Service gave a report on silvery minnow rescue operations for 2001. There were four events where the river flow became intermittent below San Acacia Dam for channel lengths ranging

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from 200 feet to five miles. The Service reported that a total take of three of the species was charged against the limit of 250 annually set by the Incidental Take Statement in the Programmatic Biological Opinion. The Service reported that during 2001 silvery minnows were found at all 19 sampling locations in the Middle Rio Grande. During 2001 no minnows from captive populations were released to the Rio Grande. In January 2002, 11,000 marked minnows reared in captive propagation facilities were released to the river below San Acacia. The Service also reported on silvery minnow captive populations: The Dexter National Fish Hatchery holds approximately 81,000 minnows, the USGS Biological Resources Division facility at New Mexico State University holds 3,900 minnows, and the Albuquerque Biological Park holds 4,000 minnows.

Vegetation Management at Elephant Butte and Caballo Reservoirs

New Mexico annually provides cooperative funding for this program, which currently relies on mowing, with the goal of reduction of non-beneficial consumption of water. Two years ago Reclamation requested and New Mexico provided additional funding for a herbicide control pilot program. The Environmental Assessment for this pilot program remains in progress following a review of a draft by New Mexico in June 2001.

Jemez Canyon Reservoir Bulkhead Repairs

The Corps reported on the status of repairs to the Jemez Canyon Reservoir bulkhead guides for the gates. The need for repairs resulted in the October 2001 release of all remaining Conservation Pool water in Jemez Canyon Reservoir. Repairs are currently scheduled to be completed in early to mid-March 2002. The Corps reported that they would not be able to store water under the CWA until after the migratory sandhill cranes that over-winter in the Middle Rio Grande depart the area (usually around March 10th). After the CWA expires the reservoir will be operated to pass-through inflow when not in flood control operations until such time as the URGWOPS review and EIS are complete.

San Acacia Levee Project

The Corps is currently estimating revised schedules and costs for the San Acacia Levee project. This project would rehabilitate 55 miles of levee between San Acacia and Bosque Del Apache including raising or relocating the railroad bridge at San Marcial. The Conservation Agreement requires New Mexico to share in the cost of relocation of the railroad bridge. The Corps could not assure that the project would be initiated before the Conservation Agreement expired.

May Spike Release from Jemez Canyon and Cochiti Reservoirs

The Corps deviated from normal operations of Cochiti and Jemez Canyon Reservoirs in April and May 2001 to create a spike flow as part of an agreement with Jemez Pueblo to allow for later

storage in Jemez Canyon Reservoir under the Conservation Water Agreement. In a 48-hour period from May 21 to 23, 2001 the Corps released a spike of approximately 1,600 cfs (about 1,300 cfs above the inflow) from Jemez Canyon Reservoir. This release, coupled with the release of a spike of approximately 4,100 cfs from Cochiti Reservoir (about 1,000 cfs above the inflow), resulted in a roughly 5,000 cfs peak flow through the Albuquerque reach, which the Corps desired to obtain to assist in the realization of the Santa Ana river restoration project objectives. The water from the release consisted of native water stored by the Corps in April and May and was not part of the CWA. The Corps did not seek the advice and consent of the Commission for deviation of the normal operations for Jemez Canyon and Cochiti Reservoirs specified in PL 86-645, as explicitly required by that law.

Programmatic Biological Opinion

The Service reported on the Programmatic Biological Opinion issued on June 29, 2001. The Programmatic Biological Opinion concluded in a jeopardy opinion for the silvery minnow and flycatcher, but also developed a Reasonable and Prudent Alternative with 14 elements. These elements included: flow requirements for specific areas, required habitat creation/restoration activities, and funding requirements for reintroduction of the silvery minnow. The Service reported that the operations with respect to the Programmatic Biological Opinion for 2001 were successful. All target flows had been met and habitat restoration activities were underway.

Silvery Minnow Critical Habitat Designation and EIS

The Service's critical habitat designation was found to be inadequately supported by a Federal District Court in November 2000. The court required the Service to prepare an economic impact analysis and EIS to analyze the impacts of critical habitat designation as required by the ESA. The Service reported that the draft EIS should be issued in March 2002. The Service noted that the area under study for critical habitat now includes the entire Rio Grande and the Pecos River. The Engineer Advisers expressed concern about the potential critical habitat including international border areas. The Engineer Advisers also inquired whether the economic impact analysis would address the costs and impacts associated with: water depletions due to habitat restoration or creation activities, loss of crops due to water shortage from minnow activities, damage due to flooding if channel capacity and levee flood protection are allowed to deteriorate, and damage to states if water is undeliverable to Compact measuring points. Service representatives noted that they had not been advised that such economic costs were important or would be addressed. The Engineer Advisers noted that the Silvery Minnow Recovery Team had not been convened to provide preparation and review of the EIS despite written requests to the Service by the states that the recovery team be a part of the study and initial indications by the Service that it would use the recovery team as a NEPA interdisciplinary team. The only meeting of the recovery team occurred on September 12, 2001, when air travel was impossible, and was not subsequently rescheduled by the Service.

Rio Grande Cutthroat Trout

The Service reported that on November 8, 2001, a settlement had been reached in a lawsuit regarding listing of the Rio Grande Cutthroat Trout as a threatened or endangered species under the ESA. The settlement requires that a Candidate Status Review be completed on the species. The preliminary decision was published in the Federal Register in December 2001 for a 60-day comment period. Due to the court ordered Internet blackout of the Interior Department, and the inability of individuals or organizations to submit email comments as directed in the public notice, it is likely that an additional 30-day comment period, until March 29, 2002, will be allowed.

BUDGET

The Engineer Advisers reviewed the Cost of Operation for the year ending June 30, 2001 and the Budget for Fiscal Year ending June 30, 2003. The Engineer Advisers found that the expenses for the administration of the Rio Grande Compact for the year ending June 30, 2001 were $169,296. The United States bore $57,439 of this total, with the balance of $111,857 borne equally by the three states. The proposed budget for the fiscal year ending June 30, 2003 indicates a total of $183,674 will be spent for administration.

Steven E. Vandiver
Engineer Adviser for Colorado

Norman Gaume
Engineer Adviser for New Mexico

Herman R. Settemeyer
Engineer Adviser for Texas

MEMORANDUM OF UNDERSTANDING

between the

RIO GRANDE COMPACT COMMISSION

and the

UNITED STATES BUREAU OF RECLAMATION

To formally describe the duties, roles and responsibilities of each agency in the water accounting, reporting and documentation of the waters of the Rio Grande Basin above Fort Quitman, Texas, in accordance with the Rio Grande Compact.

1.0 RECITALS AND PURPOSE

WHEREAS, the States of Colorado, New Mexico, and Texas are signatory States to the Rio Grande Compact (the Compact) with an effective date of May 31, 1939; and

WHEREAS, the Congress of the United States gave consent to the Compact with the passage of PL 76-96; and

WHEREAS, the President of the United States approved the Compact on May 31, 1939; and

WHEREAS, the U.S. Bureau of Reclamation (Reclamation) owns and/or operates several project works in the Rio Grande Basin including Platoro Reservoir of the San Luis Valley Project on the Conejos River, the Closed Basin portion of the San Luis Valley Project on the Rio Grande, Azotea Tunnel and Heron Reservoir of the San Juan-Chama Project on the Rio Chama, El Vado Reservoir of the Middle Rio Grande Project on the Rio Chama, and Elephant Butte and Caballo Reservoirs of the Rio Grande Project on the Rio Grande; and

WHEREAS, PL 87-483, which authorized the initial stage of the San Juan-Chama Project, required the development of the details of San Juan-Chama Project operation essential to the accounting of diverted San Juan and Rio Grande flows; and

WHEREAS, all works constructed and/or operated by Reclamation in the Rio Grande Basin are required to be operated at all times in conformance with the Compact; and

WHEREAS, strict and accurate water accounting of both native Rio Grande water and all transmountain diversions is necessary to ensure that all Reclamation project works are operated in conformance with the Compact; and

WHEREAS, such accounting procedures were developed by Reclamation, the Rio Grande Compact Commission (the Commission), the signatory States and other affected parties and agencies and approved by the Assistant Secretary of Interior on March 8, 1963, and published that same year by Reclamation in the report entitled "Accounting of Water San Juan-Chama Project, Colorado-New Mexico"; and

WHEREAS, the accounting procedures were further refined in Reclamation's report of March 18, 1974, entitled "San Juan-Chama Project, Colorado-New Mexico Water Accounting and Operational Plan, Rio Grande Basin," and formally transmitted to the Commission by Reclamation's Regional Director by letter of March 19, 1974; and

WHEREAS, such accounting procedures were successfully implemented and performed by Reclamation and the signatory States for many years; and

WHEREAS, numerous modifications to the accounting procedures have been authorized by the Commission and implemented by Reclamation since 1974, and

WHEREAS, there is currently no organized documentation of these accounting modifications nor is there a comprehensive documented description of the current accounting procedures used by Reclamation.

NOW, THEREFORE, the purpose of this agreement is to clarify and formally articulate the details of the duties, roles and responsibilities of each party for the water accounting, reporting, and documentation of the waters of the Rio Grande Basin above Fort Quitman, Texas, in accordance with the Compact.

2.0 Pertinent Data

2.1 Definitions

The following definitions provide clarification on the data and procedures used for Compact accounting.

Raw Data: Raw data are the description, measurement, and quantification of water volumes and fluxes. Table 1 contains a list of raw data required for current Compact accounting. Examples of raw data include stream flow gage readings, pan evaporation measurements, precipitation gage readings, reservoir elevations, etc.

Accounting Data: Accounting data is information describing and quantifying the delivery, use, movement, transfer, and storage of water within the Rio Grande Basin. Examples of accounting data include deliveries of San Juan-Chama (SJC) water from Heron Reservoir to a downstream storage pool, deliveries by Colorado to New Mexico at the Colorado-New Mexico state line, and deliveries by New Mexico to Texas at Elephant Butte Reservoir. Most accounting data are usually calculated values derived from an

approved method.

Calculated Values: Calculated values are numerical results of approved accounting methods. Examples of calculated values include, but are not limited to, tributary inflow above Heron Reservoir, demand for the permanent San Juan-Chama recreation pool at Cochiti Reservoir, the amount of San Juan-Chama water required at Otowi gage to offset the effects of storage at Nambe Falls Reservoir, the Conejos Index Supply, the Otowi Index Supply, and the Elephant Butte Effective Supply.

Approved Method: An approved method is a method of performing a calculation or accounting procedure formally approved by the Commission. The adjustment of New Mexico's and Colorado's Compact Credit water stored in Elephant Butte Reservoir for loss due to evaporation is an example of an approved method.

Constant Value: A constant value is a value used in a calculation defined by an approved method. The constant value typically represents a portion of a physical system or reflects a value used in an accounting calculation defined by an approved method. An example of a constant value is the 2.0 percent loss factor currently used to describe losses in San Juan-Chama water transported from Heron Reservoir to the Otowi Index gage. The Commission must approve constant values prior to their use in an approved method.

2.2 Raw Data Sources and Responsible Collecting Agency

Compact accounting of native Rio Grande water and San Juan-Chama Project and other transmountain diversions incorporates raw data from a number of different sources. This section describes the types, sources, and the agency responsible for collecting and providing the raw data required for Compact accounting. A number of state, federal and local agencies that are not party to this agreement are responsible for collecting and providing raw data used in Compact accounting. This agreement does not in any way address how such raw data is collected, reviewed, maintained or made available for Compact accounting by other agencies not party to this agreement, except to note that the U. S. Geological Survey (USGS), acting as Secretary to the Commission per the Rules and Regulations for Administration of the Rio Grande Compact as amended February 22, 1948, is responsible for preparing a summary of the raw data needed to perform the Compact accounting.

Table 1 attached to this Memorandum of Understanding provides a listing of all raw data required for Compact accounting and the agency that is responsible for its collection.

3.0 Roles and Responsibilities

3.1 U.S. Bureau of Reclamation

The roles and responsibilities of the U.S. Bureau of Reclamation as related to Compact accounting and the Commission are to:

- Collect, compile and provide various data required for Compact accounting as indicated in Table 1.
- Prepare the annual water accounting report to the Engineer Advisers to the Commission that provides details on water accounting for the San Juan-Chama Project, the San Luis Valley Project, and information on the Upper Rio Grande Water Operations Model (URGWOM) and other related water accounting matters This report will be submitted to the Engineer Advisers as a draft for review and comment no later than three weeks prior to each February's regularly scheduled meeting of the Engineer Advisers.
- Meet with the Engineer Advisers at their annual meeting to resolve any questions regarding the accounting and assist the Engineer Advisers to prepare the annual Compact accounting for Commission approval.
- Disseminate to the Commission and all interested parties, on a monthly basis, provisional San Luis Valley Project and San Juan-Chama Project water accounting data throughout the year.

3.2 Engineer Advisers/Rio Grande Compact Commission

The Engineer Advisers to the Commission, as representatives of their respective States, are responsible for collecting and providing various data as indicated in Table 1. As a collective body, the Engineer Advisers are responsible for reviewing and preparing the annual Compact accounting for Commission approval. This includes review of both the annual water accounting report produced by Reclamation and the draft compilation of Compact accounting prepared by the USGS. The Compact accounting is then presented to the Commission for formal approval as part of the annual report of the Engineer Advisers. Upon approval, the accounting is then published in the annual report of the Commission to the Governors of Colorado, New Mexico and Texas.

4.0 Communications and Coordination

4.1 Protocols

Reclamation and the States will review the adequacy of the processes for water accounting information exchange and the sufficiency of the information exchanged, on a regular basis, but not less than annually. This review will evaluate the amount and frequency of information provided by each entity, with the goal of adjusting information exchange to meet the needs of all parties. Agreed-upon outcomes of the reviews will be

documented in writing. All raw data and water accounting data required for Compact accounting that is collected or produced by any of the signatories to this agreement will be made available to the other signatories upon written or verbal request.

Reclamation and the States will work on establishing more face-to-face and/or phone communications in between the regularly scheduled yearly Engineer Advisers and Commission meetings. The goal of such communications is to address questions and concerns on a more frequent basis.

4.2 Water Accounting Documentation Report

Reclamation and the States will cooperatively conduct a Compact water accounting documentation project during the 2002 calendar year. This project will concurrently review and document the basis for both native Rio Grande and San Juan-Chama Project water accounting, and will thoroughly detail and describe all the accounting data, calculated values and constant values, and approved methods that are involved in the water accounting. The goal of the project will be to present a comprehensive final report to the Commission at its annual 2003 meeting. The report will include a section on quality assurance/quality control protocols for all future Compact water accounting.

Reclamation and the States will ensure that all agreed-upon actions related to water accounting are documented. Such documentation will be specific for water accounting for the Compact. All parties will agree to water accounting documentation before finalization.

5.0 Protocols for Implementing Future Changes to Approved Methods

The details of the approved methods for water accounting may require adjustments predicated upon changing conditions, changes in project plans, operations and water usage, and improvement in engineering and hydrologic knowledge and data. When the necessity of such an adjustment to an approved method is identified, Reclamation and the Commission will investigate and study the technical basis for the adjustment. A report or technical memorandum detailing the adjustment will be prepared by the agency proposing the adjustment and submitted to the Engineer Advisers to the Commission prior to the annual meeting of the Advisers in February. The Engineer Advisers will review the adjustment, and, if deemed appropriate, shall recommend approval of the adjustment by the Commission. No accounting adjustments will be implemented without the prior approval of the Commission.

Review of Compact water accounting procedures will be performed both informally and formally. Reclamation and the signatory States will meet every five years from the date of Commission approval of this Memorandum of Understanding to formally review all Compact accounting procedures and will document the results of this review. This Memorandum of Understanding will be revised as necessary at those times.

IN WITNESS WHEREOF, the parties have caused this instrument to be duly executed.

RIO GRANDE COMPACT COMMISSION

Hal D. Simpson
Commissioner for Colorado

Date: March 21, 2002

Thomas C. Turney
Commissioner for New Mexico

Date: March 21, 2002

Joe G. Hanson
Commissioner for Texas

Date: March 21, 2002

U.S. BUREAU OF RECLAMATION

Ken Maxey
Area Manager, Albuquerque Area Office

Date: March 21, 2002

**RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING THE NEED FOR FEDERAL AGENCIES TO APPLY FOR STATE PERMITS
IN COMPLIANCE WITH STATE WATER LAW AND REGULATIONS**

March 21, 2002
Santa Fe, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, the U.S. Army Corps of Engineers (Corps) and the U.S. Bureau of Reclamation (Reclamation) operate and maintain water storage and conveyance facilities on the Rio Grande which may include habitat restoration projects; and

WHEREAS, New Mexico reports that such federal activities have the potential to create new or additional depletions and could affect future New Mexico deliveries to the Rio Grande Project, and

WHEREAS, New Mexico reports that neither the Corps nor Reclamation have applied for permits as requested in the April 11, 2001 Resolution of the Rio Grande Compact Commission.

NOW, THEREFORE, BE IT RESOLVED THAT the Rio Grande Compact Commission again requests the above federal agencies to comply with state law by obtaining permits from the appropriate state agencies for any water-related actions that result in new or additional river depletions; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior; the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation; the Director, Regional Director, and the New Mexico Ecological Services Field Office Supervisor of the U. S. Fish and Wildlife Service, and the Commander, Division Engineer, and District Engineer of the U. S. Army Corps of Engineers.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
THE DEVELOPMENT OF AN APPROPRIATE METHODOLOGY FOR DETERMINING
THE ANNUAL ALLOCATION OF USABLE WATER IN RIO GRANDE PROJECT STORAGE

March 21, 2002
Santa Fe, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, the Rio Grande Compact obligates New Mexico to deliver water to Elephant Butte Reservoir for use by the Rio Grande Project according to an inflow-outflow schedule based on the Otowi Index Supply; and

WHEREAS, the waters of the Rio Grande Project are used to meet the United States treaty obligation to the Republic of Mexico and provide a water supply for Southern New Mexico and Texas downstream of Elephant Butte Reservoir and above Ft. Quitman, Texas; and

WHEREAS, Reclamation determines the annual allocation for Elephant Butte Irrigation District (EBID) and El Paso Water Improvement District No. 1 (EP No.1); and

WHEREAS, Reclamation's current procedure for determining the annual allocation for EBID and EP No. 1 does not include all parameters necessary to accurately determine projected reservoir storage; and

WHEREAS, the dissemination of inaccurate allotments causes unnecessary hardships to the water users of Southern New Mexico and Texas along the Rio Grande downstream of Elephant Butte Reservoir and above Ft. Quitman, Texas.

NOW, THEREFORE, BE IT RESOLVED THAT the Rio Grande Compact Commission hereby requests that the Bureau of Reclamation work cooperatively with the Engineer Advisers to develop procedures for determining the annual allotments of water supply in accordance with the Rio Grande Compact.

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
THE CONTINUING NEED FOR THE U.S. BUREAU OF RECLAMATION
TO CONTINUOUSLY EXTEND AND MAINTAIN A PILOT CHANNEL THROUGH
THE DELTA OF ELEPHANT BUTTE RESERVOIR TO THE ACTIVE RESERVOIR POOL
AS THE RESERVOIR RECEDES

March 21, 2002
Santa Fe, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, New Mexico reports that water conveyance facilities and maintenance of the active channel of the Rio Grande are important to New Mexico's compliance with its Rio Grande Compact delivery obligations; and

WHEREAS, the U.S. Bureau of Reclamation (Reclamation) is continuing to construct a temporary channel to connect the river channel at the head of Elephant Butte Reservoir, through the reservoir sediment delta, to the active reservoir pool; and

WHEREAS, Reclamation's projections of reservoir operations for Elephant Butte and Caballo Reservoirs for 2002 indicate that Elephant Butte Reservoir will be drawn down an additional 40 feet in elevation by the fall of 2002 and that the active reservoir pool will reside near the southern end of the narrows; and

WHEREAS, Reclamation currently anticipates that, due to equipment and permitting problems, the pilot channel will not be completed through the sediment delta connecting the river channel with the active reservoir pool during 2002; and

WHEREAS, the Engineer Advisers report that a functional channel through the sediment delta to the reservoir pool is important to New Mexico's delivery of water to the Rio Grande Project.

NOW, THEREFORE, BE IT RESOLVED that the Rio Grande Compact Commission requests that Reclamation continue to extend and maintain the constructed channel from San Marcial through the sediment delta to the active reservoir pool in Elephant Butte reservoir as the reservoir recedes, thereby maintaining an active river channel to the reservoir pool at all times; and

BE IT FURTHER RESOLVED that the Rio Grande Compact Commission supports full continued funding of the above project; and

BE IT FURTHER RESOLVED that the U.S. Bureau of Reclamation is requested to promptly inform the Rio Grande Compact Commission through the Engineer Advisers of any difficulties in implementing the project and that Reclamation provide the Engineer Advisers a quarterly update on project activities, problems, and results; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior; the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation; and the Director, Regional Director, and the New Mexico Ecological Services Field Office Supervisor of the U. S. Fish and Wildlife Service.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
THE U.S. BUREAU OF RECLAMATION
MAINTAINING THE MIDDLE RIO GRANDE FLOODWAY

March 21, 2002
Santa Fe, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, New Mexico reports that operation and maintenance of federal water conveyance facilities are important to New Mexico's compliance with its Rio Grande Compact delivery obligations; and

WHEREAS, the U.S. Bureau of Reclamation (Reclamation) on February 21, 2002 reported to the Engineer Advisers that the number of critical maintenance sites, defined as a location where the floodway levee is likely to fail under the mean annual flood (2.3 year return period), within the middle Rio Grande valley was approximately 25 sites; and

WHEREAS, Reclamation anticipates that the number of critical sites will continue to increase;

NOW, THEREFORE, BE IT RESOLVED that the Rio Grande Compact Commission recommends and requests that Reclamation maintain the middle Rio Grande floodway such that effective drainage and efficient transport of water can be achieved; and

BE IT FURTHER RESOLVED that the Rio Grande Compact Commission supports full funding for maintenance of the middle Rio Grande floodway for the above purpose; and

BE IT FURTHER RESOLVED that the Rio Grande Compact Commission requests that Reclamation promptly inform the Rio Grande Compact Commission through the Engineer Advisers of any additional difficulties in implementing maintenance activities and that Reclamation provide the Engineer Advisers an update at the 2003 Engineer Advisers meeting on project activities, problems, and results; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior; and the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
of the
RIO GRANDE COMPACT COMMISSION
REGARDING *A PHYSICAL ASSESSMENT, THE OPPORTUNITIES FOR IMPROVED MANAGEMENT OF THE WATER RESOURCES OF THE BI-NATIONAL RIVER BASIN*
PROPOSED BY THE NATURAL HERITAGE INSTITUTE

March 21, 2002

WHEREAS, the allocation of the water of the Rio Grande between the United States and Mexico is governed by two treaties between the two countries, the 1906 treaty for waters above Ft. Quitman, Texas and the 1944 treaty for waters below Ft. Quitman, Texas; and

WHEREAS, the States of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, which allocated among the States all the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, existing water supplies do not normally meet the existing demands in the Rio Grande Basin above Fort Quitman and each State will defend its rights granted by the Rio Grande Compact to use the waters apportioned thereby for the benefit of its citizens; and

WHEREAS, the need to manage and conserve the water supplies of the Rio Grande Basin for the benefit of present and future generations is well understood, however, that management and conservation must be done within the constraints and allocations of existing Treaties and the Compact; and

WHEREAS, it was agreed and understood among the parties to both the Treaty and the Compact that the waters of the Rio Grande, above Fort Quitman, Texas, would be fully utilized to benefit mankind in seeking to produce successful economies in this water-short region; and

WHEREAS, the description of the study proposed by the Natural Heritage Institute contains numerous statements that do not take into full account long standing legal and contractual relationships of which citizens of Texas, New Mexico and Colorado have relied on for many generations; and

WHEREAS, the States of Texas, New Mexico, and Colorado, as well as the United States Government, are seeking to resolve a wide variety of issues that affect the way in which the Rio Grande system is operated, which efforts are extremely complicated and costly; and

WHEREAS, a proposal to conduct parallel investigations will be singularly complicated, expensive, and time consuming; and

WHEREAS, past descriptions of the proposed physical assessment have strongly suggested an intention to utilize the study as a basis to redefine or alter the Treaties with Mexico and the Rio Grande Compact, which could likely have the effect of adversely affecting existing water users in the Rio Grande Basin, above Fort Quitman, Texas; and

WHEREAS, the Rio Grande Compact Commission provides the mechanism for entities and organizations to discuss and negotiate their differences and allows for consideration of the feasibility of new water management and control technology; and

WHEREAS, federal and state money should not be contributed to this proposed study.

NOW, THEREFORE, BE IT RESOLVED that the Rio Grande Compact Commission hereby requests that the States of Texas, New Mexico, and Colorado, as well as agencies of the Federal Government, decline to support or participate in the study entitled "A Physical Assessment of the Opportunities for Improved Management of the Water Resources of the Bi-National River Basin" proposed by the Natural Heritage Institute; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission is requested to transmit copies of this Resolution to the Secretary of Interior, the Commissioner of the Bureau of Reclamation, the Secretary of the Army (Corps of Engineers), the Commissioner for the International Boundary and Water Commission, and the Congressional delegations of the three States.

Dated this 21st day of March 2002.

Harold D. Simpson, Commissioner for Colorado

Joe G. Hanson, Commissioner for Texas

Thomas C. Turney, Commissioner for New Mexico

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
NEED FOR THE U.S. BUREAU OF RECLAMATION
TO DESIGN, CONSTRUCT, OPERATE, AND MAINTAIN THE LOW FLOW
CONVEYANCE CHANNEL FROM SAN ACACIA TO THE ACTIVE RESERVOIR POOL IN
ELEPHANT BUTTE RESERVOIR AT THE 2000 CFS OPERATIONAL DESIGN

March 21, 2002
Santa Fe, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits ahd debits of Colorado and New Mexico; and

WHEREAS, New Mexico reports that operation and maintenance of federal water conveyance facilities including the Low Flow Conveyance Channel are important to New Mexico's compliance with its Rio Grande Compact delivery obligations; and

WHEREAS, the U.S. Bureau of Reclamation (Reclamation) on February 21, 2002 reported to the Engineer Advisers on the status of their Low Flow Conveyance Channel (LFCC) Modification project; and

WHEREAS, Reclamation is now proposing to reconstruct the LFCC from San Marcial to Elephant Butte Reservoir at a 500 cfs design capacity which is contrary to the historical channel capacity of 2000 cfs; and

WHEREAS, Reclamation also proposes to discharge the waters of the reconstructed LFCC into a marsh area currently occupied by Southwestern willow flycatchers well before the logical terminus of the LFCC and then re-gather the discharged water; and

WHEREAS, Reclamation's proposal directly conflicts with the April 11, 2001 Resolution of the Rio Grande Compact Commission; and

WHEREAS, the Rio Grande Compact Commission contends that Reclamation's proposal, if implemented, would effectively negate operation of the LFCC, and could negatively impact the ability of the Low Flow Conveyance Channel to effectively drain and efficiently transport the waters of the Rio Grande to Elephant Butte Reservoir; and

NOW, THEREFORE, BE IT RESOLVED that the Rio Grande Compact Commission recommends and requests that Reclamation design, construct, operate, and maintain the reconstructed LFCC from

San Marcial to the active reservoir pool at Elephant Butte Reservoir at the 2000 cfs operational design such that effective drainage and efficient transport of water can be achieved; and

BE IT FURTHER RESOLVED that the Rio Grande Compact Commission supports full funding for modifications to the Low Flow Conveyance Channel at a 2000 cfs capacity all the way to the reservoir pool; and

BE IT FURTHER RESOLVED that the Rio Grande Compact Commission requests that Reclamation promptly inform the Rio Grande Compact Commission through the Engineer Advisers of any additional difficulties in implementing the project and that Reclamation provide the Engineer Advisers a quarterly update on project activities, problems, and results; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior, and the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
THE USE OF THE ACCOUNTING MODULE OF THE UPPER RIO GRANDE OPERATIONS MODEL FOR RIO GRANDE COMPACT ACCOUNTING PURPOSES

April 11, 2001
Albuquerque, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, Rio Grande Compact and San Juan-Chama Project annual water accounting is conducted using data collected by the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers (Corps), the Bureau of Reclamation (Reclamation), and the States of Colorado and New Mexico; and

WHEREAS, Reclamation systematically collects relevant data and prepares annual accounting of Rio Grande and San Juan-Chama Project reservoir operations, streamflow, and water deliveries for review and use by the Engineer Advisers to the Rio Grande Compact Commission in preparing the annual Rio Grande Compact accounting; and

WHEREAS, Reclamation has developed and continues to use a separate FORTRAN program for each reservoir to provide accounting information of native Rio Grande and San Juan-Chama waters; and

WHEREAS, the Bureau of Reclamation, the Corps, and the USGS in 1996 began to develop the Upper Rio Grande Water Operations Model (URGWOM) using the RiverWare software program, for the simulation of middle Rio Grande basin reservoir operations; and

WHEREAS, URGWOM contains an accounting module that has been applied for Rio Grande Compact accounting purposes; and

WHEREAS, accounting errors made in the process of employing the FORTRAN programs are reduced when using the URGWOM accounting module because the newer software has superior features and is easier to use; and

WHEREAS, the URGWOM accounting module was tested by comparing its results to the daily accounting FORTRAN programs currently in use, satisfactorily reproduced the accounting results of years 1995, 1996 and 2000, and resulted in the identification of data errors made in using the

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FORTRAN program based accounting that otherwise would not have been revealed; and

WHEREAS, Reclamation recommends and requests that the Rio Grande Compact Commission approve Reclamation's use of URGWOM for Rio Grande Compact and San Juan-Chama Project water accounting purposes and abandonment of the previous accounting software and methods that URGWOM replaces.

NOW, THEREFORE, BE IT RESOLVED that the Rio Grande Compact Commission hereby approves the use of the URGWOM accounting module in producing the accounting data needed by the USGS for use in the Rio Grande Compact accounting process subject to the following conditions:

1. Reclamation fulfill its commitments made during the February 2000 meeting of the Engineer Advisers to the Rio Grande Compact Commission to work with the Engineer Advisers to complete during 2001: a) review and documentation of the procedures for Rio Grande Compact accounting of Rio Grande and San Juan-Chama Project water, and b) quantification of the evaporation accounting error for the period 1993 through 1998 for accumulated credits of New Mexico and Colorado; and

2. Reclamation provide the three Compact States timely access to the URGWOM accounting module and its associated data and results, using a file transfer protocol, or FTP, site to be updated at least weekly; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Albuquerque Area Office Manager of Bureau of Reclamation and the District Engineer of the Albuquerque District of the Corps of Engineers.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING THE NEED FOR FEDERAL AGENCIES TO APPLY FOR STATE PERMITS IN COMPLIANCE WITH STATE WATER LAW AND REGULATIONS

April 11, 2001
Albuquerque, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, the U.S. Army Corps of Engineers (Corps) and the U.S. Bureau of Reclamation (Reclamation) operate and maintain water storage and conveyance facilities on the Rio Grande; and

WHEREAS, Reclamation, the Corps, the U.S. Fish & Wildlife Service, and other parties are planning and, in some cases, conducting aquatic and riparian habitat restoration activities; and

NOW, THEREFORE, BE IT RESOLVED THAT the Rio Grande Compact Commission hereby requests the above federal agencies to comply with state law by obtaining permits from the appropriate state agencies for any water-related actions that result in new or additional river depletions; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior; the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation; the Director, Regional Director, and the New Mexico Ecological Services Field Office Supervisor of the U. S. Fish and Wildlife Service, and the Commander, Division Engineer, and District Engineer of the U. S. Army Corps of Engineers.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

**RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
THE CONTINUING NEED FOR THE U.S. BUREAU OF RECLAMATION
TO CONTINUOUSLY EXTEND AND MAINTAIN A PILOT CHANNEL
THROUGH THE DELTA OF ELEPHANT BUTTE RESERVOIR TO THE ACTIVE
RESERVOIR POOL AS THE RESERVOIR RECEDES**

April 11, 2001
Albuquerque, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, New Mexico reports that water conveyance facilities and maintenance of the active channel of the Rio Grande, particularly in the San Acacia reach, are important to New Mexico's compliance with its Rio Grande Compact delivery obligations; and

WHEREAS, the U.S. Bureau of Reclamation (Reclamation) is currently constructing a temporary channel to connect the river channel at the head of Elephant Butte Reservoir, through the reservoir sediment delta, to the active reservoir pool; and

NOW, THEREFORE, BE IT RESOLVED that the Rio Grande Compact Commission requests that Reclamation continue to extend and maintain the constructed channel from San Marcial through the sediment delta to the active reservoir pool in Elephant Butte Reservoir as the reservoir recedes, thereby maintaining an active river channel to the reservoir pool at all times; and

BE IT FURTHER RESOLVED that the U.S. Bureau of Reclamation is requested to promptly inform the Rio Grande Compact Commission through the Engineer Advisers of any difficulties in implementing the pilot channel construction project and that Reclamation provide the Engineer Advisers a quarterly update on project activities, problems, and results; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior; the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation; and the Director, Regional Director, and the New Mexico Ecological Services Field Office Supervisor of the U. S. Fish and Wildlife Service.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

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RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING THE NEED FOR CONCLUSION
OF THE BUREAU OF RECLAMATION'S AND U.S. CORPS OF ENGINEERS'
ONGOING CONSULTATIONS WITH U.S. FISH AND WILDLIFE SERVICE
UNDER SECTION 7 OF THE ENDANGERED SPECIES ACT
REGARDING RIO GRANDE OPERATIONS

April 11, 2001
Albuquerque, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, New Mexico reports that water salvage and conveyance facilities located in the Middle Rio Grande Valley and maintenance of the channel of the Rio Grande have facilitated its delivery of water under the Rio Grande Compact, and that the future of such projects and facilities are uncertain while deliberation over wildlife habitat in the region continues; and

WHEREAS, the U.S. Army Corps of Engineers (Corps) and the U.S. Bureau of Reclamation (Reclamation) operate and maintain water storage and conveyance facilities on the Rio Grande; and

WHEREAS, the U. S. Fish and Wildlife Service (Service) in 1994 listed the Rio Grande silvery minnow as an endangered species under the Endangered Species Act (ESA) and further designated critical habitat for the species in 1999; and

WHEREAS, the ESA Section 7 requires federal agencies to consult with the Service regarding federal actions that might affect endangered species; and

WHEREAS, the ESA Section 7 consultations described above have not been completed; and

NOW, THEREFORE, BE IT RESOLVED THAT the Rio Grande Compact Commission requests that the Federal agencies involved in the ESA Section 7 consultations initiate, as appropriate, and bring the formal consultations to prompt resolution in accordance with the time limits set by federal regulation; and

BE IT FURTHER RESOLVED that Reclamation and the Corps assist the State of New Mexico in mitigating and offsetting any restrictions placed on the Federal agencies discretionary actions with regard to Rio Grande water storage and conveyance facilities operations that might reduce the water supply available for use within New Mexico above Elephant Butte Reservoir.

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior: the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation; the Director, Regional Director, and the New Mexico Ecological Services Field Office Supervisor of the U. S. Fish and Wildlife Service, and the Commander, Division Engineer, and District Engineer of the U. S. Army Corps of Engineers.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
THE STORAGE OF NATIVE NEW MEXICO RIO GRANDE WATER IN U.S. ARMY CORPS OF ENGINEERS MIDDLE RIO GRANDE PROJECT RESERVOIRS

April 11, 2001
Albuquerque, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, the U.S. Army Corps of Engineers (Corps) and the U.S. Bureau of Reclamation (Reclamation) operate and maintain water storage and conveyance facilities on the Rio Grande; and

WHEREAS, litigation under the federal Endangered Species Act, Cause No. 99-CIV-1320, styled *Minnow v. Martinez*, filed in the United States District Court for the District of New Mexico in Albuquerque, New Mexico, was initiated in late 1999 on the middle Rio Grande in New Mexico seeking protection for the endangered Rio Grande silvery minnow; and

WHEREAS, New Mexico has recently proposed in an offer of settlement of *Minnow v. Martinez* to make available for lease by Reclamation, for a period of three years, a total of 100,000 acre-feet of New Mexico's native Rio Grande water and to establish a Middle Rio Grande Endangered Species Conservation Pool (Conservation Pool) in the Corps' Middle Rio Grande Project Reservoirs; and

WHEREAS, New Mexico proposes to capture and store native Rio Grande water during 2001 through 2003 at times when Rio Grande flows are in excess of downstream diversion demands in New Mexico above Elephant Butte Reservoir; such water, if not stored, would have flowed downstream to Elephant Butte Reservoir and contributed to New Mexico's compact delivery; and

WHEREAS, the native Rio Grande water that New Mexico stores in the Middle Rio Grande Endangered Species Conservation Pool would be released at a sufficient flow rate to maintain flow at points in the Rio Grande critical for the silvery minnow, with total releases over the three-year term not to exceed 90,000 acre-feet, with no more than 30,000 acre-feet (plus any carryover water from the prior year) released in any one calendar year; and

WHEREAS, the Flood Control Act of 1960 (Public Law 86-645) requires the advice and consent of the Rio Grande Compact Commission for any departure from the normal operation schedules of the Corps' Middle Rio Grande Project Reservoirs; and

NOW, THEREFORE, BE IT RESOLVED that, in accordance with the Flood Control Act of 1960 (Public Law 86-645), the Rio Grande Compact Commission hereby favorably advises and consents

to the departure from normal operation schedules of the Corps= Middle Rio Grande Project Reservoirs for a term of not more than three years to allow the operation of the Middle Rio Grande Endangered Species Conservation Pool as described above; and

BE IT FURTHER RESOLVED that by approval of this resolution, the States of Colorado and Texas in no way change the obligations of New Mexico under the Rio Grande Compact.

BE IT FURTHER RESOLVED PROVIDED, HOWEVER, that the State of Texas reserves the right to rescind its approval of this resolution on March 21, 2002, and again on March 20, 2003, if Texas determines that Texas has been or will be harmed by the departure from normal operation schedules, by providing written notice of the rescission of its approval to the States of Colorado and New Mexico through each state's respective Rio Grande Compact Commissioner.

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior; the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation; the Director, Regional Director, and the New Mexico Ecological Services Field Office Supervisor of the U.S. Fish and Wildlife Service, and the Commander, Division Engineer, and District Engineer of the U.S. Army Corps of Engineers.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
NEED FOR THE U.S. BUREAU OF RECLAMATION
TO DESIGN, CONSTRUCT, OPERATE, AND MAINTAIN THE LOW FLOW
CONVEYANCE CHANNEL FROM SAN ACACIA TO THE ACTIVE RESERVOIR
POOL IN ELEPHANT BUTTE RESERVOIR AT A 2000 CFS OPERATIONAL DESIGN

April 11, 2001
Albuquerque, New Mexico

WHEREAS, the states of Colorado, New Mexico, and Texas entered into the Rio Grande Compact, signed in 1938, regarding the waters of the Rio Grande above Fort Quitman, Texas; and

WHEREAS, Article VI of the Rio Grande Compact provides for annual computation of all credits and debits of Colorado and New Mexico; and

WHEREAS, New Mexico reports that operation and maintenance of federal water conveyance facilities including the Low Flow Conveyance Channel are important to New Mexico's compliance with its Rio Grande Compact delivery obligations; and

WHEREAS, the U.S. Bureau of Reclamation (Reclamation) on September 8, 2000 submitted a Draft Environmental Impact Statement (DEIS) for the Low Flow Conveyance Channel Modification to the Engineer Advisers for review and comment; and

WHEREAS, the DEIS provides analysis of four alternatives for the future of the Low Flow Conveyance Channel south of San Marcial; and

WHEREAS, Reclamation indicated to the Compact Commission at the March 22, 2001 compact annual meeting that the Final Environmental Impact Statement should be completed by the summer of 2001; and

NOW, THEREFORE, BE IT RESOLVED that the Rio Grande Compact Commission requests that Reclamation take all appropriate steps to implement construction and operation of the Low Flow Conveyance Channel in accordance with a 2000 cfs design capacity to the active reservoir at Elephant Butte Reservoir; and

BE IT FURTHER RESOLVED that the Rio Grande Compact Commission requests that Reclamation promptly inform the Rio Grande Compact Commission through the Engineer Advisers of any additional difficulties in implementing the project and that Reclamation provide the Engineer Advisers a quarterly update on project activities, problems, and results; and

BE IT FURTHER RESOLVED that the Secretary of the Rio Grande Compact Commission transmit copies of this resolution to the Secretary of the Interior; and the Commissioner, Regional Director, and Albuquerque Area Office Manager of Reclamation.

Hal D. Simpson
Commissioner for Colorado

Thomas C. Turney
Commissioner for New Mexico

Joe G. Hanson
Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
TO EXCLUDE ACOMITA RESERVOIR FROM COMPACT ACCOUNTING

March 23, 2000
El Paso, Texas

WHEREAS, annual accounting of the allocation of the waters of the Rio Grande between the States of Colorado, New Mexico, and Texas under the Rio Grande Compact requires the change in water stored in reservoirs constructed since 1929 to be considered in the calculation of index supplies; and

WHEREAS, the Rio Grande Compact provides that the Commissioner for Texas may demand the release of water from storage reservoirs constructed after 1929 to the amounts of accrued debits of Colorado and New Mexico; and

WHEREAS, Acomita Reservoir is a small reservoir on the San Fidel Arroyo, constructed in 1938 with an original capacity of 850 acre feet and capacity, based on a 1956 sediment survey, of 650 acre-feet, that stores water diverted from the Rio San Jose; and

WHEREAS, Acomita Reservoir, which has been empty for many years, was observed in June 1999 to be essentially full; and

WHEREAS, the Acoma Pueblo did not provide reservoir storage data for 1999 for Acomita Reservoir; and

WHEREAS, the Rio Grande Compact water accounting for 1999 included an estimation that water stored in Acomita Reservoir had increased 600 acre feet; and

WHEREAS, release of water in storage from the Acomita Reservoir in response to a demand from the Texas Commissioner for release of water stored in reservoirs constructed since 1929 would be futile with regard to contributing flow to the Rio Grande and Elephant Butte Reservoir due to the large distance separating Acomita Reservoir from the Rio Grande and Elephant Butte Reservoir and the ephemeral nature of the Rio Puerco and its tributary the Rio San Jose; and

WHEREAS, the Rio Grande Compact Commission has previously excluded annual water accounting from other small reservoirs.

NOW, THEREFORE, BE IT RESOLVED THAT the Rio Grande Compact annual water accounting exclude Acomita Reservoir storage effective January 1, 2000.

H. D. S.
Harold D. Simpson, Commissioner for Colorado

Thomas C. Turney
Thomas C. Turney, Commissioner for New Mexico

Jo- G. Hanson, Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
SUPPORTING A COMPREHENSIVE PLANNING STUDY
OF THE REACH OF THE RIO GRANDE EXTENDING FROM
SAN ACACIA DIVERSION DAM TO ELEPHANT BUTTE RESERVOIR
UNDER
THE WATER RESOURCES DEVELOPMENT ACT SECTION 729

March 23, 2000
El Paso, Texas

WHEREAS, the Rio Grande Compact obligates New Mexico to deliver Rio Grande water to below Elephant Butte Dam according to an inflow outflow schedule based on the Otowi index supply; and

WHEREAS, New Mexico is entitled to deplete annually a maximum of 405,000 acre feet of the Otowi index supply and must deliver the remainder of the index supply to below Elephant Butte Dam; and

WHEREAS, New Mexico's compliance with its delivery obligations under the Rio Grande Compact is necessary to meet the United States treaty obligation to Mexico and provide the majority of water supply for Southern New Mexicans and Texans living along the Rio Grande downstream of Elephant Butte Reservoir and above Ft. Quitman, Texas; and

WHEREAS, the protection of the health and safety of the people who live in the Rio Grande basin require that the channel of the Rio Grande be maintained both to deliver water to Elephant Butte Reservoir and to avoid or reduce the adverse impacts from floods; and

WHEREAS, the history of water deliveries by New Mexico to Elephant Butte Reservoir shows that construction authorized by the Flood Control Acts of 1948 and 1950 of the Middle Rio Grande Project, including the Low Flow Conveyance Channel and the Rio Grande Floodway in the reach of the Rio Grande from the San Acacia Diversion Dam to Elephant Butte Reservoir, and subsequent operations and maintenance of these and associated water drainage and salvage facilities, have been important to New Mexico's compliance with its Rio Grande Compact delivery obligations; and

WHEREAS, the U. S. Fish and Wildlife Service (Service) in 1994 listed the Rio Grande silvery minnow as an endangered species under the Endangered Species Act and further designated critical habitat for the species in 1999 to include the reach of the Rio Grande from San Acacia Diversion Dam to the San Marcial railroad bridge; and

WHEREAS, most of the remaining population of the Rio Grande silvery minnow exist in the reach of the Rio Grande downstream of San Acacia Diversion Dam; and

WHEREAS, the reach of the Rio Grande from San Acacia Diversion Dam to Elephant Butte Reservoir supports several nesting pairs of the endangered Southwestern willow flycatcher; and

WHEREAS, the aggraded channel of the Rio Grande in this reach is confined to the east side of the floodplain by a levee constructed from sand that has been continuously raised and augmented as the river channel has aggraded and Reclamation indicates that this sand levee is inadequate to reliably contain the river under flood conditions; and

WHEREAS, the channel of the Rio Grande in the San Marcial area has aggraded substantially historically, including more than 12 feet of sediment deposition from 1979 to 1987, due to the high sediment load of the Rio Grande in this reach, causing the channel of the Rio Grande to be on the order of ten feet higher than the floodplain to the west of the channel; and

WHEREAS, the San Marcial Railroad Bridge has been raised previously due to sediment deposition in the bed of the river under the bridge; and

WHEREAS, the San Marcial Railroad Bridge now has inadequate space underneath it to pass flood flows exceeding about 6000 cubic feet per second without submergence and damage or risk to the bridge, causing an immediate need to raise it again; and

WHEREAS, operation of the Low Flow Conveyance Channel in its historic mode such that all river flows were diverted to the Low Flow Conveyance Channel when river flows were less than 2000 cubic feet per second has been discontinued due in part to endangered species habitat concerns; and

WHEREAS, an uncontrolled breach of the levee below San Marcial, where the river channel is on the order of ten feet higher than the floodplain to the west, would destroy that portion of the Low Flow Conveyance Channel and cause the waters of the river to spread out over the floodplain and be depleted rather than delivered to Elephant Butte Reservoir; and

WHEREAS, such an avulsion would also dry up or threaten existing riparian habitat including Southwest Willow Flycatcher nesting sites and kill Rio Grande silvery minnow existing in the Rio Grande channel downstream from the location of the avulsion; and

WHEREAS, drainage of the flood plain above Elephant Butte Reservoir is impaired, contributing to excessive water depletion by open water evaporation and phreatophytes, consequently diminishing compact deliveries; and

WHEREAS, proliferation of exotic, invasive phreatophytes has displaced native riparian habitat and is also causing waste of water; and

WHEREAS, the U. S. Fish and Wildlife Service recommends that an ecosystem restoration approach be the framework and basis of efforts by the signatories of the ESA Collaborative Process Memorandum of Understanding to address compliance with the Endangered Species Act while protecting New Mexico's economic water uses and compact deliveries; and

WHEREAS, the Water Resources Development Act, Section 729, authorizes comprehensive water resources investigations; the Corps of Engineers has budgeted in FY2001 to initiate such a study in the Rio Grande specifically addressing endangered species, water delivery, and flood control needs; the New Mexico Interstate Stream Commission is seeking substantial additional federal funding and has budgeted necessary matching funds for a comprehensive evaluation of the San Acacia to Elephant Butte Reservoir reach of the Rio Grande conditioned on full recognition by the Corps of Engineers and other study sponsors of the limits of water supply in this desert region, specifically including New Mexico's need to maintain economic uses of water in the Middle Rio Grande while meeting its Rio Grande Compact delivery obligations.

NOW, THEREFORE, BE IT RESOLVED THAT the Rio Grande Compact Commission finds that federal projects and facilities that have been important to convey water to Elephant Butte Reservoir and to assist New Mexico in making its Rio Grande Compact deliveries have impaired function due to sedimentation and river aggradation and due to constraints imposed by the federal government associated with the Endangered Species Act; and

BE IT FURTHER RESOLVED that the Rio Grande Compact Commission supports the State of New Mexico's initiative for a comprehensive federal study of the San Acacia to Elephant Butte Reservoir reach of the Rio Grande under the Water Resources Development Act, Section 729, to prepare a plan for physical improvements to habitat, the river and associated water conveyance, drainage, and salvage facilities in order to comply with the Endangered Species Act while managing water depletions and sediment, conveying [illegible] compact deliveries, minimizing unnecessary evapotranspiration and waste of water, and continuing irrigation uses of water in this critical reach.

Harold D. Simpson, Commissioner for Colorado

Thomas C. Turney, Commissioner for New Mexico

Joe G. Hanson, Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REQUESTING CONCLUSION
OF THE BUREAU OF RECLAMATION'S AND U.S. CORPS OF ENGINEERS' PROGRAMMATIC CONSULTATION WITH U.S. FISH AND WILDLIFE SERVICE UNDER SECTION 7 OF THE ENDANGERED SPECIES ACT REGARDING RIO GRANDE OPERATIONS

March 23, 2000
El Paso, Texas

WHEREAS, the Rio Grande Compact obligates New Mexico to deliver Rio Grande water to below Elephant Butte Dam according to an inflow outflow schedule based on the Otowi index supply; and

WHEREAS, New Mexico is entitled to deplete annually a maximum of 405,000 acre feet of the Otowi index supply and must deliver the remainder of the index supply to below Elephant Butte Dam; and

WHEREAS, New Mexico's compliance with its delivery obligations under the Rio Grande Compact is necessary to meet the United States treaty obligation to Mexico and provide the majority of water supply for Southern New Mexicans and Texans living along the Rio Grande downstream of Elephant Butte Reservoir and above Ft. Quitman, Texas; and

WHEREAS, the protection of the health and safety of the people who live in the Rio Grande basin require that the channel of the Rio Grande be maintained both to deliver water to Elephant Butte Reservoir and to avoid or reduce the adverse impacts from floods; and

WHEREAS, the history of water deliveries by New Mexico to Elephant Butte Reservoir shows that operation and maintenance of water salvage and conveyance facilities in the Middle Rio Grande Valley and maintenance of the channel of the Rio Grande are essential to New Mexico's compliance with its Rio Grande Compact delivery obligations; and

WHEREAS, under various existing legal authorities, and subject to allocation of supplies and priority of water rights under the Rio Grande Compact and the laws of the states, the U.S. Corps of Engineers (Corps) and U.S. Bureau of Reclamation (Reclamation) operate and maintain water storage and conveyance facilities on the Rio Grande to 1) store and deliver water; 2) assist New Mexico in meeting Rio Grande Compact delivery obligations; 3) provide flood protection and sediment control; and comply with existing law, contract obligations, and international treaty; and

WHEREAS, the U. S. Fish and Wildlife Service (Service) in 1994 listed the Rio Grande silvery minnow as an endangered species under the Endangered Species Act and further designated critical habitat for the species in 1999; and

WHEREAS, the Endangered Species Act in section 7 requires federal agencies to consult with the Service regarding federal actions that might affect endangered species; and

WHEREAS, Reclamation and the Corps in recent years have not timely completed section 7 consultations with the Service regarding annual plans to operate water storage and conveyance facilities prior to completion of the actions that were the subject of the consultations; and

WHEREAS, Reclamation and the Corps determined in 1998 that they would proceed with a multiple year programmatic section 7 consultation covering their Rio Grande water operations actions and discretionary authority; and

WHEREAS, an initial biological assessment submitted by Reclamation and the Corps to the Service in May 1998 to initiate that section 7 consultation was subsequently withdrawn and was replaced by another biological assessment submitted to the Service in October 1999; and

WHEREAS, Reclamation and the Service informed the Rio Grande Compact Engineer Advisers on February 22, 2000, that informal discussions were occurring regarding the Corps and Reclamation's biological assessment but that neither formal section 7 consultation nor preparation by the Service of the required biological opinion had commenced as of that date; and

WHEREAS, the Corps indicated its intention that formal section 7 consultation commence immediately upon submittal by Reclamation and the Corps of the biological assessment in October 1999; and

WHEREAS, representatives of Reclamation and the Corps and the Service did not indicate, in response to questions from the Engineer Advisers, when the formal section 7 consultation would commence or be completed; and

WHEREAS, lack of initiation or conclusion of formal consultation and prolonged informal consultation has and will continue to limit Reclamation's and the Corps effectiveness in continuing their historic and essential Rio Grande operations activities and exacerbate the uncertainty of the constraints on these activities associated with compliance with the Endangered Species Act.

NOW, THEREFORE, BE IT RESOLVED THAT the Rio Grande Compact Commission requests that the Federal agencies involved in the ESA section 7 consultation initiate and bring the formal consultation to a prompt resolution in accordance with the time limits set by federal regulation; and

BE IT FURTHER RESOLVED that Reclamation and the Corps assist the Rio Grande Compact Commission and the State of New Mexico in mitigating and offsetting any restrictions placed on the Federal agencies' discretionary actions with regard to Rio Grande water storage and conveyance facilities operations that might reduce the water supply available for use within New Mexico above Elephant Butte Reservoir and interfere with New Mexico's ability to convey Rio Grande water through the Middle Rio Grande Valley to meet its delivery obligations to below Elephant Butte Dam.

H.D. S.

Harold D. Simpson, Commissioner for Colorado

Thomas C. Turney

Thomas C. Turney, Commissioner for New Mexico

Joe G. Hanson, Commissioner for Texas

RESOLUTION
OF THE
RIO GRANDE COMPACT COMMISSION
REGARDING
THE NEED FOR THE BUREAU OF RECLAMATION TO CONTINUOUSLY EXTEND AND MAINTAIN A PILOT CHANNEL THROUGH THE DELTA OF ELEPHANT BUTTE RESERVOIR TO THE RESERVOIR POOL

March 23, 2000
El Paso, Texas

WHEREAS, the Rio Grande Compact obligates New Mexico to deliver Rio Grande water to below Elephant Butte Dam according to an inflow outflow schedule based on the Otowi index supply; and

WHEREAS, New Mexico is entitled to deplete annually a maximum of 405,000 acre feet of the Otowi index supply and must deliver the remainder of the index supply to below Elephant Butte Dam; and

WHEREAS, New Mexico's compliance with its delivery obligations under the Rio Grande Compact is necessary to meet the United States treaty obligation to Mexico and provide the majority of water supply for Southern New Mexicans and Texans living along the Rio Grande downstream of Elephant Butte Reservoir and above Ft. Quitman, Texas; and

WHEREAS, the history of water deliveries by New Mexico to Elephant Butte Reservoir shows that operation and maintenance of water conveyance facilities and maintenance of the active channel of the Rio Grande, particularly in the San Acacia to Elephant Butte Reservoir reach, are important to New Mexico's compliance with its Rio Grande Compact delivery obligations; and

WHEREAS, the Rio Grande Compact Commission emphasized the importance of maintaining a river channel connection through the Elephant Butte Reservoir delta to the reservoir pool in its discussions with Bureau of Reclamation representatives at the 1999 annual compact commission meeting; and

WHEREAS, the Rio Grande main river channel currently ends before it reaches the reservoir pool and the channel divides into several distributary channels, with the result that water and sediment are no longer being efficiently transported into the reservoir, aggravating both unnecessary losses of water and aggradation of the river channel; and

WHEREAS, Reclamation anticipated conducting river channel maintenance to reconnect the river channel to the reservoir pool during the winter of 1999-2000 but this work was not approved by the U.S. Fish and Wildlife Service (Service) due to Endangered Species Act issues; and

WHEREAS, until recently, neither the New Mexico Interstate Stream Commission nor the Engineer Advisors nor the Rio Grande Compact Commission were aware that unresolved Endangered Species Act issues were being discussed and the lack of approval from the U. S. Fish and Wildlife Service was preventing important maintenance of this portion of the river channel; and

WHEREAS, the Reclamation's projections of snow melt runoff and operations of Elephant Butte and Caballo Reservoirs, as discussed with the Engineer Advisers at their annual meeting, indicate that Elephant Butte Reservoir will be drawn down to approximately 1,000,000 acre-feet by fall 2000.

NOW, THEREFORE, BE IT RESOLVED THAT the Rio Grande Compact Commission requests that Reclamation continuously extend and maintain a pilot channel(s) from San Marcial through the sediment delta to Elephant Butte lake as the reservoir recedes, thereby maintaining an active river channel to the lake at all times.

BE IT FURTHER RESOLVED that Reclamation quickly resolve any remaining project issues with the U.S. Fish and Wildlife Service such that the pilot channel maintenance activities can commence.

BE IT FURTHER RESOLVED that Reclamation promptly inform the Rio Grande Compact Commission through the Engineer Advisors of any additional difficulties in implementing the pilot channel project and that, upon implementing the project, Reclamation keep the Engineer Advisors fully informed of the project progress, results, and problems.

H.D.S.
Harold D. Simpson, Commissioner for Colorado

Thomas C. Turney
Thomas C. Turney, Commissioner for New Mexico

Joe G. Hanson, Commissioner for Texas

RIO GRANDE COMPACT

The State of Colorado, the State of New Mexico, and the State of Texas, desiring to remove all causes of present and future controversy among these States and between citizens of one of these States and citizens of another State with respect to the use of the waters of the Rio Grande above Fort Quitman, Texas, and being moved by considerations of interstate comity, and for the purpose of effecting an equitable apportionment of such waters, have resolved to conclude a Compact for the attainment of these purposes, and to that end, through their respective Governors, have named as their respective Commissioners:

For the State of Colorado	M. C. Hinderlider
For the State of New Mexico	Thomas M. McClure
For the State of Texas	Frank B. Clayton

who, after negotiations participated in by S. O. Harper, appointed by the President as the representative of the United States of America, have agreed upon the following articles, to-wit:

ARTICLE I

(a) The State of Colorado, the State of New Mexico, the State of Texas, and the United States of America, are hereinafter designated "Colorado," "New Mexico," "Texas," and the "United States," respectively.

(b) "The Commission" means the agency created by this Compact for the administration thereof.

(c) The term "Rio Grande Basin" means all of the territory drained by the Rio Grande and its tributaries in Colorado, in New Mexico, and in Texas above Fort Quitman, including the Closed Basin in Colorado.

(d) The "Closed Basin" means that part of the Rio Grande Basin in Colorado where the streams drain into the San Luis Lakes and adjacent territory, and do not normally contribute to the flow of the Rio Grande.

(e) The term "tributary" means any stream which naturally contributes to the flow of the Rio Grande.

(f) "Transmountain Diversion" is water imported into the drainage basin of the Rio Grande from any stream system outside of the Rio Grande Basin, exclusive of the Closed Basin.

(g) "Annual Debits" are the amounts by which actual deliveries in any calendar year fall below scheduled deliveries.

(h) "Annual Credits" are the amounts by which actual deliveries in any calendar year exceed scheduled deliveries.

(i) "Accrued Debits" are the amounts by which the sum of all annual debits exceeds the sum of all annual credits over any common period of time.

(j) "Accrued Credits" are the amounts by which the sum of all annual credits exceeds the sum of all annual debits over any common period of time.

(k) "Project Storage" is the combined capacity of Elephant Butte Reservoir and all other reservoirs actually available for the storage of usable water below Elephant Butte and above the first diversion to lands of the Rio Grande Project, but not more than a total of 2,638,860 acre feet.

(l) "Usable Water" is all water, exclusive of credit water, which is in project storage and which is available for release in accordance with irrigation demands, including deliveries to Mexico.

(m) "Credit Water" is that amount of water in project storage which is equal to the accrued credit of Colorado, or New Mexico, or both.

(n) "Unfilled Capacity" is the difference between the total physical capacity of project storage and the amount of usable water then in storage.

(o) "Actual Release" is the amount of usable water released in any calendar year from the lowest reservoir comprising project storage.

(p) "Actual Spill" is all water which is actually spilled from Elephant Butte Reservoir, or is released therefrom for flood control, in excess of the current demand on project storage and which does not become usable water by storage in another reservoir; provided, that actual spill of usable water cannot occur until all credit water shall have been spilled.

(q) "Hypothetical Spill" is the time in any year at which usable water would have spilled from project storage if 790,000 acre feet had been released therefrom at rates proportional to the actual release in every year from the starting date to the end of the year in which hypothetical spill occurs; in computing hypothetical spill the initial condition shall be the amount of usable water in project storage at the beginning of the calendar year following the effective date of this Compact, and thereafter the initial condition shall be the amount of usable water in project storage at the beginning of the calendar year following each actual spill.

ARTICLE II

The Commission shall cause to be maintained and operated a stream gaging station equipped with an automatic water stage recorder at each of the following points, to-wit:

(a) On the Rio Grande near Del Norte above the principal points of diversion to the San Luis Valley;

(b) On the Conejos River near Mogote;

(c) On the Los Pinos River near Ortiz;

(d) On the San Antonio River at Ortiz;

(e) On the Conejos River at its mouths near Los Sauces;

(f) On the Rio Grande near Lobatos;

(g) On the Rio Chama below El Vado Reservoir;

(h) On the Rio Grande at Otowi Bridge near San Ildefonso;

(i) On the Rio Grande near San Acacia;

(j) On the Rio Grande at San Marcial;

(k) On the Rio Grande below Elephant Butte Reservoir;

(l) On the Rio Grande below Caballo Reservoir.

Similar gaging stations shall be maintained and operated below any other reservoir constructed after 1929, and at such other points as may be necessary for the securing of records required for the carrying out of the Compact; and automatic water stage recorders shall be maintained and operated on each of the reservoirs mentioned, and on all others constructed after 1929.

Such gaging stations shall be equipped, maintained and operated by the Commission directly or in cooperation with an appropriate Federal or State agency, and the equipment, method and frequency of measurement at such stations shall be such as to produce reliable records at all times. (Note: See Resolution of Commission printed elsewhere in this report.)

ARTICLE III

The obligation of Colorado to deliver water in the Rio Grande at the Colorado-New Mexico State Line, measured at or near Lobatos, in each calendar year, shall be ten thousand acre feet less than the sum of those quantities set forth in the two following tabulations of relationship, which correspond to the quantities at the upper index stations:

DISCHARGE OF CONEJOS RIVER

Quantities in thousands of acre feet

Conejos Index Supply (1)	Conejos River at Mouths (2)
100	0
150	20
200	45
250	75
300	109
350	147
400	188
450	232
500	278
550	326
600	376
650	426
700	476

Intermediate quantities shall be computed by proportional parts.

(1) Conejos Index Supply is the natural flow of Conejos River at the U.S.G.S. gaging station near Mogote during the calendar year, plus the natural flow of Los Pinos River at the U.S.G.S. gaging station near Ortiz and the natural flow of San Antonio River at the U.S.G.S. gaging station at Ortiz, both during the months of April to October, inclusive.

(2) Conejos River at Mouths is the combined discharge of branches of this river at the U.S.G.S. gaging stations near Los Sauces during the calendar year.

DISCHARGE OF RIO GRANDE EXCLUSIVE OF CONEJOS RIVER

Quantities in thousands of acre feet

Rio Grande at Del Norte (3)	Rio Grande at Lobatos less Conejos at Mouths (4)
200	60
250	65
300	75
350	86
400	98
450	112
500	127
550	144
600	162

DISCHARGE OF RIO GRANDE EXCLUSIVE OF CONEJOS RIVER--Con.

Quantities in thousands of acre feet

Rio Grande at Del Norte (3)	Rio Grande at Lobatos less Conejos at Mouths (4)
650	182
700	204
750	229
800	257
850	292
900	335
950	380
1,000	430
1,100	540
1,200	640
1,300	740
1,400	840

Intermediate quantities shall be computed by proportional parts.

(3) Rio Grande at Del Norte is the recorded flow of the Rio Grande at the U.S.G.S. gaging station near Del Norte during the calendar year (measured above all principal points of diversion to San Luis Valley) corrected for the operation of reservoirs constructed after 1937.

(4) Rio Grande at Lobatos less Conejos at Mouths is the total flow of the Rio Grande at the U.S.G.S. gaging station near Lobatos, less the discharge of Conejos River at its Mouths, during the calendar year.

The application of these schedules shall be subject to the provisions hereinafter set forth and appropriate adjustments shall be made for (a) any change in location of gaging stations; (b) any new or increased depletion of the runoff above inflow index gaging stations; and (c) any transmountain diversions into the drainage basin of the Rio Grande above Lobatos.

In event any works are constructed after 1937 for the purpose of delivering water into the Rio Grande from the Closed Basin, Colorado shall not be credited with the amount of such water delivered, unless the proportion of sodium ions shall be less than forty-five percent of the total positive ions in that water when the total dissolved solids in such water exceeds three hundred fifty parts per million.

ARTICLE IV

The obligation of New Mexico to deliver water in the Rio Grande at San Marcial, during each calendar year, exclusive of the months of July, August, and September, shall be that quantity set forth in the following tabulation of relationship, which corresponds to the quantity at the upper index station:

DISCHARGE OF RIO GRANDE AT OTOWI BRIDGE AND AT SAN MARCIAL EXCLUSIVE OF JULY, AUGUST AND SEPTEMBER

Quantities in thousands of acre feet

Otowi Index Supply (5)	San Marcial Index Supply (6)
100	0
200	65
300	141
400	219
500	300
600	383
700	469
800	557
900	648
1,000	742
1,100	839
1,200	939
1,300	1,042
1,400	1,148
1,500	1,257
1,600	1,370
1,700	1,489
1,800	1,608
1,900	1,730
2,000	1,856
2,100	1,985
2,200	2,117
2,300	2,253

Intermediate quantities shall be computed by proportional parts.

(5) The Otowi Index Supply is the recorded flow of the Rio Grande at the U.S.G.S. gaging station at Otowi Bridge near San Ildefonso (formerly station near Buckman) during the calendar year, exclusive of the flow during the months of July, August and September, corrected for the operation of reservoirs constructed after 1929 in the drainage basin of the Rio Grande between Lobatos and Otowi Bridge.

(6) San Marcial Index Supply is the recorded flow of the Rio Grande at the gaging station at San Marcial during the calendar year exclusive of the flow during the months of July, August and September.

The application of this schedule shall be subject to the provisions hereinafter set forth and appropriate adjustments shall be made for (a) any change in location of gaging stations; (b) depletion after 1929 in New Mexico at any time of the year of the natural runoff at Otowi Bridge; (c) depletion of the runoff during July, August and September of tributaries between Otowi Bridge and San Marcial, by works constructed after 1937; and (d) any transmountain diversions into the Rio Grande between Lobatos and San Marcial.

Concurrent records shall be kept of the flow of the Rio Grande at San Marcial, near San Acacia, and of the release from Elephant Butte Reservoir to the end that the records at these three stations may be correlated. (Note: See Resolution of Commission printed elsewhere in this report.)

ARTICLE V

If at any time it should be the unanimous finding and determination of the Commission that because of changed physical conditions, or for any other reason, reliable records are not obtainable, or cannot be obtained, at any of the stream gaging stations herein referred to, such stations may, with the unanimous approval of the Commission, be abandoned, and with such approval another station, or other stations, shall be established and new measurements shall be substituted which, in the unanimous opinion of the Commission, will result in substantially the same results so far as the rights and obligations to deliver water are concerned, as would have existed if such substitution of stations and measurements had not been so made. (Note: See Resolution of Commission printed elsewhere in this report.)

ARTICLE VI

Commencing with the year following the effective date of this Compact, all credits and debits of Colorado and New Mexico shall be computed for each calendar year; provided, that in a year of actual spill no annual credits nor annual debits shall be computed for that year.

In the case of Colorado, no annual debit nor accrued debit shall exceed 100,000 acre feet, except as either or both may be caused by holdover storage of water in reservoirs constructed after 1937 in the drainage basin of the Rio Grande above Lobatos. Within the physical limitations of storage capacity in such reservoirs, Colorado shall retain water in storage at all times to the extent of its accrued debit.

In the case of New Mexico, the accrued debit shall not exceed 200,000 acre feet at any time, except as such debit may be caused by holdover storage of water in reservoirs constructed after 1929 in the drainage basin of the Rio Grande between Lobatos and San Marcial. Within the physical limitations of storage capacity in such reservoirs, New Mexico shall retain water in storage at all times to the extent of its accrued debit. In computing the magnitude of accrued credits or debits, New Mexico shall not be charged with any greater debit in any one year than the sum of 150,000 acre-feet and all gains in the quantity of water in storage in such year.

The Commission by unanimous action may authorize the release from storage of any amount of water which is then being held in storage by reason of accrued debits of Colorado or New Mexico; provided, that such water shall be replaced at the first opportunity thereafter.

In computing the amount of accrued credits and accrued debits of Colorado or New Mexico, any annual credits in excess of 150,000 acre feet shall be taken as equal to that amount.

In any year in which actual spill occurs, the accrued credits of Colorado, or New Mexico, or both, at the beginning of the year shall be reduced in proportion to their respective credits by the amount of such actual spill; provided that the amount of actual spill shall be deemed to be increased by the aggregate gain in the amount of water in storage, prior to the time of spill, in reservoirs above San Marcial constructed after 1929; provided, further, that if the Commissioners for the States having accrued credits authorize the release of part, or all, of such credits in advance of spill, the amount so released shall be deemed to constitute actual spill.

In any year in which there is actual spill of usable water, or at the time of hypothetical spill thereof, all accrued debits of Colorado, or New Mexico, or both, at the beginning of the year shall be cancelled.

In any year in which the aggregate of accrued debits of Colorado and New Mexico exceeds the minimum unfilled capacity of project storage, such debits shall be reduced proportionally to an aggregate amount equal to such minimum unfilled capacity.

To the extent that accrued credits are impounded in reservoirs between San Marcial and Courchesne, and to the extent that accrued debits are impounded in reservoirs above San Marcial, such credits and debits shall be reduced annually to compensate for evaporation losses in the proportion that such credits or debits bore to the total amount of water in such reservoirs during the year.

ARTICLE VII

Neither Colorado nor New Mexico shall increase the amount of water in storage in reservoirs constructed after 1929 whenever there is less than 400,000 acre feet of usable water in project storage; provided, that if the actual releases of usable water from the beginning of the calendar year following the effective date of this Compact, or from the beginning of the calendar year following actual spill, have aggregated more than an average of 790,000 acre feet per annum, the time at which such minimum stage is reached shall be adjusted to compensate for the difference between the total actual release and releases at such average rate; provided, further, that Colorado, or New Mexico, or both, may relinquish accrued credits at any time, and Texas may accept such relinquished water, and in such event the state, or states, so relinquishing shall be entitled to store water in the amount of the water so relinquished.

ARTICLE VIII

During the month of January of any year the Commissioner for Texas may demand of Colorado and New Mexico, and the Commissioner for New Mexico may demand of Colorado, the release of water from storage reservoirs constructed after 1929 to the amount of the accrued debits of Colorado and New Mexico, respectively, and such releases shall be made by each at the greatest rate practicable under the conditions then prevailing, and in proportion to the total debit of each, and in amounts, limited by their accrued debits, sufficient to bring the quantity of usable water in project storage to 600,000 acre feet by March first and to maintain this quantity in storage until April thirtieth, to the end that a normal release of 790,000 acre feet may be made from project storage in that year.

ARTICLE IX

Colorado agrees with New Mexico that in event the United States or the State of New Mexico decides to construct the necessary works for diverting the waters of the San Juan River, or any of its tributaries, into the Rio Grande, Colorado hereby consents to the construction of said works and the diversion of waters from the San Juan River, or the tributaries thereof, into the Rio Grande in New Mexico, provided the present and prospective uses of water in Colorado by other diversions from the San Juan River, or its tributaries, are protected.

ARTICLE X

In the event water from another drainage basin shall be imported into the Rio Grande Basin by the United States or Colorado or New Mexico, or any of them jointly, the State having the right to the use of such water shall be given proper credit therefor in the application of the schedules.

ARTICLE XI

New Mexico and Texas agree that upon the effective date of this Compact all controversies between said States relative to the quantity or quality of the water of the Rio Grande are composed and settled; however, nothing herein shall be interpreted to prevent

recourse by a signatory state to the Supreme Court of the United States for redress should the character or quality of the water, at the point of delivery, be changed hereafter by one signatory state to the injury of another. Nothing herein shall be construed as an admission by any signatory state that the use of water for irrigation causes increase of salinity for which the user is responsible in law.

ARTICLE XII

To administer the provisions of this Compact there shall be constituted a Commission composed of one representative from each state, to be known as the Rio Grande Compact Commission. The State Engineer of Colorado shall be ex-officio the Rio Grande Compact Commissioner for Colorado. The State Engineer of New Mexico shall be ex-officio the Rio Grande Compact Commissioner for New Mexico. The Rio Grande Compact Commissioner for Texas shall be appointed by the Governor of Texas. The President of the United States shall be requested to designate a representative of the United States to sit with such Commission, and such representative of the United States, if so designated by the President, shall act as Chairman of the Commission without vote.

The salaries and personal expenses of the Rio Grande Compact Commissioners for the three States shall be paid by their respective States, and all other expenses incident to the administration of this Compact, not borne by the United States, shall be borne equally by the three States.

In addition to the powers and duties hereinbefore specifically conferred upon such Commission, and the members thereof, the jurisdiction of such Commission shall extend only to the collection, correlation and presentation of factual data and the maintenance of records having a bearing upon the administration of this Compact, and, by unanimous action, to the making of recommendations to the respective States upon matters connected with the administration of this Compact. In connection therewith, the Commission may employ such engineering and clerical aid as may be reasonably necessary within the limit of funds provided for that purpose by the respective States. Annual reports compiled for each calendar year shall be made by the Commission and transmitted to the Governors of the signatory States on or before March first following the year covered by the report. The Commission may, by unanimous action, adopt rules and regulations consistent with the provisions of this Compact to govern their proceedings.

The findings of the Commission shall not be conclusive in any court or tribunal which may be called upon to interpret or enforce this Compact.

ARTICLE XIII

At the expiration of every five-year period after the effective date of this Compact, the Commission may, by unanimous consent, review any provisions hereof which are not substantive in character and which do not affect the basic principles upon which the Compact is founded, and shall meet for the consideration of such questions on the request of any member of the Commission; provided, however, that the provisions hereof shall remain in full force and effect until changed and amended within the intent of the Compact by unanimous action of the Commissioners, and until any changes in this Compact are ratified by the legislatures of the respective states and consented to by the Congress, in the same manner as this Compact is required to be ratified to become effective.

ARTICLE XIV

The schedules herein contained and the quantities of water herein allocated shall never be increased nor diminished by reason of any increase or diminution in the delivery or loss of water to Mexico.

DISCHARGE OF RIO GRANDE AT OTOWI BRIDGE AND ELEPHANT BUTTE EFFECTIVE SUPPLY

Quantities in thousands of acre-feet

Otowi Index Supply (5)	Elephant Butte Effective Index Supply (6)
100	57
200	114
300	171
400	228
500	286
600	345
700	406
800	471
900	542
1,000	621
1,100	707
1,200	800
1,300	897
1,400	996
1,500	1,095
1,600	1,195
1,700	1,295
1,800	1,395
1,900	1,495
2,000	1,595
2,100	1,695
2,200	1,795
2,300	1,895
2,400	1,995
2,500	2,095
2,600	2,195
2,700	2,295
2,800	2,395
2,900	2,495
3,000	2,595

Intermediate quantities shall be computed by proportional parts.

(5) The Otowi Index Supply is the recorded flow of the Rio Grande at the U.S.G.S. gaging station at Otowi Bridge near San Ildefonso (formerly station near Buckman) during the calendar year, corrected for the operation of reservoirs constructed after 1929 in the drainage basin of the Rio Grande between Lobatos and Otowi Bridge.

(6) Elephant Butte Effective Index Supply is the recorded flow of the Rio Grande at the gaging station below Elephant Butte Dam during the calendar year plus the net gain in storage in Elephant Butte Reservoir during the same year or minus the net loss in storage in said reservoir, as the case may be.

The application of this schedule shall be subject to the provisions hereinafter set forth and appropriate adjustments shall be made for (a) any change in location of gaging stations; (b) depletion after 1929 in New Mexico of the natural runoff at Otowi Bridge; and (c) any transmountain diversions into the Rio Grande between Lobatos and Elephant Butte Reservoir."

Be it Further Resolved:

That the gaging stations at San Acacia and San Marcial be, and the same are hereby abandoned for Compact purposes.

Be it Further Resolved:

That this Resolution has been passed unanimously and shall be effective January 1, 1949, if within 120 days from this date the Commissioner for each State shall have received from the Attorney General of the State represented by him, an opinion approving this Resolution, and shall have so advised the Chairman of the Commission, otherwise, to be of no force and effect.

(Note: The following paragraph appears in the Minutes of the Annual Meeting of the Commission held at Denver, Colorado, February 14-16, 1949.

"The Chairman announced that he had received, pursuant to the Resolution adopted by the Commission at the Ninth Annual Meeting on February 24, 1948, opinions from the Attorneys General of Colorado, New Mexico and Texas that the substitution of stations and measurements of deliveries by New Mexico set forth in said resolution was within the powers of the Commission").

ARTICLE XV

The physical and other conditions characteristic of the Rio Grande and peculiar to the territory drained and served thereby, and to the development thereof, have actuated this Compact and none of the signatory states admits that any provisions herein contained establishes any general principle or precedent applicable to other interstate streams.

ARTICLE XVI

Nothing in this Compact shall be construed as affecting the obligations of the United States of America to Mexico under existing treaties, or to the Indian Tribes, or as impairing the rights of the Indian Tribes.

ARTICLE XVII

This Compact shall become effective when ratified by the legislatures of each of the signatory states and consented to by the Congress of the United States. Notice of ratification shall be given by the Governor of each state to the Governors of the other states and to the President of the United States, and the President of the United States is requested to give notice to the Governors of each of the signatory states of the consent of the Congress of the United States.

IN WITNESS WHEREOF, the Commissioners have signed this Compact in quadruplicate original, one of which shall be deposited in the archives of the Department of State of the United States of America and shall be deemed the authoritative original, and of which a duly certified copy shall be forwarded to the Governor of each of the signatory States.

Done at the City of Santa Fe, in the State of New Mexico, on the 18th day of March, in the year of our Lord, One Thousand Nine Hundred and Thirty-eight.

(Sgd.) M. C. HINDERLIDER
(Sgd.) THOMAS M. McCLURE
(Sgd.) FRANK B. CLAYTON

APPROVED:

(Sgd.) S. O. HARPER

RATIFIED BY:

Colorado, February 21, 1939
New Mexico, March 1, 1939
Texas, March 1, 1939

Passed Congress as Public Act No. 96, 76th Congress,

Approved by the President May 31, 1939

RESOLUTION ADOPTED BY RIO GRANDE COMPACT COMMISSION AT THE ANNUAL MEETING HELD AT EL PASO, TEXAS, FEBRUARY 22-24, 19 CHANGING GAGING STATIONS AND MEASUREMENTS OF DELIVERIES BY NEW MEXICO

RESOLUTION

Whereas, at the Annual Meeting of the Rio Grande Compact Commission year 1945, the question was raised as to whether or not a schedule for delivery of wa New Mexico during the entire year could be worked out, and

Whereas, at said meeting the question was referred to the Engineering Ac for their study, recommendations and report, and

Whereas, said Engineering Advisers have met, studied the problems and date of February 24, 1947, did submit their Report, which said Report contains the fi of said Engineering Advisers and their recommendations, and

Whereas, the Compact Commission has examined said Report and finds th matters and things therein found and recommended are proper and within the terms Rio Grande Compact, and

Whereas, the Commission has considered said Engineering Advisers' Repo all available evidence, information and material and is fully advised:

Now, Therefore, Be it Resolved:

The Commission finds as follows:

(a) That because of change of physical conditions, reliable records of the ar of water passing San Marcial are no longer obtainable at the stream g station at San Marcial and that the same should be abandoned for Co purposes.

(b) That the need for concurrent records at San Marcial and San Acacia no l exists and that the gaging station at San Acacia should be abandon Compact purposes.

(c) That it is desirable and necessary that the obligations of New Mexico und Compact to deliver water in the months of July, August, September, shou scheduled.

(d) That the change in gaging stations and substitution of the new measure as hereinafter set forth will result in substantially the same results so far rights and obligations to deliver water are concerned, and would have exi such substitution of stations and measurements had not been so made.

Be it Further Resolved:

That the following measurements and schedule thereof shall be substitut the measurements and schedule thereof as now set forth in Article IV Compact:

"The obligation of New Mexico to deliver water in the Rio Grande into Ele Butte Reservoir during each calendar year shall be measured by that qu set forth in the following tabulation of relationship which corresponds quantity at the upper index station:

RULES AND REGULATIONS FOR ADMINISTRATION OF THE RIO GRANDE COMPACT

A Compact, known as the Rio Grande Compact, between the States of Colorado, New Mexico and Texas, having become effective on May 31, 1939 by consent of the Congress of the United States, which equitably apportions the waters of the Rio Grande above Fort Quitman and permits each State to develop its water resources at will, subject only to its obligations to deliver water in accordance with the schedules set forth in the Compact, the following Rules and Regulations have been adopted for its administration by the Rio Grande Compact Commission; to be and remain in force and effect only so long as the same may be satisfactory to each and all members of the Commission, and provided always that on the objection of any member of the Commission, in writing, to the remaining two members of the Commission after a period of sixty days from the date of such objection, the sentence, paragraph or any portion or all of these rules to which any such objection shall be made, shall stand abrogated and shall thereafter have no further force and effect; it being the intent and purpose of the Commission to permit these rules to obtain and be effective only so long as the same may be satisfactory to each and all of the Commissioners.

GAGING STATIONS /1

Responsibility for the equipping, maintenance and operation of the stream gaging stations and reservoir gaging stations required by the provisions of Article II of the Compact shall be divided among the signatory States as follows:

(a) Gaging stations on streams and reservoirs in the Rio Grande Basin above the Colorado-New Mexico boundary shall be equipped, maintained, and operated by Colorado in cooperation with the U.S. Geological Survey.

(b) Gaging stations on streams and reservoirs in the Rio Grande Basin below Lobatos and above Caballo Reservoir shall be equipped, maintained and operated by New Mexico in cooperation with the U.S. Geological Survey to the extent that such stations are not maintained and operated by some other Federal agency.

(c) Gaging stations on Elephant Butte Reservoir and on Caballo Reservoir, and the stream gaging stations on the Rio Grande below those reservoirs shall be equipped, maintained and operated by or on behalf of Texas through the agency of the U.S. Bureau of Reclamation.

The equipment, method and frequency of measurements at each gaging station shall be sufficient to obtain records at least equal in accuracy to those classified as "good" by the U.S. Geological Survey. Water-stage recorders on the reservoirs specifically named in Article II of the Compact shall have sufficient range below maximum reservoir level to record major fluctuations in storage. Staff gages may be used to determine fluctuations below the range of the water-stage recorders on these and other large reservoirs, and staff gages may be used upon approval of the Commission in lieu of water-stage recorders on small reservoirs, provided that the frequency of observation is sufficient in each case to establish any material changes in water levels in such reservoirs.

/1 Amended at Eleventh Annual Meeting, February 23, 1950.

RESERVOIR CAPACITIES /1

Colorado shall file with the Commission a table of areas and capacities for each reservoir in the Rio Grande Basin above Lobatos constructed after 1937; New Mexico shall file with the Commission a table of areas and capacities for each reservoir in the Rio Grande Basin between Lobatos and San Marcial constructed after 1929; and Texas shall file with the Commission tables of areas and capacities for Elephant Butte Reservoir and for all other reservoirs actually available for the storage of water between Elephant Butte and the first diversion to lands under the Rio Grande Project.

Whenever it shall appear that any table of areas and capacities is in error by more than five per cent, the Commission shall use its best efforts to have a re-survey made and a corrected table of areas and capacities to be substituted as soon as practicable. To the end that the Elephant Butte effective supply may be computed accurately, the Commission shall use its best efforts to have the rate of accumulation and the place of deposition of silt in Elephant Butte Reservoir checked at least every three years.

ACTUAL SPILL /2, /3, /4

(a) Water released from Elephant Butte in excess of Project requirements, which is currently passed through Caballo Reservoir, prior to the time of spill, shall be deemed to have been Usable Water released in anticipation of spill, or Credit Water if such release shall have been authorized.

(b) Excess releases from Elephant Butte Reservoir, as defined in (a) above, shall be added to the quantity of water in storage in that reservoir, and Actual Spill shall be deemed to have commenced when this sum equals the total capacity of that reservoir to the level of the uncontrolled spillway less capacity reserved for flood control purposes, i.e., 1,998,400 acre-feet in the months of October through March, inclusive, and 1,973,400 acre-feet in the months of April through September, inclusive, as determined from the 1999 area-capacity table or successor area-capacity tables and flood control storage reservation of 50,000 acre-feet from April through September and 25,000 acre-feet from October through March.

(c) All water actually spilled at Elephant Butte Reservoir, or released therefrom, in excess of Project requirements, which is currently passed through Caballo Reservoir, after the time of spill, shall be considered as Actual Spill, provided that the total quantity of water then in storage in Elephant Butte Reservoir exceeds the physical capacity of that reservoir at the level of the sill of the spillway gates, i.e. -1,830,000 acre-ft in 1942.

(d) Water released from Caballo Reservoir in excess of Project requirements and in excess of water currently released from Elephant Butte Reservoir, shall be deemed Usable Water released, excepting only flood water entering Caballo Reservoir from tributaries below Elephant Butte Reservoir.

DEPARTURES FROM NORMAL RELEASES /5

For the purpose of computing the time of Hypothetical Spill required by Article VI and for the purpose of the adjustment set forth in Article VII, no allowance shall be made for the difference between Actual and Hypothetical Evaporation, and any under-release of usable water from Project Storage in excess of 150,000 acre-ft in any year shall be taken as equal to that amount.

/1 Amended at Eleventh Annual Meeting, February 23, 1950.

/2 Adopted at Fourth Annual Meeting, February 24, 1943.

/3 Amended September 9, 1998.

/4 Amended March 22, 2001; made effective January 1, 2001.

/5 Adopted June 2, 1959; made effective January 1, 1952.

EVAPORATION LOSSES /6, /7, /8

The Commission shall encourage the equipping, maintenance and operation, in cooperation with the U.S. Weather Bureau or other appropriate agency, of evaporation stations at Elephant Butte Reservoir and at or near each major reservoir in the Rio Grande Basin within Colorado constructed after 1937 and in New Mexico constructed after 1929. The net loss by evaporation from a reservoir surface shall be taken as the difference between the actual evaporation loss and the evapo-transpiration losses which would have occurred naturally, prior to the construction of such reservoir. Changes in evapo-transpiration losses along stream channels below reservoirs may be disregarded.

Net losses by evaporation, as defined above, shall be used in correcting Index Supplies for the operation of reservoirs upstream from Index Gaging Stations as required by the provisions of Article III and Article IV of the Compact.

In the application of the provisions of the last unnumbered paragraph of Article VI of the Compact:

(a) Evaporation losses for which accrued credits shall be reduced shall be taken as the difference between the gross evaporation from the water surface of Elephant Butte Reservoir and rainfall on the same surface.

(b) Evaporation losses for which accrued debits shall be reduced shall be taken as the net loss by evaporation as defined in the first paragraph.

ADJUSTMENT OF RECORDS

The Commission shall keep a record of the location, and description of each gaging station and evaporation station, and, in the event of change in location of any stream gaging station for any reason, it shall ascertain the increment in flow or decrease in flow between such locations for all stages. Wherever practicable, concurrent records shall be obtained for one year before abandonment of the previous station.

NEW OR INCREASED DEPLETIONS

In the event any works are constructed which alter or may be expected to alter the flow at any of the Index Gaging Stations mentioned in the Compact, or which may otherwise necessitate adjustments in the application of the schedules set forth in the Compact, it shall be the duty of the Commissioner specifically concerned to file with the Commission all available information pertaining thereto, and appropriate adjustments shall be made in accordance with the terms of the Compact; provided, however, that any such adjustments shall in no way increase the burden imposed upon Colorado or New Mexico under the schedules of deliveries established by the Compact.

TRANSMOUNTAIN DIVERSIONS

In the event any works are constructed for the delivery of waters into the drainage basin of the Rio Grande from any stream system outside of the Rio Grande Basin, such waters shall be measured at the point of delivery into the Rio Grande Basin and proper allowances shall be made for losses in transit from such points to the Index Gaging Station on the stream with which the imported waters are commingled.

/6 Amended at Tenth Annual Meeting, February 15, 1949.

/7 Amended at Twelfth Annual Meeting, February 24, 1951.

/8 Amended June 2, 1959.

QUALITY OF WATER

In the event that delivery of water is made from the Closed Basin into the Rio Grande, sufficient samples of such water shall be analyzed to ascertain whether the quality thereof is within the limits established by the Compact.

SECRETARY /9

The Commission, subject to the approval of the Director, U.S. Geological Survey, to a cooperative agreement for such purposes, shall employ the U.S. Geological Survey on a yearly basis, to render such engineering and clerical aid as may reasonably be necessary for administration of the Compact. Said agreement shall provide that the Geological Survey shall:

(1) Collect and correlate all factual data and other records having a material bearing on the administration of the Compact and keep each Commissioner adviser thereof.

(2) Inspect all gaging stations required for administration of the Compact and make recommendations to the Commission as to any changes or improvements in methods of measurement or facilities for measurement which may be needed to insure that reliable records be obtained.

(3) Report to each Commissioner by letter on or before the fifteenth day of each month, except January, a summary of all hydrographic data then available for the current year - on forms prescribed by the Commission - pertaining to:

(a) Deliveries by Colorado
(b) Deliveries by New Mexico
(c) Operation of Project Storage

(4) Make such investigations as may be requested by the Commission in aid of its administration of the Compact.

(5) Act as Secretary to the Commission and submit to the Commission at its regular meeting in February a report on its activities and a summary of all data needed for determination of debits and credits and other matters pertaining to administration of the Compact.

COSTS /1

In February of each year, the Commission shall adopt a budget for the ensuing fiscal year beginning July first.

Such budget shall set forth the total cost of maintenance and operating of gaging stations, of evaporation stations, the cost of engineering and clerical aid, and all other necessary expenses excepting the salaries and personal expenses of the Rio Grande Compact Commissioners.

Contributions made directly by the United States and the cost of services rendered by the United States without cost shall be deducted from the total budget amount; the remainder shall then be allocated equally to Colorado, New Mexico and Texas.

/9 The substitution of this section for the section titled "Reports to Commissioners" was adopted at Ninth Annual Meeting, February 22, 1948.

/1 Amended at Eleventh Annual Meeting, February 23, 1950.

Expenditures made directly by any State for purposes set forth in the budget shall be credited to that State; contributions in cash or in services by any State under a cooperative agreement with any federal agency shall be credited to such State, but the amount of the federal contribution shall not so be credited; in event any State, through contractual relationships, causes work to be done in the interest of the Commission, such State shall be credited with the cost thereof, unless such cost is borne by the United States.

Costs incurred by the Commission under any cooperative agreement between the Commission and any U.S. Government Agency, not borne by the United States, shall be apportioned equally to each State, and each Commissioner shall arrange for the prompt payment of one-third thereof by his State.

The Commissioner of each State shall report at the annual meeting each year the amount of money expended during the year by the State which he represents, as well as the portion thereof contributed by all cooperating federal agencies, and the Commission shall arrange for such proper reimbursement in cash or credits between States as may be necessary to equalize the contributions made by each State in the equipment, maintenance and operation of all gaging stations authorized by the Commission and established under the terms of the Compact.

It shall be the duty of each Commissioner to endeavor to secure from the Legislature of his State an appropriation of sufficient funds with which to meet the obligations of his State, as provided by the Compact.

MEETING OF COMMISSION /1, /10

The Commission shall meet in Santa Fe, New Mexico, on the third Thursday of February of each year for the consideration and adoption of the annual report for the calendar year preceding, and for the transaction of any other business consistent with its authority; provided that the Commission may agree to meet elsewhere. Other meetings as may be deemed necessary shall be held at any time and place set by mutual agreement, for the consideration of data collected and for the transaction of any business consistent with its authority.

No action of the Commission shall be effective until approved by the Commissioner from each of the three signatory States.

(Signed) M. C. HINDERLIDER

M. C. Hinderlider

Commissioner for Colorado

(Signed) THOMAS M. McCLURE

Thomas M. McClure

Commissioner for New Mexico

(Signed) JULIAN P. HARRISON

Julian P. Harrison

Commissioner for Texas

Adopted December 19, 1939.

/1 Amended at Eleventh Annual Meeting, February 23, 1950.

/10 Amended at Thirteenth Annual Meeting, February 25, 1952.

RECORDS OF DELIVERIES AND RELEASES

At the annual meeting of the Compact Commission on March 22, 2001, the records of deliveries and releases and computations of debits and credits for calendar year 2000 were reported. The records and computations as approved by the Commission are reproduced on the next three pages.

The delivery of water in the Rio Grande at the Colorado-New Mexico State line was obtained from the record of streamflow near Lobatos, Colorado; the scheduled delivery was computed as prescribed in Article III.

The delivery of water by New Mexico to Elephant Butte was computed from the record of streamflow below Elephant Butte Dam and the record of operation of Elephant Butte Reservoir; the scheduled delivery was computed as prescribed in the Resolution of the Commission adopted at the Ninth Annual Meeting held February 22-24, 1948, and published in this report.

The actual release from Project Storage during the year was measured at gaging stations below Caballo Dam. During 2001 the Commissioners found that the actual release of usable water was 788,000 acre-feet. This resulted in an accrued credit of 77,900 acre-feet as of January 1, 2002.

RIO GRANDE COMPACT - DELIVERIES BY COLORADO AT STATE LINE
YEAR 2001

Quantities in thousands of acre feet to nearest hundred

MONTH	CONEJOS INDEX SUPPLY: MEASURED FLOW: CONEJOS AT MOGOTE	LOS PINOS NEAR ORTIZ	SAN ANTONIO AT ORTIZ	TOTAL	ADJUSTMENTS: STORAGE AT END OF MONTH	CHANGE IN STORAGE	OTHER ADJUSTMENTS	NET ADJUSTMENTS	SUPPLY: SUPPLY IN MONTH	ACCUMULATED TOTAL	RIO GRANDE INDEX SUPPLY: RECORDED FLOW NEAR DEL NORTE	ADJUSTMENTS: STORAGE AT END OF MONTH	CHANGE IN STORAGE	TRANSMOUNTAIN DIVERSIONS	OTHER ADJUSTMENTS	NET ADJUSTMENTS	SUPPLY: SUPPLY IN MONTH	ACCUMULATED TOTAL	DELIVERIES: CONEJOS RIVER AT MOUTHS NEAR LOS SAUCES	RIO GRANDE LESS CONEJOS RIVER	RIO GRANDE AT LOBATOS	ACCUMULATED TOTAL AT LOBATOS
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	—	—	—	—	13.8	—	—	—	—	0.0	—	0.2	—	—	—	—	—	0.0	—	—	—	0.0
JAN	2.5	—	—	2.5	13.8	0.0		0.0	2.5	2.5	8.6	0.2	0.0			0.0	8.6	8.6	2.1	9.8	11.9	11.9
FEB	2.4	—	—	2.4	14.0	0.2		0.2	2.6	5.1	8.1	0.2	0.0			0.0	8.1	16.7	3.3	11.7	15.0	26.9
MAR	4.3	—	—	4.3	14.2	0.2		0.2	4.5	9.6	16.6	0.2	0.0			0.0	16.6	33.3	7.0	19.5	26.5	53.4
APR	15.4	10.9	4.6	30.9	14.6	0.4		0.4	31.3	40.9	52.0	0.2	0.0			0.0	52.0	85.3	7.0	12.8	19.8	73.2
MAY	78.6	40.8	5.1	124.5	27.0	12.4	0.1[a]	12.5	137.0	177.9	261.6	0.2	0.0			0.0	261.6	346.9	33.9	48.9	82.8	156.0
JUN	53.9	9.9	0.1	63.9	28.1	1.1	0.2[a]	1.3	65.2	243.1	206.5	0.2	0.0			0.0	206.5	553.4	15.7	60.2	75.9	231.9
JUL	18.4	1.8	0.0	21.2	22.0	-6.1	0.1[a]	-6.0	15.2	258.3	70.6	0.2	0.0	-0.3[b]	0.3[a]	0.0	70.6	624.0	1.9	20.8	22.7	254.6
AUG	12.1	1.4	0.1	13.6	19.0	-3.0	0.0[a]	-3.0	10.8	268.9	44.4	0.2	0.0			0.0	44.4	668.4	0.0	6.0	6.0	260.6
SEPT	6.8	0.7	0.0	7.8	15.9	-3.1	0.1[a]	-3.0	4.6	273.5	20.2	0.2	0.0			0.0	20.2	688.6	0.0	3.1	3.1	263.7
OCT	4.6	0.8	0.1	5.5	14.1	-1.8	0.1[a]	-1.7	3.8	277.3	15.9	0.2	0.0			0.0	15.9	704.5	0.0	3.4	3.4	267.1
NOV	2.7	—	—	2.7	14.1	0.0	0.0[a]	0.0	2.7	280.0	11.2	0.2	0.0			0.0	11.2	715.7	0.8	7.9	8.7	275.8
DEC	2.4	—	—	2.4	14.1	0.0		0.0	2.4	282.4	9.7	0.2	0.0			0.0	9.7	725.4	2.0	12.5	14.5	290.3
YEAR	205.2	66.3	10.0	281.5	—	0.3	0.6	0.9	282.4	—	725.4	—	0.0	-0.3	0.3	0.0	725.4	—	73.7	216.6	290.3	—

Remarks: Cols. 6 and 13 do not include transmountain water.
[a] Evaporation loss post-compact reservoirs; report of the Engineer Adviser for Colorado.
[b] 517 ac-ft minus 243 ac-ft pre-compact; report of the Engineer Adviser for Colorado.

SUMMARY OF DEBITS AND CREDITS

	ITEM	DEBIT	CREDIT	BALANCE
C1	Balance at Beginning of Year	—	—	Cr 27.0
C2	Scheduled Delivery from Conejos River	97.0	—	Dr 70.0
C3	Scheduled Delivery from Rio Grande	216.7	—	Dr 286.7
C4	Actual Delivery at Lobatos plus 10,000 Acre Feet	—	300.3	Cr 13.6
C5	Reduction of Debits o/c Evaporation	—		
C6	Reduction of Credits o/c Evaporation and Spill	3.5	—	Cr 10.1
C7				
C8	Balance at End of Year	—	—	Cr 10.1

APPROVED:
Engineer Adviser for Colorado SEV Date 2/20/2002 Engineer Adviser for New Mexico [signature] Date: 2/20/2002 Engineer Adviser for Texas HCS Date: 2/2[illegible]

RIO GRANDE COMPACT - DELIVERIES BY NEW MEXICO AT ELEPHANT BUTTE
YEAR 2001

Quantities in thousands of acre feet to nearest hundred

TH	OTOWI INDEX SUPPLY: Recorded Flow at Otowi Bridge	ADJUSTMENTS: RESERVOIRS LOBATOS TO OTOWI: Storage End of Month [a]	Change in Storage	Reservoir Evaporation	Other Adjustments	Trans-mountain Diversions	Net Adjustments	INDEX SUPPLY: During Month	Accumulated Total	Total Water Stored in New Mexico Above San Marcial at End of Month [a]	ELEPHANT BUTTE EFFECTIVE SUPPLY: STORAGE IN ELEPHANT BUTTE RESERVOIR: End of Month [a]	Change Gain (+) Loss (-)	Recorded Flow Below Elephant Butte Dam	Effective Supply: During Month	Accumulated Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	....	10.9	—	—	—	....	—	—	—	11.9	[c]1,256.5	—	—	—	—
N	33.4	10.9	0.0	0.0		0.1	0.1	33.5	33.5	11.2	1,295.4	38.9	4.3	43.2	43.2
B	34.3	11.7	0.8	0.0		0.1	0.9	35.2	68.7	10.6	1,240.3	-55.1	98.9	43.8	87.0
R	51.0	23.8	12.1	0.0		0.3	12.4	63.4	132.1	23.0	1,188.9	-51.4	96.5	45.1	132.1
R	67.2	77.1	53.3	0.3		0.4	54.0	121.2	253.3	84.0	1,131.6	-57.3	97.4	40.1	172.2
Y	169.0	196.6	119.5	1.2		-1.3	119.4	288.4	541.7	205.7	1,101.5	-30.1	106.0	75.9	248.1
N	116.5	203.8	7.2	2.3		-1.8	7.7	124.2	665.9	212.7	1,037.5	-64.0	107.5	43.5	291.6
L	76.2	185.0	-18.8	1.3		-11.5	-29.0	47.2	713.1	182.0	936.0	-101.5	113.1	11.6	303.2
G	50.1	159.0	-26.0	1.0		-6.8	-31.8	28.3	741.4	163.8	867.4	-68.6	91.9	23.3	326.5
T	62.6	112.3	-46.7	1.0		-2.0	-47.7	14.9	756.3	115.5	843.9	-23.5	40.3	16.8	343.3
T	42.7	89.6	-22.7	0.7		-3.5	-25.5	17.2	773.5	89.1	839.7	-4.2	15.3	11.1	354.4
V	27.0	89.7	0.1	0.3		-1.1	-0.7	26.3	799.8	89.1	864.8	25.1	0.4	25.5	379.9
C	35.3	90.1	0.4	0.2		-2.0	-1.4	33.9	833.7	88.8	888.1	23.3	13.2	36.5	416.4
R	775.3	—	79.2	8.3		-29.1	58.4	833.7	—	—	—	-368.4	784.8	416.4	—

[a] Storage in recreational reservoirs not included
Cols. 3 and 11 reflect implementation of revised area-capacity tables for Abiquiu, Cochiti, and Jemez Canyon Reservoirs, effective January 1, 1999.

3, 11, and 12 do not include transmountain water.

year beginning value adjusted to reflect the April 1999 Elephant Butte Reservoir area-capacity table made ive January 1, 2001. Previous value was 1,274.2

Mexico's credit at beginning of year reduced by 1.6 to reflect retroactive application of revised sediment ulation equations to 1999 and 2000 accounting for Abiquiu, Cochiti, and Jemez Canyon reservoirs and reduced by 0.4 to reflect correction of Elephant Butte evaporation data errors in 1997

SUMMARY OF DEBITS AND CREDITS

	ITEM	DEBIT	CREDIT	BALANCE
NM1	Balance at Beginning of Year	—	—	[c]Cr 269.1
NM2	Scheduled Delivery at Elephant Butte	494.9	—	Dr 225.8
NM3	Actual Elephant Butte Effective Supply	—	416.4	Cr 190.6
NM4	Reduction of Debits o/c Evaporation	—		
NM5	Reduction of Credits o/c Evaporation and Spill	34.9	—	Cr 155.7
NM6			—	
NM7				
NM8	Balance at End of Year	—	—	Cr 155.7

ED
Adviser for Colorado SEV Date 2/20/2002 Engineer Adviser for New Mexico [signature] Date 2/20/2002 Engineer Adviser for Texas HCS Date: 2/2[illegible]

RIO GRANDE COMPACT - RELEASE AND SPILL FROM PROJECT STORAGE
YEAR 2001

Quantities in thousands of acre feet to nearest hundred

MONTH	[a]Total Project Storage Capacity Available at End of Month	USABLE WATER IN STORAGE: Elephant Butte Reservoir	USABLE WATER IN STORAGE: Caballo Reservoir	USABLE WATER IN STORAGE: Total at End of Month	Unfilled Capacity of Project Storage at End of Month	CREDIT WATER IN STORAGE: Colorado Credit Water	CREDIT WATER IN STORAGE: New Mexico Credit Water	CREDIT WATER IN STORAGE: Total at End of Month	Flood Water in Storage in Caballo Reservoir at End of Month	Total Water in Project Storage at End of Month	RIO GRANDE BELOW CABALLO DAM: Measured Flow at Caballo Gaging Station	Intervening Diversions to Canals	Total Release and Spill	SPILL FROM STORAGE: Caballo Flood Water	SPILL FROM STORAGE: Credit Water	SPILL FROM STORAGE: Usable Water	USABLE RELEASE: Net During Month	USABLE RELEASE: Accumulated Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	2,131.8	[b]960.4	38.4	[b]998.8	1,133.0	[b]27.0	[b]269.1	[b]296.1		1,294.9	—	—	—	—	—	—	—	0.0
JAN	2,131.8	999.6	42.5	1,047.1	1,089.7	27.0	268.8	295.8		1,337.9	0.2	0.0	0.2				0.2	0.2
FEB	2,131.8	948.0	106.4	1,054.4	1,077.4	26.8	267.5	294.3		1,348.7	23.8	0.0	23.8				23.8	24.0
MAR	2,131.8	897.2	93.0	990.2	1,141.6	26.6	265.1	291.7		1,281.9	106.7	0.1	106.6				106.6	130.8
APR	2,106.8	844.5	96.8	941.3	1,165.5	26.2	260.9	287.1		1,228.4	87.5	0.1	87.6				87.6	218.4
MAY	2,106.8	819.5	98.1	917.6	1,189.2	25.7	256.3	282.0		1,199.6	96.8	0.2	97.0				97.0	315.4
JUN	2,106.8	761.9	72.7	834.6	1,272.2	25.1	250.5	275.6		1,110.2	131.3	0.1	131.4				131.4	446.8
JUL	2,106.8	665.2	62.2	727.4	1,379.4	24.7	246.1	270.8		998.2	130.8	0.1	130.9				130.9	577.7
AUG	2,106.8	600.2	43.5	643.7	1,463.1	24.4	242.8	267.2		910.9	110.8	0.2	111.0				111.0	688.7
SEPT	2,106.8	579.9	12.3	592.2	1,514.6	24.1	239.9	264.0		856.2	73.0	0.2	73.2				73.2	761.9
OCT	2,131.8	578.9	7.6	586.5	1,545.3	23.8	237.0	260.8		847.3	25.6	0.0	25.6				25.6	787.5
NOV	2,131.8	605.9	10.4	616.3	1,515.5	23.6	235.3	258.9		875.2	0.3	0.0	0.3				0.3	787.8
DEC	2,131.8	630.4	25.5	655.9	1,475.9	23.5	234.2	257.7		913.6	0.1	0.1	0.2				0.2	788.0
YEAR	—	—	—	—	—	—	—	—	—	—	788.9	1.1	788.0	0.0	0.0	0.0	788.0	—

[a] Temporary Project Storage Capacity for calendar year 2001 is 2,106,786 acre-feet (April to September) and 2,131,786 acre-feet (October to March) due to repair work on Caballo Dam. Project Storage Capacity after completion of repair will be 2,209,030 acre-feet (April to September) and 2,225,030 acre-feet (October to March) as recognized by the September 9, 1988 Resolution of the Rio Grande Compact Commission with flood control storage reservation at Elephant Butte Reservoir of 50,000 acre-feet from April through September and 25,000 acre-feet from October through March.

[b] Based on Balance at Beginning of Year (C1 and NM1) and implementation of area-capacity curves for Elephant Butte Reservoir (see footnote "c" on Deliveries by New Mexico at Elephant Butte accounting sheet).

ACCRUED DEPARTURE FROM NORMAL RELEASE

	ITEM	DEBIT	CREDIT	BALANCE
P1	Accrued Departure at Beginning of Year	—	—	Cr 75.9
P2	Actual Release during Year	788.0	—	Dr 712.1
P3	Normal Release for Year	—	790.0	Cr 77.9
P4			—	
P5		—		
P6				
P7	Accrued Departure at End of Year	—	—	Cr 77.9

TIME OF HYPOTHETICAL SPILL Did not occur

APPROVED.
Engineer Adviser for Colorado SEU Date 2/20/2002 Engineer Adviser for New Mexico [signature] Date: 2/20/2002 Engineer Adviser for Texas [signature] Date: 2/21/2002

BUDGET FOR FISCAL YEAR ENDING JUNE 30, 2001

Item	Total Cost	Borne by United States	Borne by Colorado	Borne by New Mexico	Borne by Texas
GAGING STATIONS					
In Colorado	$55,150	$6,450	$48,700		
In New Mexico, above Caballo Reservoir	$64,310	$39,195		$25,115	
In New Mexico, Caballo Reservoir and below	$21,329	$5,316		$1,750	$14,263
Subtotal	$140,789	$50,961	$48,700	$26,865	$14,263
ADMINISTRATION					
U.S.G.S. Contract	$25,912	$6,478	$6,478	$6,478	$6,478
Other expenses	$2,595		$865	$865	$865
Subtotal	$28,507	$6,478	$7,343	$7,343	$7,343
GRAND TOTAL	$169,296	$57,439	$56,043	$34,208	$21,606
EQUAL SHARES			$37,286	$37,286	$37,286

BUDGET FOR FISCAL YEAR ENDING JUNE 30, 2003

Item	Total Cost	Borne by United States	Borne by Colorado	Borne by New Mexico	Borne by Texas
GAGING STATIONS					
In Colorado	$58,888	$6,780	$52,108		
In New Mexico, above Caballo Reservoir	$69,170	$42,015		$27,155	
In New Mexico, Caballo Reservoir and below	$24,780	$7,390		$1,890	$15,500
Subtotal	$152,838	$56,185	$52,108	$29,045	$15,500
ADMINISTRATION					
U.S.G.S. Contract	$28,028	$7,007	$7,007	$7,007	$7,007
Other expenses	$2,808		$936	$936	$936
Subtotal	$30,836	$7,007	$7,943	$7,943	$7,943
GRAND TOTAL	$183,674	$63,192	$60,051	$36,988	$23,443
EQUAL SHARES			$40,161	$40,161	$40,161

ACKNOWLEDGMENTS

This report was prepared by the U.S. Geological Survey, secretary to the Rio Grande Compact Commission. The water-supply data contained in this report have been provided by various Federal and State agencies.

The Office of the State Engineer of Colorado provided records of discharge for the following:

Rio Grande near Del Norte, Colo.
Conejos River below Platoro Reservoir, Colo.
Conejos River near Mogote, Colo.
San Antonio River at Ortiz, Colo.
Los Pinos River near Ortiz, Colo.
Conejos River near Lasauses, Colo.
Rio Grande near Lobatos, Colo.

Records of six transmountain diversions and of storage in Platoro, Squaw, and Shaw Lakes, Rito Hondo, Hermit Lakes Reservoir No. 3, Troutvale No. 2, Jumper Creek, Alberta Park, Big Meadows, Mill Creek, Fuchs, and Trujillo Meadows Reservoirs were also provided by the Office of the State Engineer of Colorado.

The U.S. Bureau of Reclamation, Albuquerque, N. Mex., provided the following records:
Azotea tunnel at outlet, near Chama, N. Mex.
Willow Creek above Heron Res., near Los Ojos, N. Mex.
Horse Lake Creek above Heron Res., near Los Ojos, N. Mex.
Storage in Heron Reservoir near Los Ojos, N. Mex.
Willow Creek below Heron Dam, N. Mex.
Storage in El Vado Reservoir near Tierra Amarilla, N. Mex.
The U.S. Geological Survey, in cooperation with
the U.S. Bureau of Reclamation, Albuquerque, N. Mex.,
provided the following records:
Storage in Nambe Falls Reservoir near Nambe, N. Mex.
Rio Nambe below Nambe Falls Dam, near Nambe, N. Mex.

The U.S. Geological Survey supplied the record for Rio Grande below Elephant Butte Dam and, in cooperation with the New Mexico Interstate Stream Commission, also provided the following:
Rio Chama below El Vado Dam, N. Mex.
Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex.
Storage in McClure Reservoir near Santa Fe, N. Mex.
Santa Fe River near Santa Fe, N. Mex.
Storage in Nichols Reservoir near Santa Fe, N. Mex.

The U.S. Geological Survey, in cooperation with the Corps of Engineers, Albuquerque, N. Mex., also provided the following records:
Rio Chama below Abiquiu Dam, N. Mex.
Rio Grande below Cochiti Dam, N. Mex.
Galisteo Creek below Galisteo Dam, N. Mex.
Jemez River below Jemez Canyon Dam, N. Mex.

The Corps of Engineers, Albuquerque, N. Mex., provided the records of storage in Abiquiu, Galisteo, and Jemez Canyon Reservoirs and in Cochiti Lake.

The Laguna Agency, Bureau of Indian Affairs, Laguna, N. Mex., supplied the records of storage in Seama Reservoir.

The U.S. Bureau of Reclamation, El Paso, Texas, provided the following records:
Storage in Elephant Butte Reservoir at Elephant Butte, N. Mex.
Storage in Caballo Reservoir near Arrey, N. Mex.
Rio Grande below Caballo Dam, N. Mex.
Bonito Ditch below Caballo Dam, N. Mex.

The Rio Grande Compact Commission gratefully acknowledges the cooperation received from the agencies listed above.

ACCURACY OF RECORDS

The Rules and Regulations of the Commission state that the equipment, method, and frequency of measurement at each gaging station shall be sufficient to obtain records at least equal in accuracy to those classified as "good" by the U.S. Geological Survey. Within the physical limitations of stream gaging, the agencies obtaining the records at Compact gaging stations have complied with these regulations.

The accuracy of streamflow records depends primarily on (1) the stability of the stage-discharge relation or, if the control is unstable, the frequency of discharge measurements, and (2) the accuracy of observations of stage, measurements of discharge, and interpretation of records.

The station description states the degree of accuracy attributed to the records. "Excellent" means that about 95 percent of the daily discharges are within 5 percent of the true value; "good" within 10 percent; and "fair" within 15 percent. Records that do not meet the criteria mentioned are rated "poor." Different accuracies may be attributed to different parts of a given record. The probable error in a monthly or annual mean discharge depends more on the distribution of the daily errors between the limits than it does on the limits themselves. For this reason, monthly and annual records are more accurate than most daily records.

Rio Grande near Del Norte, Colo.

Location.--Water-stage recorder, lat 37°41'22", long 106°27'38", in NW1/4 sec. 29, T. 40 N., R. 5 E., on right bank 20 ft downstream from county highway bridge, 6 mi west of Del Norte, and 18 mi upstream from Pinos Creek. Datum of gage is 7,980.25 ft above mean sea level, datum of 1929. Prior to May 16, 1908, staff gage at site 4 mi downstream. Records are equivalent.
Drainage area.--1,320 sq mi, approximately.
Average discharge.--112 years (1890-2001), 904 ft³/s (654,900 acre-ft per year).
Extremes.--1889-2001: Maximum discharge, 18,000 ft³/s Oct. 5, 1911 (gage height, 6.80 ft), from rating curve extended above 12,900 ft³/s; minimum daily, 69 ft³/s Aug. 21, 1902.
Remarks.--Records good except those for winter months, which are fair. Flow regulated by four reservoirs, total capacity 126,100 acre-ft, and by several smaller ones. Six transmountain diversions import water into basin above station.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	4,350	160	120	140	8,630
February	4,100	170	120	146	8,130
March	8,384	531	160	270	16,630
April	26,245	2,560	356	875	52,060
May	131,880	5,910	1,650	4,254	261,600
June	104,090	5,600	2,330	3,470	206,500
July	35,575	2,410	519	1,148	70,560
August	22,380	995	473	722	44,390
September	10,172	494	285	339	20,180
October	8,026	291	218	259	15,920
November	5,636	286	132	188	11,180
December	4,870	180	140	157	9,660
Calendar year 2001	365,708	5,910	120	1,002	725,400

Conejos River below Platoro Reservoir, Colo.

Location.--Water-stage recorder and concrete control, lat 37°21'18", long 106°32'37", in NW1/4NW1/4 sec. 22, T. 36 N., R. 4 E., on left bank 1,100 ft downstream from valve house for Platoro Reservoir, and 0.7 mi northwest of Platoro. Datum of gage is 9,866.60 ft above mean sea level (levels by Bureau of Reclamation).
Drainage area.--40 sq mi, approximately.
Average discharge.--49 years (1890-2001), 93.2 ft³/s (67,520 acre-ft per year).
Extremes.--1952-2001: Maximum discharge, 1,160 ft³/s Nov. 1, 1957; maximum gage height, 4.29 ft June 15, 1958; no flow Oct. 16-20, 1955.
Remarks.--Records good except those for winter months, which are fair. No diversions above station. Flow completely regulated by Platoro Reservoir (capacity, 59,570 acre-ft).

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	222.1	7.3	7.0	7.13	439
February	209.1	7.6	7.3	7.47	415
March	241.8	8.0	7.6	7.80	480
April	1,226.9	181	8.0	40.9	2,430
May	7,351	531	46	237	14,580
June	10,328	577	126	344	20,490
July	5,380	283	45	174	10,670
August	3,608	196	43	116	7,160
September	2,025	118	40	67.5	4,020
October	1,242	69	15	40.1	2,460
November	254.9	22	7.0	8.50	506
December	217.0	7.0	7.0	7.00	430
Calendar year 2001	32,304.8	577	7.0	88.5	64,080

Conejos River near Mogote, Colo.

Location.--Water-stage recorder, lat 37°03'14", long 106°11'13", in SE1/4SE1/4 sec. 34, T. 33 N., R. 7 E., on right bank 25 ft upstream from bridge on State Highway 174, 0.4 mi downstream from Fox Creek, and 5.3 mi west of Mogote. Datum of gage is 8,271.54 ft above mean sea level.
Drainage area.--282 sq mi.
Average discharge.--91 years (1904, 1912-2001), 327 ft³/s (236,900 acre-ft per year).
Extremes.--1903-05, 1911-2001: Maximum discharge, 9,000 ft³/s Oct. 5, 1911 (gage height, 8.50 ft), from rating curve extended above 3,100 ft³/s; minimum daily determined, 10 ft³/s July 18, 1904.
Remarks.--Records good except those for winter months, which are fair. Diversions above station for irrigation of about 500 acres. Since 1951 flow partly regulated by Platoro Reservoir.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	1,265	43	39	40.8	2,510
February	1,206	47	39	43.1	2,390
March	2,158	129	40	69.6	4,280
April	7,770	765	94	259	15,410
May	39,626	1,820	457	1,278	78,600
June	27,171	1,560	459	906	53,890
July	9,778	544	122	315	19,390
August	6,073	339	135	196	12,050
September	3,495	194	80	116	6,930
October	2,326	103	60	75.0	4,610
November	1,345	85	26	44.8	2,670
December	1,222	43	36	39.4	2,420
Calendar year 2001	103,435	1,820	26	283	205,200

San Antonio River at Ortiz, Colo.

Location.--Water-stage recorder, lat 36°59'35", long 106°02'17", in New Mexico in NE1/4SE1/4, sec. 24, T. 32 N., R. 8 E., on left bank 800 ft south of New Mexico-Colorado State line, 0.4 mi southeast of Ortiz, and 0.4 mi upstream from Los Pinos River. Altitude of gage is 7,970 ft.
Drainage area.--110 sq mi.
Average discharge.--61 years (1941-2001), 25.6 ft³/s (18,550 acre-ft per year).
Extremes.--1920, 1925-2001: Maximum discharge, 1,750 ft³/s Apr. 15, 1937 (gage height, 5.38 ft), from rating curve extended above 1,100 ft³/s; no flow at times.
Remarks.--Records good except those for winter months, which are fair. A few small diversions above station for irrigation.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	77.8	3.1	2.2	2.51	154
February	98.9	4.9	2.7	3.53	196
March	1,420.1	190	4.9	45.8	2,820
April	2,284	240	15	76.1	4,530
May	2,539	254	12	81.9	5,040
June	66.74	10	.00	2.22	132
July	.00	.00	.00	.00	.00
August	55.64	22	.00	1.79	110
September	9.01	1.1	.00	.30	18
October	66.31	3.2	.69	2.14	132
November	74.9	4.0	1.5	2.50	149
December	64.4	2.6	1.8	2.08	128
Calendar year 2001	6,756.80	254	.00	18.5	13,400

Los Pinos River near Ortiz, Colo.

Location.--Water-stage recorder, lat 36°58'56", long 106°04'23", in New Mexico on line between secs. 26 and 27, T. 32 N., R. 8 E., on left bank 0.9 mi south of New Mexico-Colorado State line, 2.1 mi southwest of Ortiz, and 2.9 mi upstream from mouth. Altitude of gage is 8,040 ft.

Drainage area.--167 sq mi.

Average discharge.--83 years (1915-20, 1925-2001), 120 ft³/s (86,940 acre-ft per year).

Extremes.--1915-20, 1925-2001: Maximum discharge, 3,160 ft³/s May 12, 1941 (gage height, 5.77 ft, site and datum then in use), from rating curve extended above 1,600 ft³/s; minimum observed, 4.0 ft³/s Dec. 17, 1945.

Remarks.--Records good except those for winter months, which are fair. Diversions above station for irrigation.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	406	15	11	13.1	805
February	415	17	13	14.8	823
March	1,183	60	16	38.2	2,350
April	5,497	666	57	183	10,900
May	20,582	1,010	346	664	40,820
June	4,963	401	45	165	9,840
July	917	58	20	29.6	1,820
August	704	36	14	22.7	1,400
September	357.2	19	9.4	11.9	709
October	402	16	11	13.0	797
November	367.2	17	9.2	12.2	728
December	334	12	10	10.8	662
Calendar year 2001	36,127.4	1,010	9.2	99.0	71,660

Conejos River near Lasauses, Colo.

Location.--Water-stage recorders, lat 37°18'01", long 105°44'47", in secs. 2 and 11 (two channels), T. 35 N., R. 11 E., on left bank of main channel 125 ft downstream from bridge on State Highway 158 and on left bank of secondary channel 230 ft upstream from bridge, 1.0 mi upstream from mouth, and 2.1 mi north of Lasauses. Datum of gage on main channel is 7,495.02 ft and on secondary (south) channel is 7,496.89 ft above mean sea level (levels by Bureau of Reclamation).

Drainage area.--887 sq mi.

Average discharge.--80 years (1922-2001), 181 ft³/s (131,100 acre-ft per year).

Extremes.--1921-2001: Maximum discharge, 3,890 ft³/s May 15, 1941; no flow at times in some years.

Remarks.--Records good except those for winter months, which are fair. Diversions for irrigation of about 75,000 acres above station.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	1,041	40	27	33.6	2,060
February	1,632	81	35	58.3	3,240
March	3,519	257	65	114	6,980
April	3,498	325	31	117	6,940
May	17,099	967	157	552	33,920
June	7,927	554	48	264	15,720
July	974.60	72	.80	31.4	1,930
August	20.12	2.6	.10	.65	40
September	4.21	1.0	.00	.14	8.4
October	15.38	1.4	.00	.50	31
November	397.1	24	3.7	13.2	788
December	1,013	48	23	32.7	2,010
Calendar year 2001	37,140.41	967	.00	102	73,670

Rio Grande near Lobatos, Colo.

Location.--Water-stage recorder, lat 37°04'42", long 105°45'22", in sec. 22, T. 33 N., R. 11 E., on right bank at highway bridge, 6 mi north of Colorado-New Mexico State line, 10 mi east of Lobatos, and 14 mi east of Antonito. Datum of gage is 7,427.63 ft above mean sea level, datum of 1929.

Drainage area.--7,700 sq mi, approximately (includes 2,940 sq mi in closed basin in San Luis Valley).

Average discharge.--31 years (1900-30), 846 ft³/s (612,900 acre-ft per year); 71 years (1931-2001) 449 ft³/s (325,300 acre-ft per year).

Extremes.--1899-2001: Maximum discharge observed, 13,200 ft³/s June 8, 1905 (gage height, 9.1 ft), from rating curve extended above 8,000 ft³/s; no flow at times in 1950-51, 1956.

Remarks.--Records good except those for winter months, which are fair. Natural flow of stream affected by transmountain diversions, storage reservoirs, ground-water withdrawals and diversions for irrigation, and return flow from irrigated areas.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	6,010	220	170	194	11,920
February	7,571	376	180	270	15,020
March	13,373	768	308	431	26,530
April	9,996	616	172	333	19,830
May	41,746	2,140	554	1,347	82,800
June	38,250	2,010	690	1,275	75,870
July	11,467	638	130	370	22,740
August	3,025	159	61	97.6	6,000
September	1,552	115	29	51.7	3,080
October	1,718	66	43	55.4	3,410
November	4,363	259	55	145	8,650
December	7,290	290	200	235	14,460
Calendar year 2001	146,361	2,140	29	401	290,300

Willow Creek above Heron Reservoir, near Los Ojos, N. Mex.

Location.--Water-stage recorder, lat 36°44'33", long 106°37'34", in Tierra Amarilla Grant, on right bank 200 ft downstream from bridge, 0.2 mi downstream from Iron Spring Creek, 3.3 mi west of Los Ojos, and at mi 9.7. Datum of gage is 7,196.29 ft above mean sea level. Prior to Apr. 1, 1971, at site 900 ft downstream.

Drainage area.--112 sq mi.

Average discharge.--7 years (1963-69), 11.5 ft³/s (8,330 acre-ft per year) prior to completion of Azotea tunnel; 32 years (1970-2001), 137 ft³/s (99,260 acre-ft per year) subsequent to completion of Azotea tunnel.

Extremes.--1962-2001: Maximum discharge, 1,610 ft³/s Mar. 12, 1985 (gage height, 6.65 ft); no flow at times.

Remarks.--Records good except those for winter months, which are fair. Subsequent to Nov. 16, 1970, flow affected by transmountain diversions through Azotea tunnel. Flow in Rutheron Drain included prior to Apr. 1, 1971.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	0.00	0.00	0.00	0.00	0.00
February	.00	.00	.00	.00	.00
March	3,432.50	421	.00	111	6,810
April	11,890	820	133	396	23,580
May	24,533	940	443	791	48,660
June	14,281	881	175	476	28,330
July	2,286.1	177	7.1	73.7	4,530
August	2,170.2	249	4.0	70.0	4,300
September	121.80	24	.00	4.06	242
October	.00	.00	.00	.00	.00
November	.00	.00	.00	.00	.00
December	.00	.00	.00	.00	.00
Calendar year 2001	58,714.60	940	.00	161	116,500

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Horse Lake Creek above Heron Reservoir, near Los Ojos, N. Mex.

Location.--Water-stage recorder, lat 36°42'24", long 106°44'42", in Tierra Amarilla Grant, on right bank 3.7 mi northwest of Heron Dam, 7.8 mi downstream from Horse Lake, and 9.9 mi west of Los Ojos. Datum of gage is 7,188.85 ft above mean sea level. Prior to July 1, 1971, at site 1,100 ft upstream.
Drainage area.--45 sq mi, approximately.
Average discharge.--12 years (1963-73, 1986), 1.17 ft³/s (848 acre-ft per year).
Extremes.--1963-2001: Maximum discharge, 3,960 ft³/s July 30, 1968 (gage height, 4.9 ft); no flow most of time.
Remarks.--Records good. Diversions above station for irrigation of meadows and for off-channel stock tanks.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	--	--	--	--	--
February	--	--	--	--	--
March	--	--	--	--	--
April	--	--	--	--	--
May	0.62	0.18	0.00	0.02	1.2
June	.00	.00	.00	.00	.00
July	.00	.00	.00	.00	.00
August	.00	.00	.00	.00	.00
September	.00	.00	.00	.00	.00
October	--	--	--	--	--
November	--	--	--	--	--
December	--	--	--	--	--
Calendar year 2001	--	--	--	--	--

Willow Creek below Heron Dam, N. Mex.

Location.--Totalizing flowmeters, lat 36°39'56", long 106°42'12", in Tierra Amarilla Grant, in outlet conduits at Heron Dam, 0.2 mi upstream from Rio Chama, 5.1 mi northeast of El Vado Dam, and 8.7 mi southwest of Los Ojos.
Drainage area.--193 sq mi.
Average discharge.--31 years (1971-2001), 126 ft³/s (91,290 acre-ft per year).
Extremes.--1971-2001: Maximum daily discharge, 2,780 ft³/s Dec. 18, 19, 1982; no flow at times each year.
Remarks.--Records excellent. Flow completely regulated by Heron Dam.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	662.0	100	.00	21.4	1,310
February	2,800	100	100	100	5,550
March	5,360	400	100	173	10,630
April	14,031	550	400	468	27,830
May	1,736.0	419	.00	56.0	3,440
June	0.00	.00	.00	.00	.00
July	.00	.00	.00	.00	.00
August	.00	.00	.00	.00	.00
September	.00	.00	.00	.00	.00
October	992.00	400	.00	32.0	1,970
November	12,000	400	400	400	23,800
December	10,894	400	200	351	21,610
Calendar year 2001	48,475.00	550	.00	133	96,150

Rio Chama below El Vado Dam, N. Mex.

Location.--Water-stage recorder, lat 36°34'48", long 106°43'24", in Tierra Amarilla Grant, on left bank 1.5 mi downstream from El Vado Dam, 2.8 mi upstream from Rio Nutrias, and 13 mi southwest of Tierra Amarilla. Datum of gage is 6,696.12 ft above mean sea level, datum of 1929. Prior to October 1935, at site 1.5 mi upstream and October 1935 to September 1938, at site 1.1 mi upstream at different datums.
Drainage area.--877 sq mi, of which about 100 sq mi is probably noncontributing.
Average discharge.--4 years (1914, 1921-23), 444 ft³/s (321,700 acre-ft per year), prior to completion of El Vado Dam; 35 years (1936-70), 372 ft³/s (269,500 acre-ft per year), prior to release of transmountain water; 31 years (1971-2001) 479 ft³/s (347,000 acre-ft per year).
Extremes.--1914-16, 1920-24, 1936-2001: Maximum discharge observed, 9,000 ft³/s May 22, 1920 (gage height, 12 ft); no flow Mar. 25, 26, 31, 1955.
Remarks.--Records good. Diversions above station for irrigation of about 10,600 acres. Since 1935 flow regulated by El Vado Reservoir and since October 1970 flow partly regulated by Heron Reservoir. Subsequent to May 1971 flow affected by releases of transmountain water from Heron Reservoir.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	3,506	116	111	113	6,950
February	3,065	114	102	109	6,080
March	3,298	165	99	106	6,540
April	3,233	161	91	108	6,410
May	20,966	2,040	92	676	41,590
June	9,919	760	182	331	19,670
July	7,656	521	152	247	15,190
August	12,936	653	98	417	25,660
September	22,035	863	604	734	43,710
October	11,530	719	221	372	22,870
November	6,686	226	218	223	13,260
December	6,967	226	221	225	13,820
Calendar year 2001	111,797	2,040	91	306	221,700

Rio Chama below Abiquiu Dam, N. Mex.

Location.--Water-stage recorder, lat 36°14'12", long 106°24'59", in SE1/4SE1/4 sec. 8, T. 23 N., R. 5 E., on right bank 0.8 mi downstream from Abiquiu Dam and 5.9 mi northwest of Abiquiu. Altitude of gage is 6,040 ft (from river-profile map and topographic map).
Drainage area.--2,147 sq mi, of which about 100 sq mi is probably noncontributing.
Average discharge.--9 years (1962-70), 376 ft³/s (272,400 acre-ft per year), prior to release of transmountain water; 31 years (1971-2001), 534 ft³/s (387,000 acre-ft per year).
Extremes.--1961-2001: Maximum discharge, 2,990 ft³/s July 1, 1965 (gage height, 6.69 ft); minimum, about 0.5 ft³/s Mar. 17, 1966, Jan. 28, 1972.
Remarks.--Records good. Flow regulated by Heron, El Vado, and Abiquiu Reservoirs. Diversions above station for irrigation of about 17,600 acres. Subsequent to May 1971 flow affected by the release of transmountain water from Heron Reservoir.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	1,664	56	51	53.7	3,300
February	1,743	109	52	62.2	3,460
March	1,570	58	48	50.6	3,110
April	5,018	400	48	167	9,950
May	5,281	503	142	170	10,470
June	6,167	461	155	206	12,230
July	16,566	809	208	534	32,860
August	18,756	862	193	605	37,200
September	25,564	1,030	692	852	50,710
October	14,323	772	65	462	28,410
November	1,265	44	38	42.2	2,510
December	1,358	47	41	43.8	2,690
Calendar year 2001	99,275	1,030	38	272	196,900

Rio Nambe below Nambe Falls Dam, near Nambe, N. Mex.

Location.–Totalizing flowmeters, lat 35°50'46", long 105°54'17", in NE1/4SW1/4 sec. 29, T. 19 N., R. 10 E., in Nambe Indian Reservation, in outlet conduits at Nambe Falls Dam, 300 ft upstream from Nambe Falls, 2.6 mi upstream from confluence of Rio Nambe and Rio En Medio, 4.4 mi southeast of Nambe Pueblo, and 5.4 mi southeast of Nambe.
Drainage area.–34.1 sq mi.
Average discharge.–23 years (1979-2001), 14.7 ft^3/s (10,650 acre-ft per year).
Extremes.–1979-2001: Maximum discharge, 312 ft^3/s June 9, 1979 (gage height, 1.96 ft), at site 1,100 ft downstream; no flow December 31, 1994.
Remarks.–Records good. Flow completely regulated by Nambe Falls Reservoir.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	38.7	1.3	1.1	1.25	77
February	33.8	1.3	1.1	1.21	67
March	43.4	1.5	1.3	1.40	86
April	354.6	24	1.5	11.8	703
May	1,198	58	25	38.6	2,380
June	611	38	11	20.4	1,210
July	420.8	19	3.9	13.6	835
August	372.7	35	3.0	12.0	739
September	220.1	21	2.9	7.34	437
October	223.0	2.0	2.4	7.19	442
November	52.6	7.7	1.4	1.75	104
December	39.1	1.7	1.0	1.26	78
Calendar year 2001	3,607.8	58	1.0	9.88	7,160

Rio Grande at Otowi Bridge, near San Ildefonso, N. Mex.

Location.–Water-stage recorder, lat 35°52'29", long 106°08'30", in San Ildefonso Pueblo Grant, 400 ft downstream from bridge on State Highway 4, 1.8 mi southwest of San Ildefonso Pueblo, 2.5 mi downstream from Pojoaque River, and 6.8 mi west of Pojoaque. Datum of gage is 5,488.48 ft above mean sea level, datum of 1929. Prior to May 19, 1904, and July 25 to Oct. 1, 1904, staff gage at site 180 ft upstream at datum 2.02 ft lower.
Drainage area.–14,300 sq mi, approximately (includes 2,940 sq mi in closed basin in San Luis Valley, Colo.).
Average discharge.–102 years (1896-1905, 1910-2001), 1,533 ft^3/s (1,111,000 acre-ft per year).
Extremes.–1895-1905, 1910-2001: Maximum discharge, 24,400 ft^3/s May 23, 1920 (gage height, 14.1 ft); minimum daily, 60 ft^3/s July 4, 5, 1902.
Remarks.–Records good. Flow partly regulated by Heron, El Vado, and Abiquiu Reservoirs. Diversions above station for irrigation of about 620,000 acres in Colorado and 75,000 acres in New Mexico. Subsequent to May 1971 flow affected by releases of transmountain water from Heron Reservoir.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	16,822	579	471	543	33,370
February	17,315	740	529	618	34,340
March	25,721	1,250	659	830	51,020
April	33,908	1,800	721	1,130	67,260
May	85,180	3,700	1,750	2,748	169,000
June	58,720	3,190	1,100	1,957	116,500
July	38,396	1,530	904	1,239	76,160
August	30,298	1,280	588	977	60,100
September	31,570	1,300	868	1,052	62,620
October	21,519	948	511	694	42,680
November	13,629	584	358	454	27,030
December	17,789	638	512	574	35,280
Calendar year 2001	390,867	3,700	358	1,071	775,300

Santa Fe River near Santa Fe, N. Mex.

Location.–Water-stage recorder and concrete control, lat 35°41'12", long 105°50'35", in NE1/4SE1/4 sec. 23, T. 17 N., R. 10 E., 0.4 mi downstream from McClure Dam, and 5.3 mi east of Santa Fe. Altitude of gage is 7,718 ft. Prior to Nov. 4, 1930, at site 1.5 mi downstream, and Apr. 11, 1931 to Sept. 30, 1947, at site 0.3 mi upstream, each at different datum.
Drainage area.–18.2 sq mi.
Average discharge.–89 years (1913-2001), 8.16 ft^3/s (5,912 acre-ft per year).
Extremes.–1913-2001: Maximum discharge, 1,500 ft^3/s Aug. 14, 1921; minimum, no flow Aug. 2-10, 2000.
Remarks.–Records good. Flow regulated by McClure Reservoir, completed in 1926, raised in 1935 and again in 1947.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	2.94	0.14	0.06	0.095	5.8
February	4.29	.24	.08	.15	8.5
March	64.66	7.3	.12	2.09	128
April	167.2	21	1.4	5.57	332
May	566.5	35	4.4	18.3	1,120
June	334.0	15	7.7	11.1	662
July	245.3	16	4.9	7.91	487
August	383.9	18	5.0	12.4	761
September	292.4	27	1.1	9.75	580
October	272.7	16	5.8	8.80	541
November	36.95	6.0	.15	1.23	73
December	6.05	.34	.11	.20	12
Calendar year 2001	2,376.89	35	.06	6.51	4,710

Rio Grande below Cochiti Dam, N. Mex.

Location.–Water-stage recorder, lat 35°37'05", long 106°19'24", in SW1/4NE1/4 sec. 17, T. 16 N., R. 6 E., in Pueblo de Cochiti Grant, 320 ft upstream from bridge on State Highway 22, 700 ft downstream from Cochiti Dam, and 1.4 mi northeast of Cochiti Pueblo. Datum of gage is 5,226.08 ft above mean sea level, datum of 1929. Prior to Nov. 14, 1973, at site 2.4 mi downstream at altitude 5,210 ft. Nov. 14, 1973 to Jan. 8, 1976, at site 320 ft downstream at datum 1.79 ft lower.
Drainage area.–14,900 sq mi, approximately (includes 2,940 sq mi in closed basin in San Luis Valley, Colo.).
Average discharge.–31 years (1971-2001), 1,406 ft^3/s (1,019,000 acre-ft per year).
Extremes.–1971-2001: Maximum discharge, 10,300 ft^3/s July 26, 1971, at site 2.4 mi downstream prior to closure of Cochiti Dam; minimum discharge, 0.51 ft^3/s Aug. 3-5, 1977, Aug. 27-28, 1978.
Remarks.–Records good. Since Nov. 12, 1973, flow completely regulated by Cochiti Dam. Cochiti eastside main canal on left bank and Sili main canal on right bank bypass station.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	17,567	632	511	567	34,840
February	18,669	894	528	667	37,030
March	23,352	1,130	597	753	46,320
April	29,642	1,420	644	988	58,790
May	74,140	4,090	1,690	2,392	147,100
June	51,560	2,720	1,110	1,719	102,300
July	31,648	1,140	911	1,021	62,770
August	25,243	1,010	634	814	50,070
September	25,676	996	750	856	50,930
October	16,482	787	360	532	32,690
November	11,279	587	164	376	22,370
December	16,609	632	462	536	32,940
Calendar year 2001	341,867	4,090	164	937	678,100

STREAMFLOW

Galisteo Creek below Galisteo Dam, N. Mex.

Location.--Water-stage recorder, lat 35°27'56", long 106°12'57", in SE1/4SE1/4 sec. 5, T. 14 N., R. 7 E., 0.6 mi downstream from Galisteo Dam, and 5.5 mi northwest of Cerrillos. Altitude of gage is 5,450 ft.

Drainage area.--597 sq mi.

Average discharge.--31 years (1971-2001), 6.03 ft³/s (4,369 acre-ft per year).

Extremes.--1970-2001: Maximum discharge, 2,000 ft³/s July 27, 1971 (gage height, 7.00 ft); maximum gage height, 7.33 ft July 20, 1971; no flow many days each year.

Remarks.--Records poor. Flow partly regulated by uncontrolled outlet in Galisteo Dam. Capacity of outlet, 5,000 ft³/s when reservoir is full. Diversions for irrigation of about 50 acres above reservoir.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	90.75	8.6	0.00	2.93	180
February	47.84	3.2	.54	1.71	95
March	8.65	2.9	.00	.28	17
April	1.25	.61	.00	.042	2.5
May	1.15	.60	.00	.037	2.3
June	178.33	95	.00	5.94	354
July	.32	.24	.00	.010	.6
August	343.80	134	.00	11.1	682
September	.00	.00	.00	.00	.00
October	.00	.00	.00	.00	.00
November	.00	.00	.00	.00	.00
December	.00	.00	.00	.00	.00
Calendar year 2001	672.09	134	.00	1.84	1,330

Jemez River below Jemez Canyon Dam, N. Mex.

Location.--Water-stage recorder, lat 35°23'24", long 106°32'03", in NE1/4 sec. 5, T. 13 N., R. 4 E., 0.8 mi downstream from Jemez Canyon Dam, 2.0 mi upstream from mouth, and 6 mi north of Bernalillo. Datum of gage is 5,095.60 ft above mean sea level, datum of 1929. Prior to April 24, 1951, at site three-quarters mi upstream at datum 24.51 ft higher. April 24, 1951 to June 25, 1958, at site 37 ft upstream at datum 4.40 ft higher.

Drainage area.--1,038 sq mi.

Average discharge.--59 years (1937, 1944-2001), 62.7 ft³/s (45,430 acre-ft per year).

Extremes.--1937, 1944-2001: Maximum discharge, 16,300 ft³/s Aug. 29, 1943 (gage height, 5.62 ft); no flow at times.

Remarks.--Records good. Flow regulated by Jemez Canyon Dam since October 1953. Diversions for irrigation of about 3,000 acres above station.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	609.2	36	1.8	19.7	1,210
February	1,093	62	14	39.0	2,170
March	3,117.7	354	3.7	101	6,180
April	5,885.8	687	5.1	196	11,670
May	3,723.2	1,580	5.2	120	7,380
June	1,478.5	214	1.6	49.3	2,930
July	680	63	14	21.9	1,350
August	723.0	64	9.0	23.3	1,430
September	690	28	14	23.0	1,370
October	2,083.13	120	.40	67.2	4,130
November	160.57	15	.17	5.35	318
December	217.5	8.9	4.2	7.02	431
Calendar year 2001	20,461.60	1,580	.17	56.1	40,590

Rio Grande below Elephant Butte Dam, N. Mex.

Location.--Water-stage recorder, lat 33°08'54", long 107°12'22", in SW1/4 sec. 25, T. 13 S., R. 4 W. (projected), in Pedro Armendariz Grant, 1.0 mi downstream from dam and 1.5 mi upstream from Cuchillo Negro River. Datum of gage is 4,242.09 ft above mean sea level, datum of 1929. Prior to April 23, 1942, at several different sites and datums.

Drainage area.--29,450 sq mi, approximately (includes 2,940 sq mi in closed basin in San Luis Valley, Colo.).

Average discharge.--87 years (1915-2001), 1,011 ft³/s (732,500 acre-ft per year).

Extremes.--1915-2001: Maximum daily discharge, 8,220 ft³/s May 22, 1942; no flow at times prior to 1929 and March 2-4, 1979.

Remarks.--Records good. Flow regulated by Elephant Butte Reservoir. Diversions for irrigation of about 800,000 acres above station.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	2,152.6	768	9.6	69.4	4,270
February	49,880	2,440	1,280	1,781	98,940
March	48,630	1,630	1,040	1,569	96,460
April	49,130	1,670	1,620	1,638	97,450
May	53,420	1,800	1,600	1,723	106,000
June	54,190	2,440	1,470	1,806	107,500
July	57,040	2,220	1,390	1,840	113,100
August	46,319	1,660	838	1,494	91,870
September	20,327	874	370	678	40,320
October	7,713.9	1,490	7.4	249	15,300
November	208.9	7.7	6.4	6.96	414
December	6,631.1	667	7.6	214	13,150
Calendar year 2001	395,642.5	2,440	6.4	1,084	784,800

Rio Grande below Caballo Dam, N. Mex.

Location.--Water-stage recorder, lat 32°53'05", long 107°17'31", in NE1/4SW1/4 sec. 30, T. 16 S., R. 4 W., 2,000 ft upstream from Interstate Highway 25, 4,200 ft downstream from Caballo Dam, 1.3 mi upstream from Percha diversion dam, and 3 mi northeast of Arrey. Datum of gage is 4,140.90 ft above mean sea level, datum of 1929. October 13, 1938 to December 31, 1945, at datum 5.0 ft higher.

Drainage area.--30,700 sq mi, approximately (includes 2,940 sq mi in closed basin in San Luis Valley, Colo.).

Average discharge.--64 years (1938-2001) 941 ft³/s (681,800 acre-ft per year).

Extremes.--1938-2001: Maximum daily discharge, 7,650 ft³/s May 20, 1942; minimum daily, 0.1 ft³/s Oct. 31 to Nov. 14, 1954, Nov. 7 to Dec. 31, 1955, Feb. 15-29, 1972.

Remarks.--Records good. Flow regulated by Elephant Butte and Caballo Reservoirs. Diversions for irrigation of about 800,000 acres above station.

Monthly and yearly discharge, in cubic feet per second

Month	Second-foot-days	Maximum daily	Minimum daily	Mean	Runoff in acre-feet
January	93.0	3.0	3.0	3.00	184
February	12,024.0	996	3.0	429	23,850
March	53,791	2,330	901	1,735	106,700
April	44,130	1,870	1,120	1,471	87,530
May	48,780	2,000	1,110	1,574	96,760
June	66,190	2,520	1,860	2,206	131,300
July	65,950	2,600	1,710	2,127	130,800
August	55,870	2,110	1,600	1,802	110,800
September	36,820	1,770	850	1,227	73,030
October	12,892.0	1,440	4.0	416	25,570
November	142.0	7.0	1.0	4.73	282
December	40.6	1.8	1.1	1.31	81
Calendar year 2001	396,722.6	2,600	1.0	1,087	786,900

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STREAMFLOW

Bonito ditch below Caballo Dam, N. Mex.

Records available.--January 1938 to December 2001. Published as supplementary data with Rio Grande below Caballo Dam in USGS Water-Supply Papers and Water-Data Reports beginning with October 1947.

Remarks.--Ditch diverts directly from Caballo Reservoir for irrigation of lands on right bank of river. The total release from Project Storage, as used in computations of Compact Commission, is the combined flow of this ditch and Rio Grande below Caballo Dam.

Diversion, in acre-feet

January	0
February	32.3
March	141.3
April	126.3
May	144.2
June	134.8
July	88.8
August	210.5
September	155.1
October	16.1
November	0
December	70.2
Calendar year 2001	1,119.7

Reservoirs in Rio Grande Basin in Colorado (constructed or enlarged since 1937)

Squaw Lake.--Staff gage in sec. 12, T. 39 N., R. 4 W., on tributary to Squaw Creek. Completed in 1938; capacity, 162 acre-ft by 1953 survey. Water is used for irrigation below gaging station on Rio Grande near Del Norte.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	-
Contents	162	162	162	162	162	162	162	162	162	162	162	162	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

Rito Hondo Reservoir.--Staff gage in sec. 22, T. 42 N., R. 3 W., on Rito Hondo (Deep Creek) tributary to Clear Creek. Completed in 1957; capacity, 561 acre-ft. Originally filled during May and June 1958 with transmountain water; storage is not in debit status. Water is used for fish culture.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	-
Contents	561	561	561	561	561	561	561	561	561	561	561	561	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

Hermit Lakes Reservoir No. 3.--In sec. 25, T. 41 N., R. 4 W., on South Clear Creek. Completed prior to 1960; capacity, 192 acre-ft. Capacity table based on elevation above bottom of outlet. Water is used for fish culture. Includes 169 acre-ft of transmountain water by exchange in 1984 and 23 acre-ft of transmountain water by exchange in 1985.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	-
Contents	192	192	192	192	192	192	192	192	192	192	192	192	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

Troutvale No. 2 Reservoir.--Staff gage in E1/2 sec. 10, T. 41 N., R. 3 W., on South Clear Creek. Completed in 1940; capacity, 435 acre-ft. Condition of spillway limited storage to 168 acre-ft after May 1942. Repairs to spillway in 1947 increased capacity to 257 acre-ft. Water is used for fish culture with only occasional sale for irrigation. Storage omitted from accounting by action of Commission on Feb. 15, 1962.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	-
Contents	213	213	213	213	213	213	213	213	213	213	213	213	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

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STORAGE IN RESERVOIRS

Reservoirs in Rio Grande Basin in Colorado
(constructed or enlarged since 1937)

Jumper Creek Reservoir.--In sec. 5, T. 39 N., R. 2 W., on Jumper Creek, tributary to Trout Creek. Completed in 1951; capacity, 38 acre-ft. Capacity table based on elevation above bottom of outlet. Storage omitted from accounting by action of Commission on Feb. 15, 1962.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	-
Contents	38	38	38	38	38	38	38	38	38	38	38	38	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

Big Meadows Reservoir.--In NW1/4 sec. 17, T. 38 N., R. 2 E., on South Fork about 0.9 mi upstream from Hope Creek. Completed in 1967; capacity, 2,437 acre-ft. Capacity table based on elevation above outlet. Water is used for fish culture. Includes 140 acre-ft of transmountain water, by exchange, in 1967; 838 acre-ft, by exchange, in 1968; 347 acre-ft, by exchange, in 1969; and 1,112 acre-ft, by exchange, in 1983, for a total of 2,437 acre-ft.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	-
Contents	2,437	2,437	2,437	2,437	2,437	2,437	2,437	2,437	2,437	2,437	2,437	2,437	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

Alberta Park Reservoir.--In sec. 34, T. 38 N., R. 2 E., on Pass Creek. Completed in 1953; capacity, 598 acre-ft. Capacity table based on elevation above bottom of outlet. Storage prior to June 30, 1983 included 244 acre-ft of transmountain water imported in 1963. By a 1983 resolution of the Rio Grande Compact Commission, the reservoir was drained for repairs in July 1983; recovery was completed in 1984. The reservoir also contains 100 acre-ft of transmountain water stored by exchange in 1983 and 254 acre-ft of transmountain water stored in 1984.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	-
Contents	598	598	598	598	598	598	598	598	598	598	598	598	-
Change	0	0	0	0	0	0	0	0	0	0	0	- 0	0

Shaw Lake Enlargement.--In sec. 5, T. 38 N., R. 2 E., on tributary to Lake Creek. Capacity, 638 acre-ft by 1916 decree; enlarged in 1955 to 681 acre-ft. Only the storage in excess of 638 acre-ft is subject to terms of Rio Grande Compact. Includes 42 acre-ft of transmountain water imported in 1965.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	-	-	-	-	-	-	-	-	-	-	-	-	-
Contents	42	42	42	42	42	42	42	42	42	42	42	42	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

Reservoirs in Rio Grande Basin in Colorado
(constructed or enlarged since 1937)

Mill Creek Reservoir.--In sec. 16, T. 39 N., R. 3 E., on Mill Creek. Completed in 1953; capacity, 43 acre-ft. Capacity based on elevation above bottom of outlet. Includes 43 acre-ft of transmountain water, by exchange, in 1976.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	15.0	15.0	15.0	0.0	14.2	14.2	14.0	13.7	13.6	13.3	13.3	13.3	-
Contents	43	43	43	0	39	39	38	37	36	35	35	35	-
Change	0	0	0	-43	+39	0	-1	-1	-1	-1	0	0	-8

Fuchs Reservoir.--Staff gage in sec. 2, T. 37 N., R. 4 E., on East Pinos Creek. Completed in 1939; capacity, 237 acre-ft with 2 ft of flash boards in spillway. Prior to calendar year 1999, contents reported as 238 acre-ft were actually 237 acre-ft. Pinos Creek enters Rio Grande below station near Del Norte.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	9.9	12.6	15.0	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	-
Contents	92	140	188	237	237	237	237	237	237	237	237	237	-
Change	+48	+48	+48	+49	0	0	0	0	0	0	0	0	+193

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Platoro Reservoir.--Water-stage recorder in NW1/4 sec. 22, T. 36 N., R. 4 E., on Conejos River. Completed in 1951; capacity, 59,570 acre-ft at crest of spillway. Reservoir is used for irrigation and flood control. Storage affects Conejos Index Supply. Contents include 3,000 acre-ft of transmountain water stored by exchange in April 1985 on behalf of the Colorado Division of Wildlife.

Month-end elevation, in feet, and contents, in acre-feet

Date	Elevation	Contents	Change in contents
December 31, 2000	9,977.1	16,779	-
January 31, 2001	9,977.2	16,843	+64
February 28	9,977.5	17,012	+169
March 31	9,977.9	17,214	+202
April 30	9,978.6	17,584	+370
May 31	9,998.6	30,014	+12,430
June 30	9,991.3	31,105	+1,091
July 31	9,991.26	25,060	-6,045
August 31	9,986.3	21,975	-3,085
September 30	9,981.1	18,946	-3,029
October 31	9,977.7	17,097	-1,849
November 30	9,977.7	17,097	0
December 31	9,977.7	17,113	+16
Calendar year 2001	-	-	+334

Trujillo Meadows Reservoir.--In sec. 5, T. 32 N., R. 5 E., on Los Pinos River. Completed in 1957; capacity, 869 acre-ft, effective Jan. 1, 1999. Water is used for fish culture. Storage is transmountain water, by exchange, in 1959.

Month-end gage height, in feet, and contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal.yr.
Gage height	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.0	-
Contents	869	869	869	869	869	869	869	869	869	869	869	869	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

STORAGE IN RESERVOIRS

Reservoirs in Rio Grande Basin in New Mexico
(constructed or enlarged since 1929)

Heron Reservoir.--Water-stage recorder, lat 36°39'56", long 106°42'13", on Willow Creek. Storage began in October 1970. Capacity, 401,300 acre-ft at elevation 7,186.1 ft (low point on crest of spillway); dead storage, 1,340 acre-ft at elevation 7,003.0 ft. Used for storage of transmountain water.

Month-end elevation, in feet, and contents, in acre-feet

Date	Elevation	Contents	Change in contents
December 31, 2000	7,160.76	267,390	-
January 31, 2001	7,160.60	266,640	-750
February 28	7,159.80	262,900	-3,740
March 31	7,159.87	263,230	+330
April 30	7,159.50	261,510	-1,720
May 31	7,169.23	308,750	+47,240
June 30	7,174.43	335,790	+27,040
July 31	7,175.12	339,470	+3,680
August 31	7,175.65	342,320	+2,850
September 30	7,175.28	340,330	-1,990
October 31	7,174.62	336,800	-3,530
November 30	7,170.00	312,670	-24,130
December 31	7,165.76	291,420	-21,250
Calendar year 2001	-	-	+24,030

El Vado Reservoir.--Water-stage recorder and surface follower, lat 36°35'39", long 106°44'00", on Rio Chama. Storage began in January 1935. Capacity, 186,250 acre-ft at gage height 6,902.0 ft (crest of spillway); dead storage, 480 acre-ft, below gage height 6,775.0 ft (invert of outlet works), as determined by survey in 1984. Datum of gage is 8.21 ft above mean sea level, datum of 1929. Storage includes both Rio Grande and transmountain water.

Month-end gage height, in feet, and contents, in acre-feet

Date	Gage height	Contents	Change in contents	Transmountain water
December 31, 2000	6,818.24	23,940	-	14,920
January 31, 2001	6,814.99	20,990	-2,950	10,270
February 28	6,816.62	22,440	+1,450	10,480
March 31	6,828.11	34,150	+11,710	10,190
April 30	6,869.59	99,160	+65,010	23,890
May 31	6,900.02	179,900	+80,740	23,780
June 30	6,899.32	177,700	-2,200	23,640
July 31	6,895.22	165,020	-12,680	22,190
August 31	6,887.15	141,690	-23,330	19,680
September 30	6,869.17	98,280	-43,410	17,070
October 31	6,858.85	78,460	-19,820	17,760
November 30	6,865.15	90,170	+11,710	28,500
December 31	6,869.57	99,120	+8,950	36,300
Calendar year 2001	-	-	+75,180	-

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Reservoirs in Rio Grande Basin in New Mexico
(constructed or enlarged since 1929)

Abiquiu Reservoir.--Water-stage recorder, lat 36°14'24", long 106°25'44", on Rio Chama. Completed in February 1963; capacity, 1,192,800 acre-ft at elevation 6,350 ft (crest of spillway) by 1998 survey. Reservoir is operated by Corps of Engineers for flood control and sediment storage. A resolution granting permission to store transmountain waters was approved by Rio Grande Compact Commission on May 3, 1974. Storage includes both Rio Grande and transmountain water.

Month-end elevation, in feet, and contents, in acre-feet

Date	Elevation	Contents	Change in contents	Transmountain water
December 31, 2000	6,193.31	91,320	-	88,650
January 31, 2001	6,194.72	95,470	+4,150	94,820
February 28	6,196.23	100,010	+4,540	99,760
March 31	6,197.91	105,180	+5,170	104,880
April 30	6,199.01	108,620	+3,440	106,270
May 31	6,201.74	144,970	+36,350	103,970
June 30	6,211.48	151,290	+6,320	100,950
July 31	6,206.23	132,550	-18,740	89,800
August 31	6,203.14	121,960	-10,590	84,390
September 30	6,201.06	115,110	-6,850	83,360
October 31	6,199.40	109,850	-5,260	80,320
November 30	6,202.69	120,460	+10,610	91,840
December 31	6,205.83	131,160	+10,700	103,260
Calendar year 2001	-	-	+39,840	-

Nambe Falls Reservoir.--Water-stage recorder in NE1/4SW1/4 sec. 29, T. 19 N., R. 10 E., in Nambe Indian Reservation, on Rio Nambe. Completed in 1976; capacity 2,023 acre-ft at elevation 6,826.6 ft (crest of spillway), dead storage 121 acre-ft at elevation 6,760.9 ft. Storage is transmountain water by exchange (see resolution adopted March 27, 1975).

Month-end elevation, in feet, and contents, in acre-feet

Date	Elevation	Contents	Change in contents
December 31, 2000	6,812.43	1,310	-
January 31, 2001	6,815.24	1,430	+120
February 28	6,817.86	1,560	+130
March 31	6,823.54	1,850	+290
April 30	6,826.66	2,030	+180
May 31	6,826.76	2,030	0
June 30	6,824.19	1,880	-150
July 31	6,816.25	1,480	-400
August 31	6,811.04	1,250	-230
September 30	6,807.27	1,090	-160
October 31	6,801.23	880	-210*
November 30	6,804.29	980	+100
December 31	6,807.83	1,110	+130
Calendar year 2001	-	-	-200

Reservoirs in Rio Grande Basin in New Mexico
(constructed or enlarged since 1929)

McClure (Granite Point) Reservoir.--Water-stage recorder in NE1/4SW1/4 sec. 24, T. 17 N., R. 10 E., on Santa Fe River. Original reservoir completed in 1926, capacity, 561 acre-ft; in 1935, permanent flash boards were installed in spillway, increasing capacity to 650 acre-ft; in 1947 both dam and spillway were reconstructed, increasing capacity to 2,615 acre-ft (gage height, 9,788.4 ft, crest of spillway). In 1953 spillway was equipped with radial gates that opened automatically, increasing capacity to over 3,000 acre-ft. In 1972, radial gates were removed, decreasing capacity to 2,615 acre-ft. In 1989, modifications to the dam and spillway increased capacity to 2,813 acre-ft. In 1995, modification to the dam and spillway increased capacity to 3,257 acre-ft. No dead storage. Altitude of gage is 7,790 ft. Water is for municipal use in Santa Fe. Storage includes both Rio Grande water and transmountain water by exchange. Capacity includes 561 acre-ft for pre-Compact storage and additional capacity as may be available to accommodate up to a total of 1,061 acre-ft of pre-Compact storage in McClure and Nichols Reservoirs combined.

Month-end gage height, in feet, and contents, in acre-feet

Date	Gage height	Contents	Change in contents	Pre-Compact water	Transmountain water
December 31, 2000	7,848.52	1,050	-	726	324
January 31, 2001	7,852.99	1,150	+100	746	404
February 28	7,855.65	1,280	+130	876	404
March 31	7,867.01	1,920	+640	1,060	404
April 30	7,877.95	2,660	+740	1,060	404
May 31	7,885.78	3,260	+600	1,060	404
June 30	7,881.39	2,920	-340	1,060	404
July 31	7,876.00	2,520	-400	1,060	404
August 31	7,865.96	1,860	-660	1,060	404
September 30	7,855.17	1,250	-600	846	404
October 31	7,842.63	733	-517	329	404
November 30	7,842.31	722	-11	318	404
December 31	7,843.91	777	+55	373	404
Calendar year 2001	-	-	-273	-	-

Nichols Reservoir.--Water-stage recorder in SE1/4NE1/4 sec. 21, T. 17 N., R. 10 E., on Santa Fe River. Completed in 1942; capacity, 685 acre-ft at gage height 167.0 ft (crest of spillway), dead storage, 14 acre-ft at gage height 121.1 ft. Datum of gage is 7,313.2 ft above mean sea level, datum of 1929. Water is for municipal use in Santa Fe. Storage includes both Rio Grande water and transmountain water by exchange. Capacity may include pre-Compact storage such that total pre-Compact storage in McClure and Nichols Reservoirs combined does not exceed 1,061 acre-ft.

Month-end gage height, in feet, and contents, in acre-feet

Date	Gage height	Contents	Change in contents	Pre-Compact water	Transmountain water
December 31, 2000	156.28	407	-	167	240
January 31, 2001	150.16	282	-125	122	160
February 28	144.42	195	-87	35	160
March 31	149.65	274	+79	0	160
April 30	145.59	211	-63	0	160
May 31	167.04	687	+476	0	160
June 30	164.17	603	-84	0	160
July 31	151.19	319	-284	0	160
August 31	159.10	479	+160	0	160
September 30	153.90	440	-39	215	160
October 31	163.37	581	+141	421	160
November 30	161.30	526	-55	366	160
December 31	158.44	455	-71	295	160
Calendar year 2001	-	-	+48		-

STORAGE IN RESERVOIRS

Reservoirs in Rio Grande Basin in New Mexico
(constructed or enlarged since 1929)

Cochiti Lake.--Water-stage recorder and manometer in NW1/4SW1/4 sec. 16, T. 16 N., R. 6 E., in Pueblo de Cochiti Grant, on Rio Grande. Completed in 1975; capacity 491,259 acre-ft at elevation 5,450.0 ft (crest of service spillway); zero storage at elevation 5,255.0 ft, from 1998 survey. A 50,000-acre-ft permanent pool was authorized by Public Law 88-293, 88th Congress, March 26, 1964. Reservoir is operated by Corps of Engineers for flood control, sediment storage, and recreation. Storage began Nov. 12, 1973.

Month-end elevation, in feet, and contents, in acre-feet

Date	Elevation	Contents	Change in contents	Transmountain water
December 31, 2000	5,342.06	51,700	-	49,890
January 31, 2001	5,341.49	50,960	-740	49,930
February 29	5,340.85	50,170	-790	50,030
March 31	5,341.59	51,090	+920	50,270
April 30	5,341.59	51,090	0	49,820
May 31	5,340.53	49,780	-1,310	49,320
June 30	5,340.72	50,010	+230	49,920
July 31	5,340.13	49,300	-710	48,290
August 31	5,339.07	48,080	-1,220	47,870
September 30	5,339.21	48,230	+150	47,360
October 31	5,338.88	47,860	-370	46,990
November 30	5,338.93	47,920	+60	47,050
December 31	5,340.84	50,160	+2,240	49,010
Calendar year 2001	-	-	-1,540	-

Galisteo Reservoir.--Water-stage recorder and manometer in NW1/4 sec. 9, T. 14 N., R. 7 E., on Galisteo Creek. Storage records begin in October 1970. Capacity 88,990 acre-ft at elevation 5,608.0 ft (crest of spillway). No dead storage. Reservoir is operated by Corps of Engineers for flood control and sediment storage.

Month-end contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal. yr.
Contents	0	0	0	0	0	0	0	0	0	0	0	0	-
Change	0	0	0	0	0	0	0	0	0	0	0	0	0

STORAGE IN RESERVOIRS

Reservoirs in Rio Grande Basin in New Mexico
(constructed or enlarged since 1929)

Jemez Canyon Reservoir.--Water-stage recorder in SW1/4SW1/4 sec. 32, T. 14 N., R. 4 E., on Jemez River. Completed in 1953; capacity, 259,423 acre-ft at elevation 5,271.20 ft. Maximum controlled capacity at elevation 5,232.0 ft (floor of spillway) is 97,425 acre-ft by 1998 survey. Reservoir is operated by Corps of Engineers for flood control and sediment storage. A sediment pool of about 2,000 acre-ft of transmountain water has been maintained since August 1979.

Month-end elevation, in feet, and contents, in acre-feet

Date	Elevation	Contents	Change in contents	Transmountain water
December 31, 2000	5,173.69	4,510	-	4,390
January 31, 2001	5,173.99	4,640	+130	4,350
February 29	5,172.50	3,990	-650	4,300
March 31	5,172.27	3,890	-100	4,180
April 30	5,180.96	9,410	+5,520	3,980
May 31	5,183.49	11,510	+2,100	3,920
June 30	5,179.09	7,940	-3,570	791
July 31	5,176.54	6,060	-1,880	0
August 31	5,175.13	5,210	-850	0
September 30	5,171.70	3,660	-1,550	0
October 31	5,155.59	0	-3,660	0
November 30	5,155.00	0	0	0
December 31	5,155.00	0	0	0
Calendar year 2001	-	-	-4,510	-

Acomita Reservoir.--Staff gage in SE1/4 sec. 29, T. 10 N., R. 7 W., on San Fidel Arroyo; water for reservoir is diverted from Rio San Jose. Completed in 1938; original capacity, 850 acre-ft; present capacity, 650 acre-ft on basis of 1956 sediment survey. Water is used for irrigation on Acoma Indian Reservation. Storage omitted from accounting by action of Commission on March 23, 2000.

Month-end contents, in acre-feet

Calendar Year 2001

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Cal. yr.
Contents	-	-	-	-	-	-	-	-	-	-	-	-	-
Change	-	-	-	-	-	-	-	-	-	-	-	-	-

Seama Reservoir.--In sec. 36, T. 10 N., R. 7 W., off channel from Rio San Jose. Completed in October 1980; capacity approximately 400 acre-ft. Water is used for irrigation on Laguna Indian Reservation.

No storage during 2001.

Reservoirs in Rio Grande Basin in New Mexico
(project storage)

Elephant Butte Reservoir.--Water-stage recorder in NW1/4 sec. 30, T. 13 S., R. 3 W., on Rio Grande. Storage began Jan. 6, 1915; capacity, 2,023,400 acre-ft at gage height 4,407.0 ft (crest of spillway), by survey of 1999 with flood control storage reservation of 50,000 acre-ft from April through September and 25,000 acre-ft from October through March in accordance with the Sept. 9, 1998, resolution of the Rio Grande Compact Commission. Datum of gage is 43.3 ft above mean sea level, datum of 1929. Water is used for power development and irrigation in New Mexico and Texas. Records furnished by Bureau of Reclamation. Delivery of transmountain water for minimum recreation pool was initiated in December 1975. Beginning Jan. 1, 1977, gage readings are midnight readings.

Month-end gage height, in feet, and contents, in acre-feet

Date	Gage height	Contents	Change in contents	Transmountain water
December 31, 2000	4,381.74	1,268,340	-	10,840
January 31, 2001	4,383.24	1,306,110	+37,770	10,670
February 29	4,381.04	1,250,970	-55,140	10,640
March 31	4,378.92	1,199,420	-51,550	10,570
April 30	4,376.48	1,142,020	-57,400	10,450
May 31	4,375.16	1,111,830	-30,190	10,320
June 30	4,372.26	1,047,610	-64,220	10,140
July 31	4,367.38	946,010	-101,600	10,020
August 31	4,363.86	877,360	-68,650	9,920
September 30	4,362.60	853,720	-23,640	9,840
October 31	4,362.36	849,270	-4,450	9,580
November 30	4,363.70	874,330	+25,060	9,530
December 31	4,364.92	897,630	+23,300	9,490
Calendar year 2001	-	-	-370,710	-

Caballo Reservoir.--Water-stage recorder in SE1/4SW1/4 sec. 19, T. 16 S., R. 4 W., on Rio Grande. Storage began Feb. 8, 1938; capacity, 326,700 acre-ft (by 1999 resurvey), at gage height 4,182.0 ft (above which spillway gates open automatically). Datum of gage is 43.3 ft above mean sea level, datum of 1929. 100,000 acre-ft of storage reserved for flood control. Records furnished by Bureau of Reclamation. Beginning Jan. 1, 1977, gage readings are midnight readings.

Month-end gage height, in feet, and contents, in acre-feet

Date	Gage height	Contents	Change in contents
December 31, 2000	4,142.94	42,850	-
January 31, 2001	4,144.12	42,490	-360
February 29	4,157.33	108,370	+65,880
March 31	4,154.82	92,970	-15,400
April 30	4,155.46	96,760	+3,790
May 31	4,155.68	98,080	+1,320
June 30	4,151.12	72,740	-25,340
July 31	4,148.96	62,240	-10,500
August 31	4,144.40	43,500	-18,740
September 30	4,132.18	12,320	-31,180
October 31	4,129.26	7,610	-4,710
November 30	4,131.04	10,380	+2,770
December 31	4,138.44	25,490	+15,110
Calendar year 2001	-	-	-17,360

Reservoirs in Rio Grande Basin in New Mexico
(project storage)

Project storage.--The combined usable storage in Elephant Butte and Caballo Reservoirs.

Month-end contents, in acre-feet

Date	Contents	Change in contents
December 31, 2000	1,311,200	-
January 31, 2001	1,348,600	+37,400
February 29	1,359,300	+10,700
March 31	1,292,400	-66,900
April 30	1,238,800	-53,600
May 31	1,209,900	-28,900
June 30	1,120,400	-89,500
July 31	1,008,200	-112,200
August 31	920,900	-87,300
September 30	866,000	-54,900
October 31	856,900	-9,100
November 30	884,700	+27,800
December 31	923,100	+38,400
Calendar year 2001	-	-388,100

NOTE.--Values of combined contents may not agree with sum of individual values because of rounding.

TRANSMOUNTAIN DIVERSIONS

Pine River - Weminuche Pass ditch (Fuchs ditch).--Water-stage recorder and 3-ft Parshall flume in sec. 33, T. 40 N., R. 4 W., at Weminuche Pass in Colorado. Diversion is from North Fork Los Pinos River in San Juan River Basin into Weminuche Creek in Rio Grande Basin. Second enlargement was completed in 1936. Diversion for irrigation is from Rio Grande above the Del Norte gaging station.

Weminuche Pass ditch (Raber-Lohr ditch).--Water-stage recorder and 4-ft rectangular flume in sec. 33, T. 40 N., R. 4 W., at Weminuche Pass in Colorado. Diversion is from Rincon la Vaca Creek in San Juan River Basin into Weminuche Creek in Rio Grande Basin. Second enlargement was completed in 1936. Diversion for irrigation is from Rio Grande above the Del Norte gaging station.

Williams Creek - Squaw Pass ditch.--Water-stage recorder and 2-ft Parshall flume in sec. 21, T. 39 N., R. 3 W., at Squaw Pass in Colorado. Diversion is from Williams Creek in San Juan River Basin into Squaw Creek in Rio Grande Basin. Constructed in 1938. Diversion for irrigation is from Rio Grande below Del Norte gaging station.

Tabor ditch.--Water-stage recorder and 3-ft Parshall flume in sec. 35, T. 43 N., R. 3 W., at Spring Creek Pass in Colorado. Diversion is from Cebolla Creek in Gunnison River Basin into tributary of Clear Creek in Rio Grande Basin. Completed in 1910 or 1911. Diversion for irrigation is from Rio Grande below Del Norte gaging station.

Don La Font No. 1 & 2 ditches (Piedra Pass ditch).--Water-stage recorder and 2-ft Parshall flume in sec. 4, T. 38 N., R. 1 W., at Piedra Pass in Colorado. Diversion is from tributaries of Piedra River in San Juan River Basin to South River in Rio Grande Basin. Original ditch completed in 1938; first enlargement completed in 1940. Water is imported by Colorado Game and Fish Department, beginning in 1959, to offset losses from fish culture reservoirs.

Treasure Pass diversion ditch.--Water-stage recorder and 2-ft Parshall flume in sec. 31, T. 38 N., R. 2 E., at Wolf Creek Pass in Colorado. Diversion is from Wolf Creek in San Juan River Basin to a tributary of South Fork Rio Grande. Completed in 1923 or 1924. Water is diverted for irrigation from Rio Grande above the Del Norte gaging station, beginning in 1959. Prior to 1959 it was diverted below gaging station.

Azotea tunnel.--Water-stage recorder and 10-ft Parshall flume, lat 36°51'12", long 106°40'18", at south portal of Azotea tunnel, San Juan-Chama Project. Diversion is from Rio Blanco, Little Navajo River, and Navajo River in Colorado and discharge is into Azotea Creek in New Mexico. Construction completed in 1970.

Imported quantities, in acre-feet, 2001

Month	Pine River-Weminuche Pass ditch	Weminuche Pass ditch	Williams Creek-Squaw Pass ditch	Tabor ditch	Don La Font ditches	Treasure Pass diversion ditch	Azotea tunnel
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	1,510
April	0	0	0	0	0	0	19,280
May	0	0	0	38	0	0	51,090
June	236	0	258	204	0	46	29,280
July	83	0	87	113	0	11	4,640
August	46	0	40	65	0	0	4,460
September	55	0	2	48	0	0	310
October	42	0	0	13	0	0	0
November	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0
Calendar year	462	0	387	501	0	57	110,570

EVAPORATION AND PRECIPITATION

The last paragraph of Article VI of the Compact states, in part, --- "such credits and debits shall be reduced annually to compensate for evaporation losses in the proportion that such credits or debits bear to the total amount of water in such reservoirs during the year."

To provide the data needed for the computation of such evaporation losses, the Commission has encouraged the establishment and operation of evaporation stations near each major reservoir in the basin and at other selected locations.

Evaporation and other climatological data collected at the several stations in Colorado and New Mexico are tabulated on the next page. At some of the stations, it was not possible to obtain evaporation records throughout the winter period.

The measurements of evaporation were made in accordance with standard practice for the type of pan in use. Measurements of precipitation were made in standard 8-inch rain gages, which were supplemented at some of the stations by recording rain gages.

Records for the evaporation stations at the State University, Elephant Butte Dam, and El Vado Dam antedated the creation of the Commission; the stations at Abiquiu Dam, Cochiti Dam, and Jemez Canyon Dam were established by the Corps of Engineers. All others were established at the request of the Commission.

The Rio Grande Compact Commission gratefully acknowledges the cooperation of the National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, and U.S. Bureau of Reclamation for furnishing the climatological records contained in this report.

Alamosa Airport.--Lat 37°27', long 105°52', in Alamosa County at airport near Alamosa, Colo. Standard class A pan, anemometer, maximum and minimum thermometers, standard 8-inch and recording rain gages at elevation 7,536 ft.

Platoro Dam.--Lat 37°21', long 106°30', in Conejos County near Platoro, Colo. Standard class A pan, anemometer, maximum and minimum thermometers, fan type psychrometer, standard 8-inch and recording rain gages at elevation 9,826 ft.

Heron Dam.--Lat 36°40', long 106°42', in Rio Arriba County about 4 mi. northeast of Heron Dam near Tierra Amarilla, N. Mex. Standard class A pan, maximum and minimum thermometers, and standard 8-inch rain gage at elevation 7,310 ft.

El Vado Dam.--Lat 36°36', long 106°44', in Rio Arriba County at El Vado Dam near Tierra Amarilla, N. Mex. Standard class A pan, anemometer, maximum and minimum thermometers, standard 8-inch and recording rain gages at elevation 6,750 ft.

Abiquiu Dam.--Lat 36°14', long 106°26', in Rio Arriba County at Abiquiu Dam near Abiquiu, N. Mex. Standard class A pan, maximum and minimum thermometers, standard 8-inch and recording rain gages at elevation 6,380 ft.

Nambe Falls Dam.--Lat 35°51', long 105°54', in Santa Fe County at Nambe Falls Dam, N. Mex. Standard class A pan, maximum and minimum thermometers, recording thermograph, standard 8-inch and recording rain gages at elevation 6,840 ft.

Cochiti Dam.--Lat 35°38', long 106°19', in Sandoval County at operations building, at Cochiti Dam, N. Mex. Standard class A pan, anemometer, maximum and minimum thermometers, standard 8-inch and recording rain gages at elevation 5,560 ft.

Jemez Canyon Dam.--Lat 35°23', long 106°32', in Sandoval County at Jemez Canyon Dam, N. Mex. Standard class A pan, anemometer, maximum and minimum thermometers, standard 8-inch and recording rain gages at elevation 5,388 ft.

Elephant Butte Dam.--Lat 33°09', long 107°11', in Sierra County at Elephant Butte Dam, N. Mex. Standard class A pan, anemometer, maximum and minimum thermometers, and standard 8-inch rain gage at elevation 4,576 ft.

Caballo Dam.--Lat 32°54', long 107°18', in Sierra County at Caballo Dam, N. Mex. Standard class A pan, anemometer, maximum and minimum thermometers, standard 8-inch and recording rain gages at elevation 4,190 ft.

New Mexico State University.--Lat 32°17', long 106°45', in Doña Ana County at University Park, N. Mex. Standard class A pan, anemometer, maximum and minimum thermometers, standard 8-inch and recording rain gages at elevation 3,881 ft.

EVAPORATION AND PRECIPITATION
2001

Evaporation and precipitation, in inches

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Alamosa Airport	Evap.	-	-	-	-	-	-	-	-	-	-	-	-	-
	Precip.	0.36	0.56	1.02	0.27	1.09	0.07	2.75	3.22	0.11	0.03	0.26	0.13	9.87
Platoro Dam	Evap.	-	-	-	-	4.72	8.88	6.60	4.37	4.39	3.40	-	-	-
	Precip.	-	-	-	-	0.12	0.94	3.01	0.46	1.33	0.91	-	-	-
Heron Dam	Evap.	-	-	-	5.04	8.09	9.81	8.32	6.86	7.22	4.60	-	-	-
	Precip.	1.76	0.73	1.82	1.21	1.91	0.31	2.58	1.98	0.30	0.54	1.25	0.79	15.18
El Vado Dam	Evap.	-	-	-	5.64	8.31	10.10	9.01	7.27	6.86	5.70	-	-	-
	Precip.	1.20	0.27	0.74	0.94	0.71	0.61	1.69	2.33	0.20	0.62	0.95	0.41	10.67
Abiquiu Dam	Evap.	-	-	-	7.49	10.77	12.02	9.80	8.52	8.30	5.88	-	-	-
	Precip.	0.57	0.35	0.09	0.48	0.46	0.17	2.46	1.11	0.31	0.17	0.91	0.27	7.35
Nambe Falls Dam	Evap.	-	-	-	4.50	7.69	11.67	7.96	6.12	6.36	4.37	-	-	-
	Precip.	1.08	0.02	0.0	0.0	1.58	0.77	1.67	2.43	0.13	0.16	0.37	0.0	8.21
Cochiti Dam	Evap.	-	-	-	8.22	10.72	13.94	12.60	10.58	10.28	7.14	-	-	-
	Precip.	1.48	0.46	0.39	0.36	0.64	0.65	1.13	2.19	0.51	0.09	0.24	0.53	8.67
Jemez Canyon Dam	Evap.	-	-	-	9.22	11.97	15.73	17.01	15.59	13.91	5.60	-	-	-
	Precip.	0.16	0.46	0.42	0.12	0.28	0.18	1.76	1.38	0.70	0.16	0.30	0.14	6.06
Elephant Butte Dam	Evap.	2.70	5.38	7.88	13.00	15.34	19.11	15.70	12.71	11.68	9.88	6.06	3.84	123.28
	Precip.	1.17	0.79	0.21	0.0	0.50	0.57	1.45	1.65	1.76	0.09	0.24	0.20	8.63
Caballo Dam	Evap.	2.83	4.39	7.06	11.31	13.24	15.23	12.89	11.70	10.57	8.06	4.79	3.30	105.37
	Precip.	0.92	0.77	0.11	0.03	0.86	0.95	0.99	1.19	1.50	0.15	0.10	0.05	7.62
State Univer.	Evap.	-	-	6.95	9.90	11.08	11.97	11.90	10.60	8.79	7.26	4.79	-	-
	Precip.	0.29	0.17	0.35	0.04	0.71	0.36	0.99	1.49	0.61	0.01	0.21	0.02	5.25

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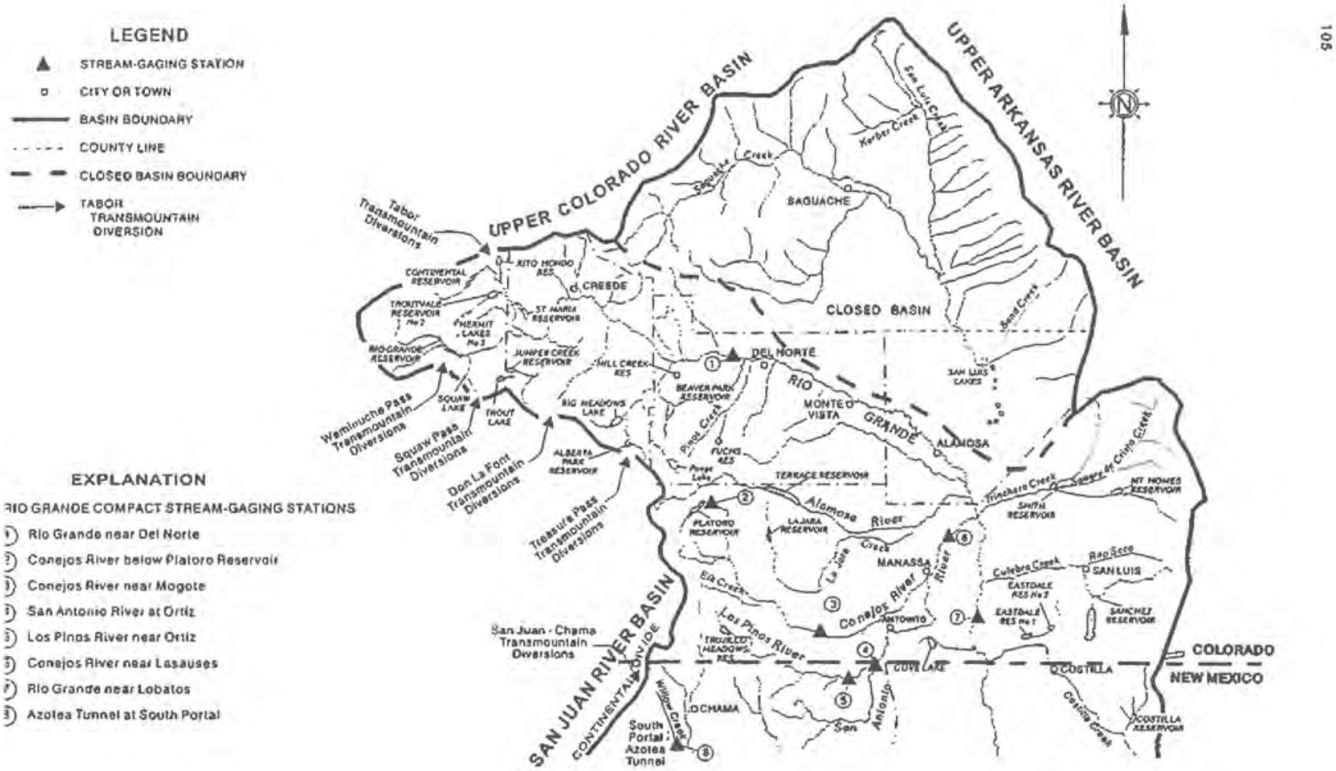
LEGEND
STREAM-GAGING STATION
CITY OR TOWN
BASIN BOUNDARY
COUNTY LINE
CLOSED BASIN BOUNDARY
TABOR TRANSMOUNTAIN DIVERSION
EXPLANATION
RIO GRANDE COMPACT STREAM-GAGING STATIONS
1 Rio Grande near Del Norte
2 Conejos River below Platoro Reservoir
3 Conejos River near Mogote
4 San Antonio River at Ortiz
5 Los Pinos River near Ortiz
6 Conejos River near Lasauses
7 Rio Grande near Lobatos
8 Azotea Tunnel at South Portal
UPPER COLORADO RIVER BASIN
UPPER ARKANSAS RIVER BASIN
SAN JUAN RIVER BASIN
CONTINENTAL DIVIDE
CLOSED BASIN
SAGUACHE
CREEDE
DEL NORTE
MONTE VISTA
ALAMOSA
MANASSA
SAN LUIS
COSTILLA
CHAMA
COLORADO
NEW MEXICO
Tabor Transmountain Diversions
Weminuche Pass Transmountain Diversions
Squaw Pass Transmountain Diversions
Don La Font Transmountain Diversions
Treasure Pass Transmountain Diversions
San Juan - Chama Transmountain Diversions
South Portal Azotea Tunnel
RIO GRANDE
Alamosa River
Conejos River
Los Pinos River
Trinchera Creek
Culebra Creek
TERRACE RESERVOIR
PLATORO RESERVOIR
SANCHEZ RESERVOIR
COSTILLA RESERVOIR


9 Willow Creek above Heron Reservoir
10 Horse Lake Creek above Heron Reservoir
11 Willow Creek below Heron Reservoir, near Parkview
12 Rio Chama below El Vado Dam
13 Rio Chama below Abiquiu Dam
14 Rio Grande at Otowi Bridge
15 Santa Fe River near Santa Fe
16 Rio Grande below Cochiti Dam
17 Galisteo Creek below Galisteo Dam
18 Jemez River below Jemez Canyon Dam
NOTE: Screened areas denote reservoirs, whose capacity is all or in part subject to provisions of the
Rio Grande Compact
Revised March 1989
RIO GRANDE BASIN
ABOVE BERNALILLO, NEW MEXICO
0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS
SAN JUAN RIVER BASIN
CANADIAN RIVER BASIN
PECOS RIVER BASIN
CONTINENTAL DIVIDE
HERON RES
EL VADO RES
TIERRA AMARILLA
TRES PIEDRAS
QUESTA
RED RIVER
TAOS
ABIQUIU RES
ABIQUIU
ESPAÑOLA
CUBA
SAN GREGORIO RES
LOS ALAMOS
SANTA FE
NICHOLS RES
McCLURE RES
NAMBE FALLS RES
SANTA CRUZ RES
COCHITI LAKE
GALISTEO RESERVOIR
JEMEZ CANYON RESERVOIR
BERNALILLO
RIO GRANDE
RIO CHAMA
JEMEZ RIVER
RIO PUERCO
Embudo Creek
Galisteo Creek

Tab 5

No. 141, Original

In the

SUPREME COURT OF THE UNITED STATES

STATE OF TEXAS,

Plaintiff,

v.

STATE OF NEW MEXICO and
STATE OF COLORADO,

Defendants.

OFFICE OF THE SPECIAL MASTER

DECLARATION OF WILLIAM R. HUTCHISON IN SUPPORT OF THE STATE OF TEXAS'S MOTION FOR PARTIAL SUMMARY JUDGMENT; MEMORANDUM OF POINTS AND AUTHORITIES IN SUPPORT THEREOF FEDERAL RULE OF CIVIL PROCEDURE 56

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**Counsel of Record*

October 29, 2020

I, William R. Hutchison, declare as follows:

BACKGROUND AND EXPERIENCE

1. My name is William R. Hutchison, Ph.D., P.E., P.G. I was born on November 4, 1958 in Nueces County, Texas, and I am competent to make this declaration.

2. I am an independent consultant with over 35 years of professional experience as a groundwater hydrologist. I have been retained by the State of Texas to provide consulting services on hydrologic issues presented in the Lawsuit. My professional resume is included as Attachment 1.

3. My street address is 16717 Captain Hook Road, Jamaica Beach, TX 77554. The United States Postal Service does not provide home mail service to my address. My mailing address is 9305 Jamaica Beach, Jamaica Beach, TX 77554.

4. My education includes a Bachelor of Science degree in Soil and Water Science from the University of California, Davis, a Master of Science degree in Hydrology from the University of Arizona, and a Ph.D. in Environmental Science and Engineering from the University of Texas at El Paso.

5. I am licensed in Texas as follows: Professional Engineer (Geological and Civil) No. 96287, Engineering Firm No. 14526, and Professional Geoscientist (Geology) No. 286.

6. From August 1983 to October 2001, I was employed by various consulting firms or worked as an independent consultant in California and Arizona.

7. From October 2001 to June 2009, I was employed by El Paso Water Utilities in El Paso, Texas.

8. From June 2009 to August 2011, I was the Director of the Groundwater Resources Division of the Texas Water Development Board in Austin, Texas.

9. From August 2011 to July 2012, I was employed by LBG-Guyton Associates in Austin, Texas.

10. Since July 2012, I have been an independent consultant based in Austin,

Texas (July 2012 to July 2015), Aberdeen, North Carolina (July 2015 to January 2016), and Jamaica Beach, Texas (January 2016 to present).

11. I have completed (or I am actively working on) over 60 consulting assignments for over 30 different clients in Texas.

12. In the last four years, I have testified as an expert witness in two cases.

13. In August 2016, I was retained by the Middle Pecos Groundwater Conservation District to testify at a mandamus action filed against the District by Republic Water Company of Texas, LLC (Republic). Republic sued the District to have its permit application declared administratively complete despite not including results from a model run, which was required by the rules of the District. My testimony involved details of the required model run. The Court agreed with the District's interpretation of the District's administrative completeness requirements.

14. In March 2019, I was retained as an expert witness for the General Manager of the Lost Pines Groundwater Conservation District in a contested case hearing. The Lower Colorado River Authority submitted eight applications to withdraw 25,000 acre-feet of water per year from eight wells in Bastrop County, Texas. I prepared an expert report and pre-filed written testimony regarding the use of models to evaluate potential impacts of the proposed pumping. As part of the assignment, I reviewed model runs of the applicant's and protesting parties' experts. Specifically, I processed model output to assess surface water-groundwater interaction impacts, provided predicted impacts to over 2,600 registered wells in the District, and processed model output to provide predicted impacts to 39 monitoring wells for use in future monitoring. I was deposed on my expert report and pre-filed written testimony, and I testified at the contested case hearing.

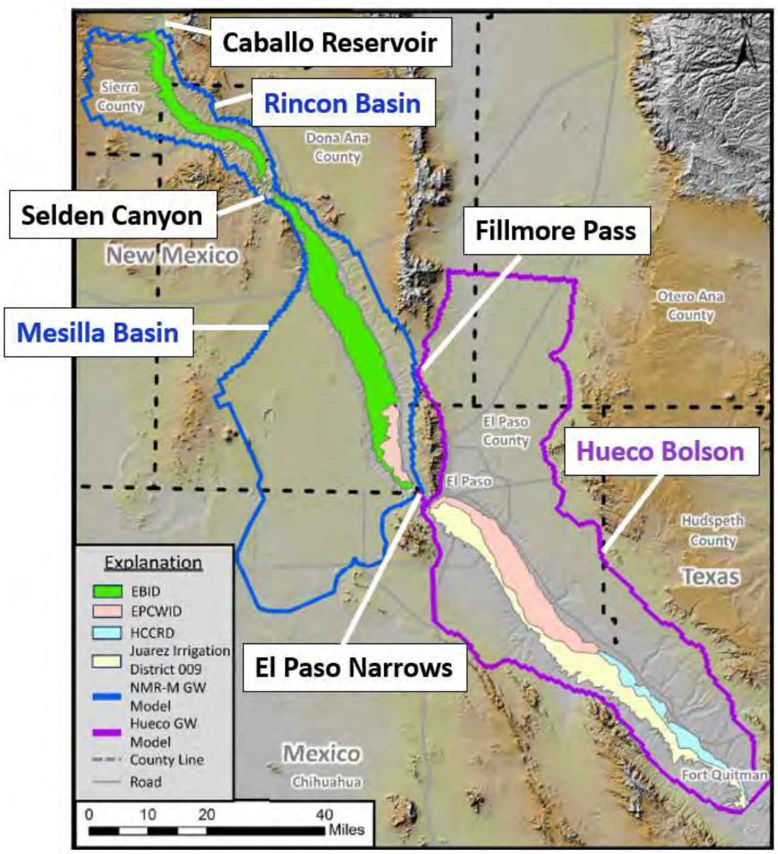
15. A summary of my experience with developing, reviewing, updating, and running simulations with 37 groundwater models in Texas since 2001 is presented in Attachment 2, and 24 models outside of Texas prior to 2001 is presented in Attachment 3.

16. My direct experience in the El Paso, Texas area began in 2001 as an employee of El Paso Water Utilities.

17. In 2006, I completed my doctoral dissertation, titled Groundwater Management in El Paso, Texas, which included details of modeling and management of the Mesilla Basin in New Mexico and Texas.

HYDROGEOLOGIC BACKGROUND

18. The map shown is a modified version of a map in the expert report of Daniel J. Morrissey, one of the New Mexico experts, and is intended to provide some geographic background of the surface water and groundwater resources of the El Paso area. The only modifications to Mr. Morrissey's version of the map is that the labeling in white boxes was added.



19. Water is released from Caballo Reservoir and flows in the Rio Grande through the Rincon Basin.

20. The Rio Grande flows through Selden Canyon from the Rincon Basin to the Mesilla Basin.

21. The Rio Grande flows through the El Paso Narrows from the Mesilla Basin to the El Paso Valley, where the groundwater basin is known as the Hueco Bolson.

22. The Rio Grande at El Paso stream gage is in the El Paso Narrows.

23. The two major diversion points on the Rio Grande just below the El Paso Narrows are the Acequia Madre (for Mexico) and the American Canal (for Texas).

24. The Rincon Basin is entirely in New Mexico (the green area of the map).

25. Most of the Mesilla Basin is in New Mexico (the green area of the map). A small area at the southern end of Mesilla Basin (upstream of the El Paso Narrows) is in Texas (the peach area of the map).

26. Throughout the Rincon and Mesilla Basins in both New Mexico and Texas, there has been varying amounts of groundwater pumping for irrigated agriculture, municipal use, industrial, commercial, domestic, and livestock use.

27. Groundwater flow from the Rincon and Mesilla Basins to the Hueco Bolson is limited to minor flow through Fillmore Pass and the El Paso Narrows due to the geologic structure of the area. This hydrogeologic isolation between the basins means that the Rio Grande at El Paso stream gage is an ideal location to measure and assess impacts of groundwater pumping in the Rincon and Mesilla Basins to Rio Grande flow.

28. Because of the relative geologic isolation and the minimal flow between the Rincon-Mesilla Basin and the Hueco Bolson, groundwater models of the Rincon-Mesilla Basin and the Hueco Bolson can be developed independently.

29. Surface water and groundwater are connected in the Rincon and Mesilla Basins. As water flows in a surface water feature (i.e. a stream, canal, or river), the surface water flow can either increase from the inflow of groundwater or decrease due to seepage losses to the underlying aquifer.

30. When groundwater elevations are higher than surface water elevations, groundwater flows into the surface water body and surface flow increases (a gaining stream condition). Figure 1 conceptually illustrates a gaining stream condition.

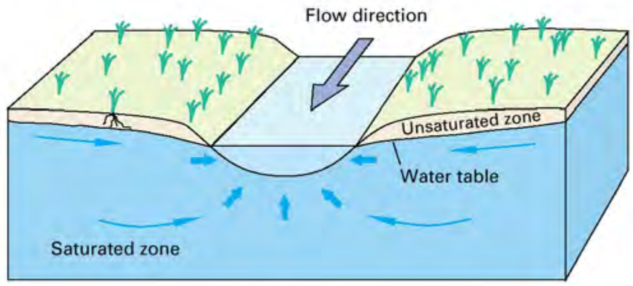


Figure 1. Illustration of a Gaining Stream (from Winter and others, 1988)

31. When groundwater elevations are lower than surface water elevations, surface water flows into the surrounding aquifer and surface flow decreases (a losing stream condition). Figures 2 and 3 conceptually illustrate two types of losing stream conditions.

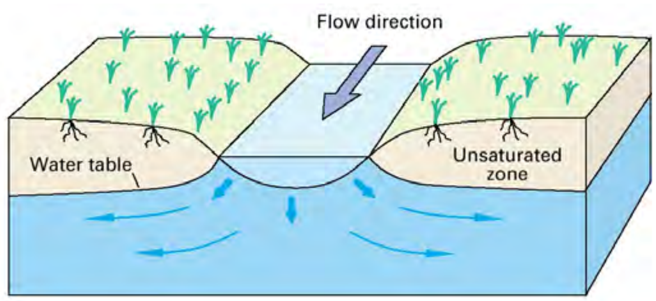


Figure 2. Illustration of a Losing Stream (from Winter and others, 1988)

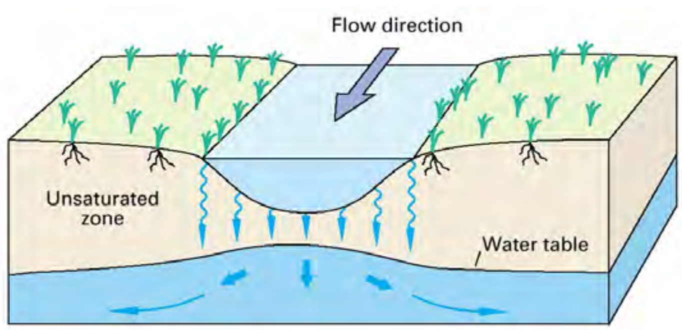


Figure 3. Illustration of a Disconnected Stream (from Winter and others, 1988)

32. Figure 2 illustrates a condition where groundwater elevations are lower than the stream elevation, but still connected to the stream bottom. This is a losing stream condition, and the seepage rate out of the stream is dependent on the difference between the elevation of the water in the stream and the elevation off the groundwater.

33. Figure 3 illustrates a condition where groundwater elevations have dropped lower than the stream bottom elevation. In this case (a disconnected stream), the seepage rate out of the stream has reached its maximum and is based on the depth of the stream only.

34. One of the impacts of groundwater pumping is the reduction of groundwater elevations (also known as drawdown). Long-term groundwater pumping can result in drawdown to the point where a stream that has been historically gaining (i.e. groundwater flows into the stream providing base flow) can be changed to a losing or disconnected stream (i.e. water percolates out of the stream and recharges the underlying aquifer).

SUMMARY OF NEW MEXICO MODEL (INTEGRATED LOWER RIO GRANDE MODEL)

35. New Mexico has disclosed the "Integrated Lower Rio Grande Model" (ILRGM) for use in this case. The ILRGM combines a River Ware model of the surface water network (and includes a simplified representation of the shallow groundwater system) and two detailed groundwater flow models using the MODFLOW-OWHM code: one of the Rincon Basin and the-Mesilla Basin and one of the Hueco Bolson.

36. One of the important outputs from the ILRGM is the flow of the Rio Grande in the El Paso Narrows (Rio Grande at El Paso). As described above, the El Paso Narrows represents the geographic and hydrogeologic boundary between the Mesilla Basin (upstream) and the El Paso Valley (downstream). If groundwater pumping in the Rincon and Mesilla Basins results in stream depletions, it can be measured at the gaging station in the El Paso Narrows. Any model that simulates surface water-groundwater interactions of the Rincon and Mesilla Basins should reproduce historic flows at this measuring point and should be capable of quantitatively assessing depletions at this measuring point.

37. As described in the expert reports of Greg Sullivan and Heidi Welsh, New Mexico completed a calibration run of the model (Run 0) simulating historic conditions from 1940 to 2017, a run simulating historic conditions using Rio Grande Project operations rules developed by New Mexico experts (Run 1), and 26 predictive simulations using the ILRGM.

38. The relevant ILRGM runs for this declaration are:

- Run 3 – NM Pumping Off (all New Mexico pumping off);
- Run 6 – RM Pumping Off (all Rincon-Mesilla pumping off); and
- Run 7 – TX Mesilla Pumping Off (all Texas pumping in the Mesilla Basin off).

39. These "pumping off" runs hypothetically assumed no groundwater pumping from 1940 to 2017 and resulted in higher simulated Rio Grande at El Paso flows as compared to the historic operation simulation (Run 1). Under the pumping off runs, groundwater elevations in the Rincon and Mesilla Basins are generally higher than the groundwater elevations in the Rincon and Mesilla Basins in the Run 1 simulation. The higher groundwater elevations result in more groundwater discharge to the surface water system (canals, drains and the Rio Grande itself), and, thus, results in higher surface water flows.

40. The New Mexico experts interchangeably use the terms "depletion" and "pumping impact" in the text of their reports, the figures associated with the reports, and the Excel spreadsheets that contain the results of the ILRGM simulations. New Mexico experts generally calculated depletion as the difference between the stream flow associated with a "no pumping" run of the ILRGM and the stream flow associated with the historic operation run of the ILRGM (Run 1).

ILRGM RIO GRANDE DEPLETION RESULTS

41. New Mexico experts provided ILRGM results for the relevant runs of the model in the following Excel spreadsheets:

- *Run 1 Summary – Operational – All Pumping On v116.xlsx*;
- *Run 3 Summary – Operational – NM Pumping Off v116.xlsx*;

- *Run 6 Summary – Operational – RM Pumping Off v116.xlsx*; and
- *Run 7 Summary – Operational – TX Mesilla Pumping Off v116.xlsx*.

42. New Mexico completed a specific analysis of Rio Grande at El Paso depletions using data and results from the ILRGM results described above. Attachment 4 is the *DataAnn* sheet of the Excel file named *Ferguson Rebuttal revised 9-15-20 v116.xlsx* that was disclosed by New Mexico.

43. The first line of Attachment 4 distinguishes results from the ILRGM, and calculations completed in the spreadsheet for the depletion analysis. The first eight columns are labeled "ILRG", which means that the data in the columns are directly from ILRGM. The final 11 columns are labeled "Calc", which means that the data in the columns are calculations completed in this spreadsheet based on ILRGM results. Please note that the blue color of the "Calc" columns was from the original Excel file disclosed by New Mexico.

44. The results in the *DataAnn* sheet of the Excel file can be grouped as follows:

- Rio Grande at El Paso Flow;
- Northwest Wastewater Treatment Plant (WWTP) Discharge;
- Sum of Rio Grande at El Paso Flow and Northwest WWTP Discharge;
- Pumping Impact in acre-feet per year; and
- Specific State Pumping Impact as a Percentage of Total Impact.

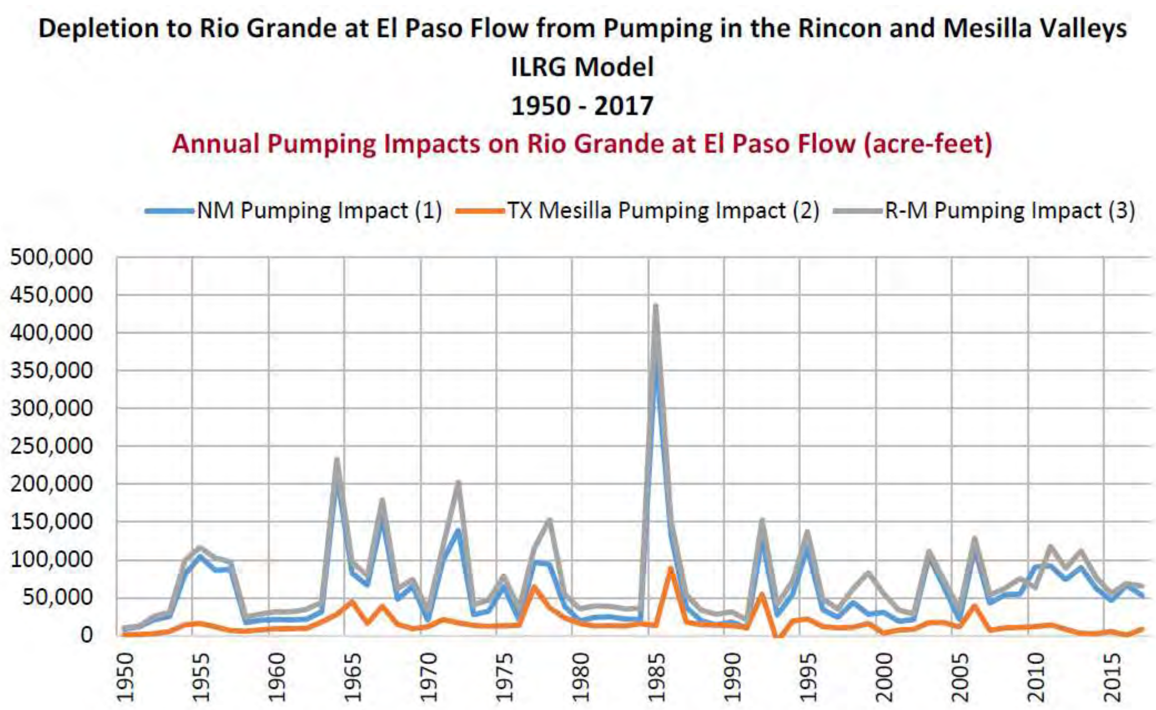
45. WWTP flow is from Texas Mesilla pumping Rio Grande at El Paso flow, Northwest WWTP discharge, and the sum of Rio Grande at El Paso flow and Northwest WWTP discharge are provided for each model run (Run 1, Run 3, Run 6, and Run 7) in the spreadsheet.

46. The Northwest WWTP is a El Paso Water facility that treats municipal wastewater from the west side of El Paso. The source of the water supply on the west side of El Paso (and, thus, the origin of the wastewater) is almost exclusively from groundwater pumping in the Texas portion of the Mesilla Basin (i.e. the Canutillo well field).

47. The Northwest WWTP discharge enters the Rio Grande downstream of the Rio Grande at El Paso stream gage. Thus, the sum of Rio Grande at El Paso and the Northwest WWTP discharge represents the available flow for diversions to the Acequia Madre (Mexico) and the American Canal (Texas) below the El Paso Narrows.

48. The difference in the sum of Rio Grande at El Paso flow and Northwest WWTP between a relevant "no pumping" run and the historic operation simulation (Run 1) is defined as the "pumping impact" in the spreadsheet (in acre-feet per year), and is either termed "depletion" or "pumping impact" in the text and figures of the New Mexico expert reports.

49. The annual depletions were presented in Figure 19-2 (page 147) of the September 15, 2020 version of the report by Greg Sullivan and Heidi Welsh and is reproduced below.



50. The columns on the right side of the *DataAnn* sheet (Attachment 4) are calculations of the pumping impact caused by each state's pumping expressed as a percentage of the total impact. New Mexico experts alternatively defined the total impact as

the impact simulated in Run 6 or as the sum of the impact simulated in the two state runs (Run 3 and Run 7), so there are two calculations of each state's impact.

51. The final line of New Mexico's spreadsheet with ILRGM results related to streamflow depletions (Attachment 4) are the average flows and depletions (calculated for each column in the spreadsheet) for the period 1940 to 2017.

52. Average stream depletions (or groundwater pumping impacts) as calculated at the Rio Grande at El Paso gage for the period 1940 to 2017 based on ILRGM results (as shown in Attachment 4) were reported by experts retained by New Mexico as follows:

- Total Rincon-Mesilla Groundwater Pumping Impact: 66,351 AF/yr
- New Mexico Groundwater Pumping Impact: 52,610 AF/yr
- New Mexico Groundwater Pumping Impact: 79 percent of total impact
- Texas Mesilla Groundwater Pumping Impact: 13,700 AF/yr
- Texas Mesilla Groundwater Pumping Impact: 21 percent of total impact

DISCUSSION OF ILRGM RESULTS AND ILRGM LIMITATIONS

53. The analysis presented in the spreadsheet (Attachment 4) completed by New Mexico experts establishes that groundwater pumping in New Mexico has depleted surface water flow in the Rio Grande.

54. In addition, Daniel J. Morrissey, one of New Mexico's experts acknowledged that the ILRGM shows depletions due to pumping in the Rincon and Mesilla Basins to streamflow measured at El Paso (Morrissey deposition, December 9, 2019, page 75, lines 12 to 18).

55. The ILRGM can be used for analyses that focus on large geographic areas and over a period of few to several years.

56. Limitations of the ILRGM affect the reliability of results focused on a single year or time periods less than one year, and results that focus on a small geographic area. The geographic and temporal scale limitation of ILRGM results is primarily because the

RiverWare model "governs" the results (Daniel J. Morrissey deposition of December 10, 2019, page 65, lines 13 to 23).

57. All models are simplifications of real-world systems. The New Mexico RiverWare model calculates surface water-groundwater interaction within "groundwater objects" that are several square miles in area. In contrast, the New Mexico groundwater models of the Rincon-Mesilla Basins and the Hueco Bolson calculates surface water-groundwater interactions in cells that are 10 acres in area. The groundwater objects in the RiverWare model are analogous to the groundwater model cells when comparing the surface water-groundwater interaction calculations. Daniel J. Morrissey acknowledged that the calculations in the RiverWare model are more "generalized" than in the groundwater models (Daniel J. Morrissey deposition of December 10, 2019, page 65, lines 6 to 12).

58. In summary, the ILRGM calculations rely on surface water-groundwater interaction calculations that are averaged over an area of several square miles and ignore groundwater model calculations that are averaged over an area of 10 acres in the groundwater models.

59. The surface water-groundwater interaction issue is one of the most important aspects of this litigation. Stream depletion is a reduction in streamflow that is caused by groundwater pumping. Calculations of stream depletion with the groundwater models are averaged over areas of about 10 acres, but calculations with the RiverWare model represent averages over areas that are several square miles. The choice by New Mexico experts to rely on the RiverWare model results instead of the groundwater model results is inconsistent with their claims of the sophistication and necessary complexity of the ILRGM (e.g. Daniel J. Morrissey deposition of December 9, 2019, page 44, line 22 to page 45, line 4).

60. Reliance on the ILRGM and its simplified representation of the surface water-groundwater interactions in the RiverWare model is appropriate for evaluating impacts of pumping over a large scale (i.e. impacts of pumping in New Mexico and impacts of pumping in Texas) and over a few to many years.

61. However, the limitations prevent reliable use of ILRGM results for analyses over smaller scales (several square miles) and for short time scales (months to a single year).

CONJUNCTIVE MANAGEMENT

62. Estevan Lopez, one of New Mexico's expert witnesses, defined conjunctive use during his July 6, 2020 deposition on page 68, lines 3 to 6 as: "using the available surface water as the primary irrigation supply and making up the difference up to the crop irrigation requirements with supplemental groundwater."

63. A proper conjunctive management approach increases total supply because the surface water component and the groundwater component are different sources.

64. If the groundwater supply is connected to the surface water supply (i.e. they are interconnected), the groundwater pumping depletes the surface water supply to some extent. The surface water depletion component of the groundwater pumping is not a "new supply" or "separate supply."

65. New Mexico's practice of conjunctive use is to use surface water ***and*** to pump interconnected groundwater limited only by crop needs or permit limits (Estevan Lopez 30(b)(6) deposition, September 18, 2020 page 36, lines 17 to 22).

66. New Mexico's "conjunctive use" as defined by Mr. Lopez ensures that New Mexico water users receive all the water they need while decreasing some water that would have otherwise flowed into Texas.

I declare under penalty of perjury that the foregoing is true and correct. Executed this 29th day of October 2020 at Aberdeen, North Carolina

William R Hutchison

William R. Hutchison, Ph.D., P.E., P.G

Tab 6

ATTACHMENT 1

Attachment 1

October 2020

WILLIAM R. HUTCHISON, Ph.D., P.E., P.G.

Independent Groundwater Consultant
9305 Jamaica Beach
Jamaica Beach, TX 77554
512-745-0599
billhutch@texasgw.com

EDUCATION

University of Texas at El Paso: Ph.D., Environmental Science and Engineering, 2004-2006
University of Arizona: M.S., Hydrology, 1980-1981, 1982-1983
University of California, Davis: B.S., Soil and Water Science, 1976-1980

PROFESSIONAL LICENSES

Professional Engineer (Geological and Civil) No. 96287 (Texas)
Engineering Firm Registration No. 14526 (Texas)
Professional Geoscientist (Geology) No. 286 (Texas)
Registered Professional Geologist No. 0779 (Mississippi)

PROFESSIONAL HISTORY

Organization and Location(s)	Position	Dates
Independent Groundwater Consultant Jamaica Beach, TX		2012 – pres.
LBG-Guyton Associates Austin, TX	Associate	2011 – 2012
Texas Water Development Board Austin, TX	Director, Groundwater Resources Division	2009 – 2011
El Paso Water Utilities El Paso, TX	Water Resources Manager	2006 – 2009
	Hydrogeology Manager	2003 – 2006
	Hydrogeologist	2001 – 2003
TEAM Engineering and Management, Inc. Bishop, CA and Phoenix, AZ	Senior Hydrologist	1998 – 2001
Woodward-Clyde Consultants Santa Ana, CA and Phoenix, AZ	Associate	1996 – 1998
	Sr. Project Hydrologist	1993 – 1996
Luhdorff & Scalmanini Consulting Engineers Woodland, CA	Principal Hydrologist	1991 – 1993
	Senior Hydrologist	1988 – 1991
Inyo County Water Department Bishop, CA (now in Independence, CA)	County Hydrologist	1985 – 1988
Geothermal Surveys, Inc. South Pasadena, CA	Hydrologist	1983 – 1985
University of Arizona Tucson, AZ	Research Assistant	1982 – 1983
Mobil Oil Corporation Denver, CO and Glendive, MT	Hydrologist	1981
Metropolitan Water District of Southern California Yorba Linda, California	Intern	1979

REPRESENTATIVE CONSULTING EXPERIENCE SINCE 2011

Groundwater Model of Rincon and Mesilla Basins (New Mexico, Texas, Mexico)

Developed a groundwater model using MODFLOW-USG along with associated pre- and post-processors as an expert witness for the State of Texas for the Texas v. New Mexico litigation. The primary issue of the litigation is the impact of groundwater pumping on Rio Grande streamflow. The model uses a variable grid of Voronoi cells and incorporated data and information on historic surface water and groundwater use for irrigation. (2012 to present)

Groundwater Management Plan for Middle Pecos Groundwater Conservation District

Consultant to the Middle Pecos Groundwater Conservation District in Pecos County, Texas in the preparation of an update to their management plan. This assignment required revising the previous plan in terms of format and content to reflect updated policies related to updated management zone boundaries, special permit conditions, and comparisons of monitoring data to adopted desired future conditions. A review draft plan was prepared and approved by the Texas Water Development Board with no changes. After a public hearing, the plan was approved by the District Board of Directors, and final administrative completeness approval was obtained by the Texas Water Development Board. (2020)

Update to Groundwater Availability Model for the Southern Carrizo-Wilcox Aquifer

Principal Hydrogeologist for a team of consultants developing an updated flow model for the Southern Carrizo-Wilcox Aquifer (GMA 13 area of Texas) under a contract with the Texas Water Development Board. The updated model uses MODFLOW 6 and will address documented issues with the current model related to outcrop area calibration, surface water-groundwater interactions, and application to long-term predictive simulations. (2019 to present)

Update to Groundwater Availability Model for the Northern Carrizo-Wilcox Aquifer

Principal Hydrogeologist for a team of consultants developing an updated flow model for the Northern Carrizo-Wilcox Aquifer (GMA 11 area of Texas) under a contract with the Texas Water Development board. The updated model uses MODFLOW 6 and will address documented issues with the current model related to outcrop area calibration, surface water-groundwater interactions, and application to long-term predictive simulations. (2017 to present)

Groundwater Monitoring Thresholds in Pecos County, Texas

Reviewed historic groundwater data and model results to develop a groundwater monitoring plan, including regulatory thresholds for eleven specific monitoring wells. The regulatory thresholds were used in the settlement of several years of litigation between the Middle Pecos Groundwater Conservation District and a permit applicant. Work on implementing the settlement continues with the development of an expanded monitoring program, including expansion of establishing a baseline of groundwater quality, spring flow, and vertical gradients. (2017 to present)

Joint Planning in Groundwater Management Areas 2, 3, 4, 7, and 11 (3rd Round)

Consultant for GMAs 2, 3, 4, 7, and 11 to develop updated desired future conditions. Included in this effort are the review of aquifer conditions and uses, review of water management strategies, review of hydrologic information and data, developing future pumping estimates, running alternative simulations with the Groundwater Availability Models, and preparing explanatory reports. (2019 to present)

Lower Colorado River Authority Groundwater Permit Contested Case Hearing

Consultant for the General Manager of the Lost Pines Groundwater Conservation District. The Lower Colorado River Authority (LCRA) submitted eight applications to the Lost Pines Groundwater Conservation District seeking authorization to withdraw 25,000 acre-feet of water per year from eight wells in Bastrop County. Dr. Hutchison was retained an expert witness for the General Manager of the Lost Pines Groundwater Conservation District for a contested case hearing before the Texas State Office of Administrative Hearings. Dr. Hutchison prepared an expert report and pre-filed written testimony regarding the use of models to evaluate potential impacts of the proposed pumping. As part of the assignment, Dr. Hutchison reviewed model runs completed by the applicant's and protesting parties' experts. Specifically, Dr. Hutchison processed model output to assess surface water-groundwater interaction impacts, provided predicted impacts to over 2,600 registered wells in the District, and processed model output to provide predicted impact to 39 monitoring wells for use in future monitoring. Dr. Hutchison was deposed on the expert report and pre-filed testimony and testified at the hearing. In a Proposal for Decision, the Administrative Law Judges recommended that the Lost Pines Groundwater Conservation District issue the Operating and Transport Permits with some recommended changes. The Lost Pines Groundwater Conservation District has not yet acted on the application. (2019 to present)

<u>Groundwater Model for Pecos County, Texas</u>
Developing a groundwater model that covers all aquifers in Pecos County. The five aquifers in the county are covered in four regional groundwater models which limits the ability to fully understand the vertical connection between the aquifers. Initial geologic work to focus and improve the complex faulting and structure has been completed by other District consultants. Work on developing a numerical groundwater flow model is underway and should be completed in late 2021. (2019 to present)

<u>Groundwater Management Activities in Kinney County, Texas</u>
Completed a management plan update, reviewed permit applications, and initiated a data collection effort in Kinney County for the Kinney County Groundwater Conservation District. Currently developing an updated groundwater flow model of Kinney County that will be used for management initiatives and rules revisions. (2013 to present)

<u>Joint Planning in Groundwater Management Areas 2, 3, 4, 7, 11, and 13 (2nd Round)</u>
Consultant for GMAs 2, 3, 4, 7, 11 and 13 to develop updated desired future conditions. Included in this effort were the review of aquifer conditions and uses, review of water management strategies, review of hydrologic information and data, developing future pumping estimates, running alternative simulations with the Groundwater Availability Models, and preparing explanatory reports. (2012 to 2018)

<u>Groundwater Flow and Transport Model of Lower Rio Grande Valley</u>
Principal Hydrogeologist for a team of consultants that developed a flow and transport model for the Lower Rio Grande Valley using MODFLOW-USG under a contract for the Texas Water Development Board. The model objectives included the simulation of 23 water management strategies related to proposed fresh groundwater development and brackish groundwater desalination plants. Simulation results included quantitative estimates of groundwater elevation changes, changes in salinity, and impacts to surface water flows. (2015 to 2017).

<u>Groundwater Model Reviews in Pecos County, Texas</u>
Reviewed two existing groundwater models for Middle Pecos Groundwater Conservation District: one developed by the USGS in 2014 and one developed by a team of consultants in 2011. The models were evaluated in terms of how they could be used for predictive simulations in support of developing desired future conditions and in support of permit applications. (2016 to 2017)

Joint Planning Support for Bluebonnet Groundwater Conservation District and Lower Trinity Groundwater Conservation District

Dr. Hutchison has provides consulting services to the Bluebonnet Groundwater Conservation District (Austin, Grimes, Waller and Walker counties) and the Lower Trinity Groundwater Conservation District (Polk and San Jacinto counties) to support the joint planning process in Groundwater Management Area 14. Completed analyses and simulations related to a proposal to revise the desired future conditions pursuant to a request by Lone Star Groundwater Conservation District. The request to revise the desired future conditions adopted in 2016 was part of the settlement of litigation over the reasonableness of the desired future conditions. The requested revision was reviewed and documented, and various alternative revisions were simulated using inverse runs of the Groundwater Availability Model to provide perspective on the requested revision. Work continues in the support of these districts in the development of new desired future conditions by Groundwater Management Area 14. (2018 to present)

Groundwater Availability Model Development using MODFLOW-USG

As a consultant to the Hickory Underground Water Conservation District No. 1, Dr. Hutchison worked with staff of the Texas Water Development Board in the development of the Groundwater Availability Model for the Llano Uplift Aquifers. This model was developed with MODFLOW-USG. (2013 to 2016)

Hydrogeologic Study of Val Verde County, Texas

Completed a hydrogeologic study of the Edwards-Trinity (Plateau) Aquifer in Val Verde County for the County of Val Verde and City of Del Rio. The study included developing, calibrating, and applying a groundwater flow model of the area to assess impacts of proposed pumping on local spring flow and Rio Grande flows. (2013 to 2014)

Subsidence Analysis for Bluebonnet Groundwater Conservation District

As part of a rules revision that simplified the permitting process for small diameter wells and included more detailed requirements to consider subsidence analysis in the permit review process, simulations have been completed to estimate the maximum pumping that would avoid subsidence using the Houston Area Groundwater Model, which had been adopted by TWDB as the Groundwater Availability Model for the northern portion of the Gulf Coast Aquifer. (2014 to 2015)

Comparison of Groundwater Monitoring Data with Groundwater Model Results

As part of the current round of joint groundwater planning, completed assignments for groundwater conservation districts in Groundwater Management Area 9 and Groundwater Management Area 13 to compare groundwater monitoring data with groundwater model results from the desired future conditions process. These efforts examined, in detail, the various assumptions used in developing the initial round of desired future conditions adopted in 2010. (2012 to 2013)

Groundwater Model Review Panel

Participated as a member of the Groundwater Review Panel for the Edwards Aquifer Authority related to the new finite element model being developed for the Edwards Aquifer by Southwest Research Institute. (2012 to 2015)

Groundwater Transport Permit Review

A private landowner submitted a permit application to transport 22,500 acre-feet per year of groundwater from Austin and Waller Counties to the cities of Richmond and Rosenberg in Fort Bend County. Dr. Hutchison completed the technical review of the application for the Bluebonnet Groundwater Conservation District as part of a contested case hearing. The applicant subsequently withdrew the application. (2012 to 2014)

Well Classification Study and Hydrogeologic Report Guidelines Update

Over 2,500 wells in the Bluebonnet Groundwater Conservation District (Austin, Grimes, Waller and Walker Counties) were evaluated to determine the aquifer completion interval by comparing the screened interval with various groundwater models of the region (Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, and Gulf Coast). The results of this evaluation were used to update and enhance the review process of permit applications submitted to the district. (2012 to 2014)

Rules Update for Bluebonnet Groundwater Conservation District

Based on the well classification study and the review of the groundwater transport permit (please see above), the Board of Directors completed a revision to the district rules that simplified the permitting process for small diameter wells and included more detailed requirements to consider subsidence analysis in the permit review process. (2014)

Groundwater Management Plan for Red River Groundwater Conservation District

Consultant to the Red River Groundwater Conservation District in Fannin and Grayson Counties in the preparation of their initial management plan. This assignment required compiling and organizing the goals, objectives, and performance measures from management plans of neighboring districts, preparing a handout for Board members, and reviewing the various approaches with the Board in an open workshop session. Based on the discussion, a draft plan was prepared and approved by the Board. The review draft was subsequently approved by the Texas Water Development Board with no changes. The public hearing and final approval were completed by District personnel as a means of reducing costs. (2012)

Mine Dewatering Groundwater Pumping Permit

Hickory Underground Water Conservation District No. 1 received a permit application from Premier Silica LLC to pump groundwater for dewatering associated with an expansion of an existing aggregate mine in the Brady area. Dr. Hutchison was retained to review the groundwater model that has been developed in support of the permit application, and to review the impact of the proposed pumping on the adopted desired future condition for the Hickory Aquifer. (2012 to 2013)

Evaluation of a Proposed Groundwater Development Project in East Texas

Completed an evaluation of potential effects of a proposed groundwater development project located in Anderson, Cherokee, and Houston counties in east Texas for the Neches & Trinity Valleys Groundwater Conservation District. Consultants for the project proponents and the Texas Water Development Board (TWDB) had previously completed simulations of the proposed pumping using the Groundwater Availability Model (GAM) of the Northern Carrizo-Wilcox Aquifer. Neches & Trinity Valleys Groundwater Conservation District asked for the completion of three tasks: 1) review TWDB GAM run reports, including the GAM run model run that was used to establish Desired Future Conditions, and the GAM run that was used to evaluate the regional effects of the proposed project, 2) extend the previous analyses of the project proponent's consultant and the TWDB by evaluating the effects of the proposed pumping on specific wells, and 3) recommend and monitoring network. The analysis was presented to the Neches & Trinity Valleys Groundwater Conservation District and was presented at the GMA 11 petition hearing in February 2012. (2011 to 2012)

Evaluation of Groundwater Availability using Groundwater Budget Analysis

Completed a groundwater budget analysis to provide data and information pertaining to groundwater availability for a private property owner in California. The analysis involved identifying and quantifying individual components of the inflows to and outflows from the defined area. Based on an analysis of precipitation and groundwater elevation changes, a series of historic groundwater budgets were developed for 20-year periods ranging from 1949-1968 to 1991-2010. The analysis was extended to estimate changes to the groundwater budget, generally, and groundwater elevations, specifically under alternative groundwater pumping scenarios from the subject property. (2011 to 2012)

REPRESENTATIVE AGENCY EXPERIENCE (EPWU and TWDB, 2001 to 2011)

Joint Groundwater Planning in Texas (1st Round)

In 2005, the Texas Legislature adopted HB 1763, which required that groundwater conservation districts within each groundwater management area adopt desired future conditions by September 1, 2010. The Texas Water Development Board provided technical assistance to this process. As Director of the Groundwater Resources Division, Dr. Hutchison was responsible for coordinating the effort of division staff and took the lead in 9 of the 15 Groundwater Management Areas. Technical support included developing and running groundwater models to estimate impacts of alternative pumping scenarios and attending meeting to discuss and interpret the results of these analyses. Partly because of the technical support provided by the Groundwater Resources Division staff, all desired future conditions were adopted prior to the statutory deadline. (2009 to 2010)

Challenges to the Reasonableness of Desired Future Conditions in Texas

Prepared technical reports related to petitions challenging the reasonableness of desired future conditions for Groundwater Management Area 1 (Ogallala Aquifer) and Groundwater Management Area 9 (Edwards Group of the Edwards-Trinity (Plateau) Aquifer). These petitions were filed with the Texas Water Development Board in accordance with statute and agency rules. The technical analysis was submitted to the Board for consideration in their deliberations as to the reasonableness of the adopted desired future condition. (2009 to 2010)

Modeled Available Groundwater Development in Texas

Managed development of modeled available groundwater estimates that were based on the desired future conditions adopted by the groundwater conservation districts. These estimates, required by statute, include estimating the total pumping that will achieve the desired future condition and estimating the exempt use of the area. Prior to the 2011 legislative session, these estimates were termed Managed Available Groundwater, and represented the amount of groundwater available for permitting, and were calculated as the total pumping minus the exempt use. (2010 to 2011)

Update of the Hueco Bolson Model in Chihuahua, New Mexico and Texas

Completed an update of the USGS model of the Hueco Bolson (Texas, New Mexico, and Chihuahua) by extending the model period to 2002. The model was used to complete simulations of alternative groundwater management strategies. Based on the results of this work, recommendations were developed regarding long-term groundwater management strategies for the Hueco Bolson. (2001 to 2003)

Groundwater Availability Model Updates in Texas

Completed updates to groundwater availability models in support of the Joint Groundwater Planning Process in Texas. Updated models included: Dockum Aquifer, Edwards-Trinity (Plateau) Aquifer and Pecos Valley Aquifer, Barton Springs Segment of the Edwards (Balcones Fault Zone) Aquifer, Kinney County portions of the Edwards (Balcones Fault Zone) Aquifer and Edwards-Trinity (Plateau) Aquifer, and Southern Gulf Coast Aquifer (GMA 16 portion). These models were updated because the existing models proved to be inadequate for assisting the groundwater conservation districts in developing desired future conditions. (2009 to 2010)

Groundwater Model of the Dell City, Texas Area

Developed a regional groundwater flow model covering a large area in Hudspeth and Culberson Counties, Texas and Otero County, New Mexico. This objective of this groundwater model was to develop a more complete understanding of the hydrogeology of the karstic aquifer in the region, and develop data and information related to acquiring property and water rights for a potential groundwater importation project for the City of El Paso. In 2016, the model was adopted by the Texas Water Development Board as the official Groundwater Availability Model for the Bone Spring-Victorio Peak Aquifer. (2001 to 2008)

Hueco Bolson Evaluation, Texas

Completed analyses of groundwater flow and groundwater quality of the Hueco Bolson covering west Texas, southern New Mexico, and northern Chihuahua. These analyses included evaluating historic groundwater flow patterns, mapping current groundwater quality in three dimensions, evaluating historic groundwater quality changes caused by pumping, and changes in the groundwater budget including induced inflow from the Rio Grande. Prepared comprehensive report of findings that was peer reviewed by a 5-member panel. Results included the finding that the reduction in groundwater pumping from 1989 to 2002 had fundamentally changed conditions in the Hueco Bolson. Moreover, the assumptions that were the foundation of a conclusion made in a 1979 analysis (depletion of fresh groundwater by 2030) were no longer applicable. (2001 to 2004)

Mesilla Bolson Groundwater Management, El Paso, Texas

Completed analyses of groundwater flow and groundwater quality of the Mesilla Bolson in west Texas and southern New Mexico. These analyses included evaluating previous groundwater models developed for a variety of objectives and analyzing the role of the Rio Grande in the recharge of the Mesilla. As a result of the analyses a series of piezometers were constructed to improve data coverage and long-term monitoring of the area. In addition, limitations to previous models were identified, and work is currently underway to better incorporate the known hydrostratigraphy in an updated and improved model of the area. (2001 to 2009)

Model Documentation of Groundwater Availability Models in Texas

Completed documentation of the Hueco Bolson and Mesilla Bolson groundwater flow models (Texas, New Mexico, and Chihuahua). These models had been previously developed and were designated as official Groundwater Availability Models (GAM) for the Hueco-Mesilla Aquifer by the Texas Water Development Board. Documentation was needed to fully satisfy the requirements of the Texas Water Development Board. (2001 to 2004)

Brackish Groundwater Well Location, El Paso, Texas

Completed analyses of the Hueco Bolson related to locations of new wells for use in the Kay Bailey Hutchison Desalination Plant, a joint project between El Paso Water Utilities and Fort Bliss. After initial concerns were raised by Fort Bliss, an investigation was completed in cooperation with the US Army Corps of Engineers to evaluate five alternative well field locations. The wells were sited to meet the dual objectives of producing a targeted quantity of brackish groundwater for treatment and establishing a hydraulic barrier to prevent further movement of brackish groundwater into areas with municipal wells. Based on this analysis, an alternative was selected and agreed upon. (2003)

Desalination Concentrate Injection Wells in El Paso, Texas

Completed preliminary analyses of impacts from injection wells that were proposed for use as part of the Kay Bailey Hutchison Desalination Plant in El Paso, Texas. The analyses included the development of a simple numerical flow model based on a subsurface geologic model developed by researchers at UTEP from gravity data and on the results from slug tests completed during a test hole drilling project funded and managed by the US Army Corps of Engineers. These analyses were incorporated into the Environmental Impact Statement (EIS) for the overall project. Based on the results of the analysis, a full-size injection well was constructed and tested to obtain better data to support authorization from the Texas Commission on Environmental Quality (TCEQ) under the Underground Injection Control (UIC) program. Once authorization was obtained, two additional wells were constructed, and all three wells were equipped and tested. Issues related to the potential for mineral precipitation in the well bores and reservoir were evaluated with a combination of geochemical modeling, experiments with formation samples, formation water and concentrate, and monitoring of initial operation. (2004 to 2009)

Simulations of Potential Desalination Plant in Mission Valley, El Paso, Texas

Completed a preliminary analysis of a proposed desalination plant in the Mission Valley area of El Paso. This analysis consisted of simulating three potential configurations of well fields to assess impacts to groundwater elevations and gradients, and to estimate potential impacts to the groundwater budget of the area. Based on this analysis, and a companion engineering analysis completed by a consultant, future pre-design work was recommended. (2003)

Impacts of Climate Variability and Climate Change in El Paso, Texas

Analyzed the reliability of El Paso's municipal water supplies under a wide range of climate scenarios, including integration of the Intergovernmental Panel on Climate Change (IPCC) projections for the region. Because El Paso practices conjunctive use management, the analysis included evaluation of impacts to both surface water (Rio Grande) and groundwater impacts. The analysis included developing simulated Rio Grande flows entering Elephant Butte reservoir based on a published 1000-yr tree ring record, developing a simple reservoir operations model to estimate Elephant Butte outflows and El Paso municipal diversions, estimating groundwater pumping, and simulating groundwater storage changes using a groundwater model. A total of 60 climatic scenarios were developed. Each scenario was simulated under 958 50-year simulations for a total of 57,480 simulations. The results demonstrated the effectiveness of the investments in water infrastructure and the efficacy of the management approach that has been developed over the last several decades in meeting municipal water demands over a wide range of climatic conditions. (2007 to 2008)

Region E Water Planning, Far West Texas

Developed the conceptual approach of an Integrated Water Management Strategy for El Paso County that was used in the 2005 Regional Water Plan for Far West Texas. Working with Far West Texas Regional Planning Group and their consultants, the conceptual plan was used to develop six specific alternatives designed to meet expected increased water demands in El Paso County through 2060. Alternatives ranged from reliance on single existing sources to a balanced approach that relied on numerous sources, including importation from Hudspeth, Culberson, Jeff Davis, and Presidio Counties. (2004 to 2005)

Well Construction

Managed a well construction and equipping program while employed by El Paso Water Utilities that resulted in:

- Drilling of 50 test holes
- Construction of 14 monitoring wells
- Construction of 3 multi-zone piezometers
- Construction and equipping of 16 fresh groundwater production wells
- Construction and equipping of 32 brackish groundwater production wells

Well designs and construction management were completed in-house. Equipping design and construction management were supervised through a consulting engineer. (2001 to 2009)

REPRESENTATIVE CONSULTING EXPERIENCE (1983 to 2001)

Owens Valley, California

Hydrology consultant to the Inyo County (California) Board of Supervisors, Water Department, Water Commission and Environmental Health Department from 1985 to 1999 on issues related to water resources management and protection in the Owens Valley and Death Valley regions, including a key role in the development and negotiation of an historic water management agreement between Inyo County and the City of Los Angeles for the Owens Valley and the preparation of the associated environmental documentation. Assignments also included review and analysis of the Anheuser-Busch groundwater export project in the Cartago area, review and analysis of the groundwater pumping proposed by OLSAC in the Cottonwood Creek area, review and analysis of the groundwater export project proposed by Western Water in the Olancha area, and many others. Many of these assignments included the development and application of groundwater models and the development of monitoring networks and environmental triggers and thresholds to manage the pumping operations. (1985 to 1999)

Owens Valley Indian Reservation Groundwater Modeling

Completed local scale groundwater models of three Indian Reservations in the Owens Valley, California. The regional model developed by the USGS was used as a starting point for these models. The initial phase consisted of using Telescopic Mesh Refinement to define the boundary conditions of the three local scale models. Subsequent phases included enhancing and updating the local scale models. The preliminary model of the Big Pine area was used to evaluate potential increases in pumping that are associated with the Big Pine Ditch System project. (2000 to 2006)

Los Angeles Aqueduct Simulation Model

Consultant to the California State Water Resources Control Board related to the Mono Basin Water rights decision, a court ordered review of water rights licenses held by the City of Los Angeles. Working in partnership with State Board staff and Board members, hydrologic analyses were completed, and a simulation model (LAAMP) of the Mono Basin and Los Angeles Aqueduct system was developed and applied to evaluate the impacts of alternative water rights decisions. The simulation model was accepted by all parties involved in the process and was ultimately used in the final water rights decision that resulted in decreased diversions in order to maintain fish flows and restore lake elevation. (1992 to 1994)

Tri-Valley Groundwater Evaluation, Mono County, California

Completed a preliminary groundwater model for the Tri-Valley Groundwater Management District in Mono County, California. This model was based on existing data and was used to preliminarily evaluate the potential impacts of a proposed groundwater export project. Based on the model results, additional data requirements were identified and recommended for Phase 2 of the project. (2000 to 2001)

Evaluation of Impacts of Increased Capacity of Salinas Dam, California

Completed analyses related to the evaluation of potential downstream impacts of increased storage capacity of the Salinas Dam in central California. These analyses included estimates of reduced spills associated with the increased storage, evaluating the relationship of river flows and groundwater levels in the Atascadero area, and estimating potential groundwater level impacts that may result from the reduced spills. The analyses were summarized in an Environmental Impact Report, and in several technical appendices to the EIR. Because the work involved modification of a water right held by the City of San Luis Obispo, expert witness testimony was given at the California State Water Resources Control Board. (1997 to 1999)

Aggregate Mine Expansion, Ventura County, California

Consultant to Ventura County (California) Resource Management Agency on the analysis of potential hydrologic impacts of the expansion of an aggregate mine. Concerns had been raised about the potential impact of the mine expansion on seawater intrusion and nitrate contamination. The assignment began with the review of a groundwater model prepared by the project proponent's consultant. As a result of the review, the existing analyses was expanded with the development of a site-specific groundwater model to enhance the simulation of the potential impacts on nearby spreading facilities, the development of a solute transport model, the completion of a risk assessment of potential groundwater pollution, and the preparation of the water resources and water quality sections of an Environmental Impact Report. (1995 to 1996)

Simulation of Impacts of Tunnel Construction, California

Developed a finite element model for the Metropolitan Water District of Southern California using FRAC3DVS to simulate groundwater inflow during the construction of the Inland Feeder East Tunnel near San Bernardino, California. The model was calibrated under steady-state conditions using groundwater level data from geotechnical boreholes constructed during the design-phase geotechnical investigation. The model was calibrated under transient conditions using tunnel inflow data and groundwater level changes caused by groundwater inflow into the tunnel. Based on the model results, recommendations were made regarding grouting operations for later phases of construction. (1996 to 2002)

Los Osos Groundwater Model

Updated and enhanced a groundwater model and developed a groundwater management plan for the three water purveyors in Los Osos, California (Southern California Water Co, S&T Mutual Water Company, and Los Osos Community Services District). The original model had been developed in 1987 by the USGS, and the updated version was used to address specific management questions related to construction and operation of a sewer project, seawater intrusion, conjunctive use strategies, and the need to import surface water. (1997 to 2000)

San Benito County Groundwater Evaluation, California

Conducted a countywide evaluation of the groundwater resources of San Benito County, California. This effort included the evaluation of surface water and groundwater quantity and quality, development and calibration of a basin wide numerical model of the groundwater system, and the evaluation of recharge patterns altered by the delivery of supplemental surface water, some of which is used for direct groundwater recharge. At the completion of the model and report, expert witness testimony was given in a groundwater rights lawsuit between a developer and the local water district. Four years after the model was completed, the County requested that the model be updated and enhanced. (1991 to 1992, 1996)

San Luis Obispo Groundwater Evaluation

Completed analyses related to a proposed increase in groundwater pumping in the San Luis Obispo area of central California. The initial analysis consisted of integrating potential local groundwater pumping increases into the reservoir operations planning model used by the City of San Luis Obispo to identify conjunctive use opportunities and limitations. The second phase of the analysis consisted of developing and calibrating a groundwater model of the entire groundwater basin. This model was then used to identify potential impacts of increased pumping on groundwater levels in nearby wells, potential reductions in streamflow, and potential subsidence effects. (2000 to 2001)

Groundwater Management Spreadsheet Models

Developed management tools in the form of empirical models that can be run in a spreadsheet format for the Soquel Creek Water District in central California, and the Vista Irrigation District in southern California. The models were designed to provide a tool for Soquel Creek Water District to manage their groundwater pumping with the objective of preventing seawater intrusion, and by Vista Irrigation District to conjunctively use local surface water, local groundwater, and imported water (1988 to 1991).

Cadiz Valley Groundwater Exploration and Development

Completed a comprehensive groundwater exploration and development project in the Cadiz Valley near the Fenner Gap in the Mojave Desert region of southeastern California. Exploration work included review of available information and data on groundwater conditions and geology. An extensive geophysical study using shallow ground temperatures was completed and results were used to select drilling sites. Three test holes were drilled, and two production wells were constructed and tested. Based on the results of the investigations, a report was prepared, and a groundwater budget of the area was estimated. Sixteen years later, assisted the Metropolitan Water District of Southern California in the review of a proposed groundwater storage and recovery project in the Cadiz Valley. As part of this assignment, the groundwater model that had been developed to evaluate the feasibility and potential impacts of the project was modified and enhanced. (1983 to 1984, 2000 to 2001)

Groundwater Storage Project Evaluation in Southeastern California

Developed groundwater models for four basins in southeastern California to evaluate the feasibility of storing Colorado River water for the Metropolitan Water District of Southern California. These models were used to simulate the storage of water in wet years, “holding” the water for 5 to 10 years, then extracting after the “hold” period. Models were developed for the Hayfield, Palen, Chuckwalla, and Rice Valleys. Based on the initial modeling work, a focused field investigation was completed in the Hayfield Valley are, the site chosen as the most desirable. (1996 to 2001)

PEER REVIEWED PUBLICATIONS

Druhan, Jennifer L., Hogan, James F., Eastoe, Christopher J., Hibbs, Barry J., and Hutchison William R., 2008. Hydrogeologic Controls on Groundwater Recharge and Salinization: A Geochemical Analysis of the Northern Hueco Bolson Aquifer, El Paso, Texas, USA. Hydrogeology Journal, Vol. 16, No. 2, pp. 281-296.

Eastoe, Christopher J., Hibbs, Barry J., Granados-Olivas, Alfredo, Hogan, James F., Hawley, John, and Hutchison, William R., 2008. Isotopes in the Hueco Bolson Aquifer, Texas (USA) and Chihuahua (Mexico): Local and General Implications for Recharge Sources in Alluvial Basins. Hydrogeology Journal, Vol. 16 No. 4, pp.737-747.

Eastoe, Christopher J., Hutchison, William R., Hibbs, Barry J., Hawley, John, and Hogan, James F., 2010. Interaction of a River with an Alluvial Basin Aquifer: Stable Isotopes, Salinity and Water Budgets. J. Hydrol. doi:10.1016/j.jhydrol.2010.10.012.

Hutchison, William R., 2006. Groundwater Management in El Paso, Texas. Ph.D. Dissertation, The University of Texas at El Paso. Obtainable at http://www.dissertation.com/book.php?method=ISBN&book=1581123280

Hutchison, William R. and Hibbs, Barry J., 2008. Ground Water Budget Analysis and Cross-Formational Leakage in an Arid Basin. Ground Water, Vol. 46, No. 3, pp. 384-395.

OTHER PUBLICATIONS (e.g. Conference Proceedings, Magazine Articles)

Hibbs, Barry J. and Hutchison William R., 2006. Environmental Isotopes and Numerical Models Estimate Induced Recharge in the El Paso/Juarez Area. In: Increasing Freshwater Supplies, 2006 UCOWR/NIWR Annual Conference Proceedings, Santa Fe, New Mexico.

Hutchison, William R., 2006. Desalination of Brackish Groundwater and Deep Well Injection of Concentrate in El Paso, Texas. In: Stars of the Future, Reuse & Desalination, 2006 WateReuse Association Annual Symposium Proceedings.

Hutchison, William R., 2006. Integrated Water Management Strategies for the City and County of El Paso. In: Increasing Freshwater Supplies, 2006 UCOWR/NIWR Annual Conference Proceedings, Santa Fe, New Mexico.

Hutchison, William R., 2007. El Paso Groundwater Desalination Project: Initial Operation. Water Reuse and Desalination, As Bright as the Florida Sun, 2007 WateReuse Association Annual Symposium Proceedings.

Hutchison, William R., 2008. Deep Well Injection of Desalination Concentrate in El Paso, Texas. Southwest Hydrology, Vol. 7, No. 2, March/April 2008, pp. 28-30.

Hutchison, William R., 2008. Desalination of Brackish Groundwater and Deep Well Injection of Concentrate in El Paso, Texas. Texas WET, Vol. 25, No. 5, September 2008, pp. 5-8.

Norman, Monique and Hutchison, William R., 2020. Groundwater Management Area Joint Planning. Chapter 21 of Sahs, Mary K (ed.), Essentials of Texas Water Resources, Sixth Edition, State Bar of Texas, Environmental & Natural Resources Law Section.

AGENCY REPORTS (2002-present)

Hutchison, William R., 2002. Documentation of Files for Steady State and Annual Versions of Groundwater Flow Model of Hueco Bolson. El Paso Water Utilities Hydrogeology Report 02-01.

Hutchison, William R., 2002. Conceptual Model of the Groundwater Flow System, Bone Spring-Victorio Peak Aquifer, Salt Basin and Diablo Plateau, Hudspeth and Culberson Counties, Texas. El Paso Water Utilities Hydrogeology Report 02-02.

Hutchison, William R., 2003. Hueco Bolson Groundwater Model Update. El Paso Water Utilities Hydrogeology Report 03-01.

Hutchison, William R., 2003. Lower Valley Desalination Well Analysis. El Paso Water Utilities Hydrogeology Report 03-03.

Hutchison, William R., 2004. Hueco Bolson Groundwater Conditions and Management in the El Paso Area. El Paso Water Utilities Hydrogeology Report 04-01

Hutchison, William R., 2004. Documentation of Files for Canutillo Wellfield Groundwater Flow Model. El Paso Water Utilities Hydrogeology Report 04-03.

Hutchison, William R., 2008. Preliminary Groundwater Flow Model, Dell City Area, Hudspeth and Culberson Counties, Texas. El Paso Water Utilities Hydrogeology Report 08-01.

Hutchison, William R., 2008. Conceptual Evaluation of Surface Water Storage in El Paso County. El Paso Water Utilities Hydrogeology Report 08-02. Prepared for the Far West Texas Regional Planning Group.

Hutchison, William R., 2017. Predictive Simulation Report: Lower Rio Grande Valley Groundwater Transport Model. Report Submitted to Texas Water Development Board, October 31, 2017.

Hutchison, William R., Davidson, Sarah C., Brown, Brenner J., and Mace, Robert E. (editors), 2009. Aquifers of the Upper Coastal Plains of Texas. Texas Water Development Board, Report 374.

Hutchison, William R. and Granillo, Jose A., 2004. Preliminary Analysis of Impacts of Joint Desalination Facility Injection Wells. El Paso Water Utilities Hydrogeology Report 04-02.

Hutchison, William R. and Hill, Melissa E., 2011. Recalibration of the Edwards BFZ (Barton Springs Segment) Aquifer Groundwater Flow Model. Texas Water Development Board, Unnumbered report.

Hutchison, William R.; Hill, Melissa E.; Anaya, Roberto, Hassan, Mohammed M.; Oliver, Wade; Jigmond, Marius; Wade, Shirley, 2011. Groundwater Management Area 16 Groundwater Flow Model. Texas Water Development Board, Unnumbered report.

Hutchison, William R.; Jones, Ian C.; Anaya, Roberto; and Jigmond, Marius, 2011. Update of the Groundwater Availability Model for the Edwards-Trinity (Plateau) and Pecos Valley Aquifers. Texas Water Development Board, Unnumbered report.

Hutchison, William R., Pease, R. Eric and Hess, Suzanne, 2003. Joint Desalination Facility Blend Well Analysis. El Paso Water Utilities Hydrogeology Report 03-02.

Hutchison, William R.; Shi, Jerry; and Jigmond, Marius, 2011. Groundwater Flow Model of the Kinney County Area. Texas Water Development Board, Unnumbered report.

Jigmond, Marius, Hutchison, William R., Shi, and Jianyou (Jerry), 2014. Final Report: Groundwater Availability Model of the Seymour Aquifer in Haskell, Knox, and Baylor Counties. Texas Water Development Board, Unnumbered report.

Oliver, Wade and Hutchison, William R., 2010. Modification and Recalibration of the Groundwater Availability Model of the Dockum Aquifer. Texas Water Development Board, Unnumbered report.

Panday, Sorab; Rumbaugh, James; Hutchison, William R.; and Schorr, Staffan; 2017. Numerical Model Report: Lower Rio Grande Valley Groundwater Transport Model. Report submitted to Texas Water Development Board, 23 October 2017.

Schorr, Staffan; Hutchison, William R.; Panday, Sorab; and Rumbaugh, James, 2017. Conceptual Model Report: Lower Rio Grande Valley Groundwater Transport Model. Report submitted to Texas Water Development Board, June 30, 2017.

Shi, Jianyou(Jerry): Boghici, Radu: Kohlrenken, William, and Hutchison, William R., 2016. Conceptual Model Report: Minor Aquifers in Llano Uplift Region of Texas. Texas Water Development Board, March 7, 2016, 305p.

Shi, Jianyou(Jerry): Boghici, Radu: Kohlrenken, William, and Hutchison, William R., 2016. Numerical Model Report: Minor Aquifers of the Llano Uplift Region of Texas (Marble Falls, Ellenburger-San Saba, and Hickory). Texas Water Development Board, November 4, 2016.

Wade, Shirley C., Hutchison, William R., Chowdhury, Ali H., and Coker, Doug, 2011. A Conceptual Model of Groundwater Flow in the Presidio and Redford Bolsons Aquifers. Texas Water Development Board, August 2011, 102p.

Tab 7

ATTACHMENT 2

Attachment 2
William R. Hutchison, Ph.D., P.E., P.G. - Groundwater Modeling Experience in Texas

Model	Area	Developed Model		Updated Model	Reviewed Model	Simulations with Model
		Primary Role	Secondary Role			
Bluebonnet GCD Model	Southeast Texas	in progress				
Bone Spring-Victorio Peak Aquifer	Dell City area, Texas	x				x
Canutillo Area	West Texas and Southern New Mexico (El Paso area)				x	x
Capitan Reef Complex Aquifer	West Texas				x	x
Central Carrizo-Wilcox Aquifer (Version 2)	Central Texas				x	x
Central Carrizo-Wilcox Aquifer (Version 3)	Central Texas				x	x
Dockum Aquifer GAM	Texas Panhandle, Texas High Plains, and West Texas				x	x
Dockum Aquifer Alternative GAM	Texas Panhandle, Texas High Plains, and West Texas		x			x
Edwards BFZ (Barton Springs Segment) Aquifer	Travis County	x				x
Edwards BFZ (San Antonio Segment) Aquifer	Southwest Texas				x	x
Edwards-Trinity (Plateau) and Pecos Valley Aquifers	West Texas	x				x
GMA 16 Model	Rio Grande Valley (South Texas)	x				x
Hill Country	Central Texas		x			x
Hueco Bolson (USGS)	West Texas, Southern New Mexico, and Mexico			x	x	x
Hueco Bolson Flow and Transport (EPWU)	West Texas, Southern New Mexico, and Mexico		x			x
Kinney County (Version 1)	Southwest Texas	x				x
Kinney County (Version 2)	Southwest Texas	in progress				
Lipan Aquifer GAM	Central Texas				x	x
Llano Uplift Region	Central Texas		x			x
Lower Rio Grande Flow and Transport Model	Rio Grande Valley (South Texas)		x			x
Northern Carrizo-Wilcox Aquifer (Version 2)	Northeast Texas			x	x	x
Northern Carrizo-Wilcox Aquifer (Version 3)	Northeast Texas		in progress			x
Northern Gulf Coast Aquifer (HAGM)	Southeast Texas				x	x
Ogallala Aquifer (Northern portion)	Texas Panhandle				x	x
Ogallala Aquifer (Northern portion)	Texas High Plains and West Texas				x	x
Ogallala, Dockum, ETHP Aquifers (HPAS)	Texas Panhandle, Texas High Plains, and West Texas				x	x
Pecos County (USGS)	West Texas				x	x
Pecos County (MPGCD)	West Texas	in progress				
Presidio and Redford Bolsons	West Texas		x			
Rustler Aquifer	West Texas				x	x
Seymour Aquifer	North Texas		x			
Southern Carrizo-Wilcox Aquifer	Southwest Texas				x	x
Southern Carrizo-Wilcox Aquifer (Version 2)	Southwest Texas		in progress			
Val Verde County	Southwest Texas	x				x
Western Pecos County (Harden and others)	West Texas				x	x
West Texas Bolsons and Igneous Aquifer	West Texas				x	x
Yegua-Jackson Aquifer	Southwest Texas				x	x

Tab 8

ATTACHMENT 3

Attachment 3
William R. Hutchison, Ph.D., P.E., P.G. - Groundwater Modeling Experience Outside of Texas

Model	Area	Developed Model		Updated Model	Reviewed Model	Simulations with Model
		Primary Role	Secondary Role			
Big Pine Area Model	Owens Valley, CA	x				x
Bishop Area Model	Owens Valley, CA	x				x
Cadiz Area Model	San Bernadino County, CA				x	x
Casa Grande Area Model	Pinal County, AZ	x				x
Chuckwalla Valley Model	San Bernadino County, CA	x				x
Hayfield Valley Model	San Bernadino County, CA	x				x
Hollywood Reservoir Groundwater Model	Los Angeles County, CA	x				x
Independence Area Model	Owens Valley, CA	x				x
Inland Feeder Model - Badlands	Riverside County, CA	x				x
Inland Feeder Model - Mountain	San Bernadino County, CA	x				x
Kaweah Area Model	Tulare County, CA				x	
Lone Pine Area Model	Owens Valley, CA	x				x
Los Osos Model	San Luis Obispo County, CA	x				x
Modesto-Turlock Model	Stanislaus County, CA	x				x
Mojave Area Model	Kern County, CA	x				x
Owens Valley Model	Owens Valley, CA				x	x
Palen Valley Model	San Bernadino County, CA	x				x
Piceance Basin Model	Western Colorado		x			
Rice Valley Model	San Bernadino County, CA	x				x
San Benito County Model (original version and update)	San Benito County, CA	x		x		x
San Luis Obispo Model	San Luis Obispo, CA	x				x
Swall Meadows Area Model	Mono County, CA	x				x
Tri-Valley Model	Mono County, CA	x				x
Ventura Slice Model	Ventura County, CA	x				x

Tab 9

ATTACHMENT 4

Attachment 4

DataAnn sheet of Excel file named ***Ferguson Rebuttal_revised 9-15-20v116.xlsx***

Source	ILRG	ILRG	ILRG	ILRG	ILRG	ILRG	ILRG	ILRG	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.
				ILRG MODEL RESULTS										**ILRG MODEL RESULTS**					
Note	Run 1	Run 3	Run 7	Run 6	Run 1	Run 3	Run 7	Run 6	Run 1	Run 3	Run 7	Run 6	Run 3	Run 7	Run 6				
Year	El Paso Flow (Base Run 1)	El Paso Flow (NM Pump Off Run 3)	El Paso Flow (TX Mesilla Pump Off Run 7)	El Paso Flow (R-M Pump Off Run 6)	Northwest WWTP Discharge (Base Run 1)	Northwest WWTP Discharge (NM Pump Off Run 3)	Northwest WWTP Discharge (TX Mesilla Pump Off Run 7)	Northwest WWTP Discharge (R-M Pump Off Run 6)	El Paso Flow + NW (Base Run 1)	El Paso Flow + NW (NM Pump Off Run 3)	El Paso Flow + NW (TX Mesilla Pump Off Run 7)	El Paso Flow + NW (R-M Pump Off Run 6)	NM Pumping Impact (1)	TX Mesilla Pumping Impact (2)	R-M Pumping Impact (3)	NM Pumping Impact (1) / R-M Pumping Impact (3)	TX Mesilla Pumping Impact (2) / R-M Pumping Impact (3)	NM Pumping Impact (1) / Total NM (1) plus TX (2) Pumping Impact	TX Mesilla Pumping Impact (2) / Total NM (1) plus TX (2) Pumping Impact
1938																			
1939																			
1940	552,764	552,736	552,741	552,736	0	0	0	0	552,764	552,736	552,741	552,736	-29	-23	-28	101%	83%	55%	45%
1941	458,189	458,465	458,274	458,480	0	0	0	0	458,189	458,465	458,274	458,480	276	86	291	95%	29%	76%	24%
1942	1,504,863	1,505,016	1,504,880	1,505,027	0	0	0	0	1,504,863	1,505,016	1,504,880	1,505,027	153	18	164	93%	11%	90%	10%
1943	576,168	576,288	576,158	576,287	0	0	0	0	576,168	576,288	576,158	576,287	120	-10	119	101%	-8%	109%	-9%
1944	483,966	483,892	483,811	483,894	0	0	0	0	483,966	483,892	483,811	483,894	-73	-154	-71	103%	217%	32%	68%
1945	545,391	545,480	545,390	545,501	0	0	0	0	545,391	545,480	545,390	545,501	89	-1	110	81%	-1%	101%	-1%
1946	525,340	525,509	525,407	525,552	0	0	0	0	525,340	525,509	525,407	525,552	169	67	212	80%	32%	72%	28%
1947	496,315	496,458	496,350	496,495	0	0	0	0	496,315	496,458	496,350	496,495	143	36	180	79%	20%	80%	20%
1948	497,678	497,695	497,723	497,745	0	0	0	0	497,678	497,695	497,723	497,745	17	45	68	25%	67%	27%	73%
1949	489,207	489,100	489,233	489,141	0	0	0	0	489,207	489,100	489,233	489,141	-107	26	-66	162%	-40%	132%	-32%
1950	388,095	396,991	389,565	398,474	0	0	0	0	388,095	396,991	389,565	398,474	8,896	1,471	10,379	86%	14%	86%	14%
1951	346,936	358,701	348,284	359,954	0	0	0	0	346,936	358,701	348,284	359,954	11,765	1,348	13,018	90%	10%	90%	10%
1952	314,660	335,827	317,304	340,210	0	0	0	0	314,660	335,827	317,304	340,210	21,167	2,644	25,550	83%	10%	89%	11%
1953	361,452	386,715	366,987	392,726	0	0	0	0	361,452	386,715	366,987	392,726	25,263	5,535	31,274	81%	18%	82%	18%
1954	143,986	224,944	158,128	243,156	0	0	0	0	143,986	224,944	158,128	243,156	80,958	14,142	99,170	82%	14%	85%	15%
1955	83,646	188,363	99,836	200,418	0	0	0	0	83,646	188,363	99,836	200,418	104,717	16,190	116,772	90%	14%	87%	13%
1956	91,244	177,134	103,026	193,876	0	0	0	0	91,244	177,134	103,026	193,876	85,890	11,783	102,633	84%	11%	88%	12%
1957	136,149	224,042	142,952	233,534	0	0	0	0	136,149	224,042	142,952	233,534	87,893	6,803	97,385	90%	7%	93%	7%
1958	335,540	352,935	341,522	359,978	0	0	0	0	335,540	352,935	341,522	359,978	17,395	5,983	24,438	71%	24%	74%	26%
1959	350,524	371,102	358,377	379,188	0	0	0	0	350,524	371,102	358,377	379,188	20,578	7,853	28,664	72%	27%	72%	28%
1960	337,479	358,694	346,849	368,883	0	0	0	0	337,479	358,694	346,849	368,883	21,215	9,370	31,404	68%	30%	69%	31%
1961	314,751	335,711	323,880	346,333	0	0	0	0	314,751	335,711	323,880	346,333	20,960	9,129	31,581	66%	29%	70%	30%
1962	320,866	342,663	330,534	355,578	0	0	0	0	320,866	342,663	330,534	355,578	21,798	9,668	34,712	63%	28%	69%	31%
1963	298,952	330,476	316,856	342,948	0	0	0	0	298,952	330,476	316,856	342,948	31,524	17,904	43,996	72%	41%	64%	36%
1964	110,864	324,072	139,102	343,729	0	0	0	0	110,864	324,072	139,102	343,729	213,207	28,238	232,865	92%	12%	88%	12%
1965	227,718	310,568	272,367	324,660	0	0	0	0	227,718	310,568	272,367	324,660	82,850	44,649	96,942	85%	46%	65%	35%
1966	268,926	335,576	285,188	348,512	0	0	0	0	268,926	335,576	285,188	348,512	66,650	16,262	79,587	84%	20%	80%	20%
1967	181,407	337,919	220,530	360,166	0	0	0	0	181,407	337,919	220,530	360,166	156,512	39,123	178,759	88%	22%	80%	20%
1968	256,788	304,573	271,996	318,787	0	0	0	0	256,788	304,573	271,996	318,787	47,784	15,208	61,998	77%	25%	76%	24%
1969	305,283	370,573	314,412	379,714	0	0	0	0	305,283	370,573	314,412	379,714	65,290	9,129	74,431	88%	12%	88%	12%
1970	334,900	354,894	346,776	367,688	0	0	0	0	334,900	354,894	346,776	367,688	19,994	11,876	32,788	61%	36%	63%	37%
1971	247,193	346,919	268,319	366,280	0	0	0	0	247,193	346,919	268,319	366,280	99,727	21,127	119,087	84%	18%	83%	17%
1972	131,542	270,976	148,230	333,742	0	0	0	0	131,542	270,976	148,230	333,742	139,434	16,688	202,200	69%	8%	89%	11%
1973	278,794	306,691	292,285	319,987	0	0	0	0	278,794	306,691	292,285	319,987	27,897	13,492	41,194	68%	33%	67%	33%
1974	321,260	353,391	333,882	368,076	0	0	0	0	321,260	353,391	333,882	368,076	32,131	12,622	46,816	69%	27%	72%	28%
1975	278,465	343,232	291,794	357,246	0	0	0	0	278,465	343,232	291,794	357,246	64,767	13,328	78,780	82%	17%	83%	17%
1976	287,245	308,193	300,648	322,730	0	0	0	0	287,245	308,193	300,648	322,730	20,948	13,404	35,485	59%	38%	61%	39%
1977	210,882	307,934	275,836	326,288	0	0	0	0	210,882	307,934	275,836	326,288	97,052	64,954	115,406	84%	56%	60%	40%
1978	167,704	261,679	204,697	320,876	0	0	0	0	167,704	261,679	204,697	320,876	93,976	36,993	153,173	61%	24%	72%	28%

Attachment 4

DataAnn sheet of Excel file named ***Ferguson Rebuttal_revised 9-15-20v116.xlsx***

Source	ILRG	ILRG	ILRG	ILRG	ILRG	ILRG	ILRG	ILRG	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.
				ILRG MODEL RESULTS										**ILRG MODEL RESULTS**					
Note	Run 1	Run 3	Run 7	Run 6	Run 1	Run 3	Run 7	Run 6	Run 1	Run 3	Run 7	Run 6	Run 3	Run 7	Run 6				
Year	El Paso Flow (Base Run 1)	El Paso Flow (NM Pump Off Run 3)	El Paso Flow (TX Mesilla Pump Off Run 7)	El Paso Flow (R-M Pump Off Run 6)	Northwest WWTP Discharge (Base Run 1)	Northwest WWTP Discharge (NM Pump Off Run 3)	Northwest WWTP Discharge (TX Mesilla Pump Off Run 7)	Northwest WWTP Discharge (R-M Pump Off Run 6)	El Paso Flow + NW (Base Run 1)	El Paso Flow + NW (NM Pump Off Run 3)	El Paso Flow + NW (TX Mesilla Pump Off Run 7)	El Paso Flow + NW (R-M Pump Off Run 6)	NM Pumping Impact (1)	TX Mesilla Pumping Impact (2)	R-M Pumping Impact (3)	NM Pumping Impact (1) / R-M Pumping Impact (3)	TX Mesilla Pumping Impact (2) / R-M Pumping Impact (3)	NM Pumping Impact (1) / Total NM (1) plus TX (2) Pumping Impact	TX Mesilla Pumping Impact (2) / Total NM (1) plus TX (2) Pumping Impact
1979	279,978	318,719	303,521	334,625	0	0	0	0	279,978	318,719	303,521	334,625	38,741	23,544	54,647	71%	43%	62%	38%
1980	332,070	351,451	348,156	367,674	0	0	0	0	332,070	351,451	348,156	367,674	19,381	16,087	35,604	54%	45%	55%	45%
1981	324,245	348,302	337,129	363,596	0	0	0	0	324,245	348,302	337,129	363,596	24,057	12,883	39,350	61%	33%	65%	35%
1982	329,923	354,723	342,975	368,912	0	0	0	0	329,923	354,723	342,975	368,912	24,800	13,052	38,989	64%	33%	66%	34%
1983	306,563	328,447	319,242	341,751	0	0	0	0	306,563	328,447	319,242	341,751	21,884	12,679	35,188	62%	36%	63%	37%
1984	321,246	342,567	337,040	357,589	0	0	0	0	321,246	342,567	337,040	357,589	21,321	15,793	36,343	59%	43%	57%	43%
1985	345,847	717,772	359,179	781,597	0	0	0	0	345,847	717,772	359,179	781,597	371,925	13,332	435,750	85%	3%	97%	3%
1986	1,153,486	1,286,599	1,242,712	1,305,478	0	0	0	0	1,153,486	1,286,599	1,242,712	1,305,478	133,112	89,226	151,992	88%	59%	60%	40%
1987	1,067,954	1,105,757	1,087,980	1,123,877	2,089	2,089	0	0	1,070,042	1,107,845	1,087,980	1,123,877	37,803	17,938	53,835	70%	33%	68%	32%
1988	611,555	631,389	627,790	647,168	2,095	2,095	0	0	613,649	633,483	627,790	647,168	19,834	14,141	33,519	59%	42%	58%	42%
1989	416,354	430,542	432,313	446,723	2,089	2,089	0	0	418,442	432,631	432,313	446,723	14,188	13,870	28,281	50%	49%	51%	49%
1990	295,480	313,611	310,748	328,935	2,089	2,089	0	0	297,568	315,699	310,748	328,935	18,131	13,179	31,367	58%	42%	58%	42%
1991	335,563	345,465	348,312	358,632	2,089	2,089	0	0	337,651	347,553	348,312	358,632	9,902	10,661	20,981	47%	51%	48%	52%
1992	431,819	560,100	488,743	586,431	2,095	2,095	0	0	433,913	562,195	488,743	586,431	128,281	54,829	152,518	84%	36%	70%	30%
1993	613,864	640,841	607,988	657,541	2,089	2,089	0	0	615,953	642,930	607,988	657,541	26,977	-7,965	41,588	65%	-19%	142%	-42%
1994	638,104	692,589	659,473	711,907	2,089	2,089	0	0	640,192	694,678	659,473	711,907	54,486	19,281	71,715	76%	27%	74%	26%
1995	727,783	843,906	757,229	872,395	7,310	7,310	0	0	735,093	851,216	757,229	872,395	116,123	22,136	137,302	85%	16%	84%	16%
1996	525,962	560,367	545,239	581,878	7,331	7,331	0	0	533,293	567,699	545,239	581,878	34,405	11,946	48,584	71%	25%	74%	26%
1997	328,104	352,350	345,813	370,706	7,310	7,310	0	0	335,414	359,660	345,813	370,706	24,246	10,399	35,292	69%	29%	70%	30%
1998	468,057	512,105	486,208	537,413	7,310	7,310	0	0	475,367	519,415	486,208	537,413	44,048	10,841	62,046	71%	17%	80%	20%
1999	461,965	490,047	485,489	552,243	7,310	7,310	0	0	469,275	497,357	485,489	552,243	28,082	16,214	82,967	34%	20%	63%	37%
2000	440,141	471,087	453,149	505,300	9,661	9,662	0	0	449,803	480,748	453,149	505,300	30,945	3,347	55,497	56%	6%	90%	10%
2001	395,519	414,530	411,564	437,673	8,592	8,592	0	0	404,111	423,122	411,564	437,673	19,011	7,453	33,562	57%	22%	72%	28%
2002	414,288	435,598	430,372	450,933	7,652	7,652	0	0	421,940	443,250	430,372	450,933	21,310	8,432	28,993	74%	29%	72%	28%
2003	280,965	385,759	305,077	399,276	6,795	6,795	0	0	287,760	392,554	305,077	399,276	104,794	17,317	111,516	94%	16%	86%	14%
2004	231,937	295,368	255,088	310,395	5,785	5,785	0	0	237,722	301,153	255,088	310,395	63,431	17,366	72,673	87%	24%	79%	21%
2005	347,785	368,891	364,675	387,692	5,686	5,686	0	0	353,471	374,577	364,675	387,692	21,106	11,205	34,222	62%	33%	65%	35%
2006	259,801	374,734	305,316	394,482	6,047	6,047	0	0	265,847	380,780	305,316	394,482	114,933	39,469	128,635	89%	31%	74%	26%
2007	315,441	358,167	328,547	375,606	6,197	6,197	0	0	321,638	364,364	328,547	375,606	42,726	6,909	53,968	79%	13%	86%	14%
2008	327,937	381,999	343,897	396,282	5,821	5,821	0	0	333,758	387,820	343,897	396,282	54,062	10,139	62,524	86%	16%	84%	16%
2009	388,423	443,302	405,049	469,472	5,538	5,538	0	0	393,961	448,840	405,049	469,472	54,879	11,088	75,511	73%	15%	83%	17%
2010	322,459	413,240	340,368	391,975	6,312	6,312	0	0	328,771	419,552	340,368	391,975	90,781	11,597	63,204	144%	18%	89%	11%
2011	232,153	324,284	255,478	358,955	9,061	9,061	0	0	241,214	333,345	255,478	358,955	92,132	14,265	117,741	78%	12%	87%	13%
2012	157,505	231,504	172,608	253,189	6,712	6,712	0	0	164,217	238,216	172,608	253,189	73,998	8,391	88,972	83%	9%	90%	10%
2013	70,457	160,508	80,895	189,940	7,351	7,351	0	0	77,808	167,859	80,895	189,940	90,050	3,087	112,131	80%	3%	97%	3%
2014	130,887	193,412	141,681	215,851	8,053	8,053	0	0	138,940	201,465	141,681	215,851	62,525	2,741	76,911	81%	4%	96%	4%
2015	226,971	272,930	238,705	289,000	6,320	6,320	0	0	233,291	279,250	238,705	289,000	45,959	5,413	55,708	82%	10%	89%	11%
2016	282,459	349,150	289,591	357,400	6,310	6,310	0	0	288,769	355,460	289,591	357,400	66,691	822	68,631	97%	1%	99%	1%
2017	322,514	376,045	338,504	395,616	7,475	7,475	0	0	329,989	383,520	338,504	395,616	53,531	8,515	65,627	82%	13%	86%	14%
1940-2017 Avg	372,137	424,747	388,128	440,778	2,291	2,291	0	0	374,428	427,038	388,128	440,778	52,610	13,700	66,351	79%	21%	79%	21%

TX_MSJ_000695

Tab 10

No. 141, Original

In the

SUPREME COURT OF THE UNITED STATES

STATE OF TEXAS,

Plaintiff,

v.

STATE OF NEW MEXICO and
STATE OF COLORADO,

Defendants.

OFFICE OF THE SPECIAL MASTER

DECLARATION OF STAFFAN W. SCHORR IN SUPPORT OF THE STATE OF TEXAS'S MOTION FOR PARTIAL SUMMARY JUDGMENT; MEMORANDUM OF POINTS AND AUTHORITIES IN SUPPORT THEREOF
FEDERAL RULE OF CIVIL PROCEDURE 56

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Francis M. Goldsberry II, Esq.
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**Counsel of Record*

November 5, 2020

I, Staffan W. Schorr, declare as follows:

1. My name is Staffan Wagner Schorr, I am 48 years of age and reside in Tucson, Arizona.

2. I am competent to make this declaration.

3. I am an independent consultant with over 20 years of professional experience as a groundwater hydrologist.

4. I have been retained by the State of Texas through my firm, Montgomery & Associates, to provide consulting services related to water budget issues presented in the Lawsuit.

5. My professional resume is included as Attachment 1. The information in my resume is true and correct.

6. My education includes Bachelor's of Science degree in Geosciences from the University of Arizona, and a Master's of Science degree in hydrogeology from the University of Arizona.

7. I am a principle hydrogeologist in the firm of Montgomery & Associates where I consult with clients on ground water modeling, hydrogeologic characterization, and data management.

8. I have consulting experiences relevant to my work in this case, including supervising and assisting with the development of hydrogeologic conceptual models for two separate regional groundwater availability models for the Texas Water Development Board; assisting with an update and calibration of a groundwater model for the Hueco Bolson for the El Paso Water utility; conducting hydrogeologic assessment, well inventories, and wellfield analysis for recovering stored groundwater for the Central Arizona Water Conservation District; and developing and updating spreadsheet water budget models for a copper mine operation in Arizona for Freeport-McMoRan Corporation.

9. With the exception of my deposition taken in this case, I have not testified in any cases in the last four years.

10. Current water users in the Lower Rio Grande Basin are primarily divided between irrigators and municipal users. Irrigation is the primary use of water in the Lower Rio Grande in New Mexico.

11. From my work in this case, I have concluded that the volume of groundwater pumped in the Rincon and Mesilla Valleys of New Mexico has increased since 1938.

12. Few groundwater wells were in use at the time the Compact was adopted in 1938.

13. Also based on my work on this matter, I conclude that the number of groundwater wells in the Rincon and Mesilla Valleys (below the Elephant Butte and Caballo Reservoirs and above the New Mexico-Texas state line at El Paso, Texas) has increased since 1938 from less than 60 to about 8000 in 2020. I made this conclusion based on well data and information my office obtained, and that I personally reviewed and analyzed, from the New Mexico OSE.

14. I was asked by counsel to prepare a map of the groundwater wells in the Rincon and Mesilla Valleys of New Mexico (below the Elephant Butte and Caballo Reservoirs and above the New Mexico-Texas state line at El Paso, Texas) existing in 1938, and the groundwater wells in the same geographic area that currently exist as of October 2020. To do that, I obtained well data from the New Mexico OSE and displayed wells based on location coordinates, well type, and installation date specified in the datasets.

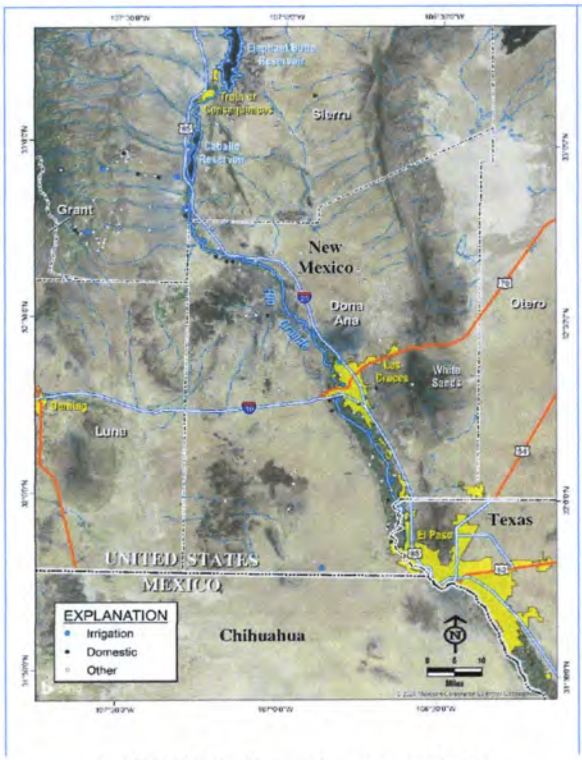

FIGURE 3: Groundwater wells in New Mexico in 1938

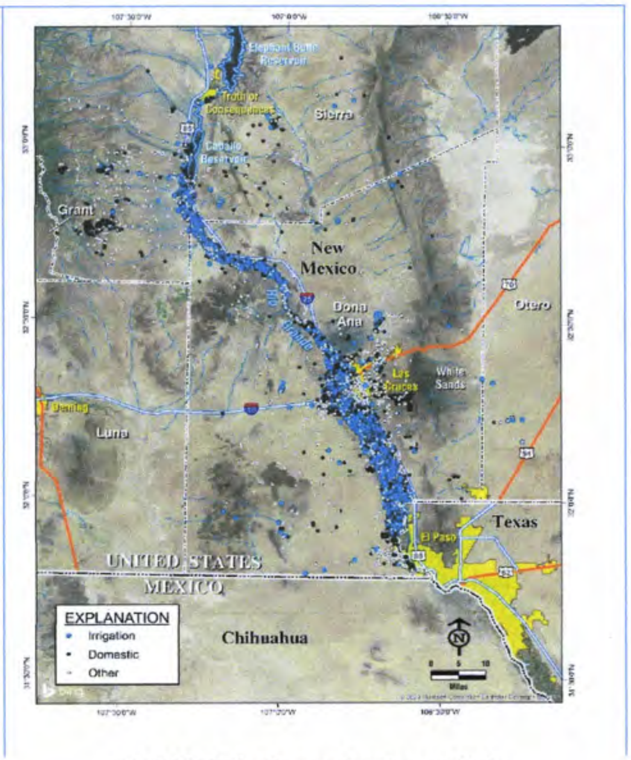

FIGURE 4: Groundwater wells in New Mexico in 2020

15. Figures 3 and 4, depicted above, accurately reflect the change in number and distribution of groundwater wells in New Mexico in the Rincon and Mesilla Valleys in New Mexico (below Elephant Butte and Caballo Reservoirs and above the New Mexico-Texas state line at El Paso, Texas).

I declare under penalty of perjury that the foregoing is true and correct. Executed this 5th day of November, 2020, at Tucson, Arizona.

Staffan W. Schorr

TX_MSJ_000699

Tab 11

Staffan W. Schorr, Hydrogeologist / Principal

Office: TUCSON

Years Experience

Total: 20 | M&A: 12

Education

M.S., Hydrology, University of Arizona (2005)

B.S., Geology, University of Arizona (1997)

Key Areas of Expertise

Regional hydrogeologic characterization

Flow and transport modeling

Development of geologic models

Integration of GIS and conceptual models for numerical model construction

Database development and management

Aquifer test design, implementation, and data analysis

Staffan Schorr specializes in regional hydrogeologic characterization in support of groundwater modeling. He applies his background in numerical and analytical groundwater flow modeling to a variety of M&A projects to simulate the effects of long-term pumping, mine dewatering, and managed aquifer recharge and recovery. He has extensive experience using GIS methods to develop numerical model inputs, display model results, and develop geospatial databases for conceptual hydrogeologic models. He also manages M&A's GIS and 3D modeling services, and specializes in the use of Leapfrog software to develop volumetric geologic and geochemical interpolation models. His other interests include characterizing the interactions between groundwater and surface water along riparian corridors. Prior to joining M&A, Staffan worked for 8 years in watershed planning at Pima Association of Governments, a regional agency that facilitates coordination among local jurisdictions.

Representative Projects

Groundwater Modeling | Groundwater Resource Development

Groundwater Flow Model • Hueco Bolson • El Paso Water Utility
Updated hydrogeologic sections with new borehole data and geophysical logs, evaluated data from the Texas Water Development Board's groundwater database, developed a 3D geologic model, and constructed and calibrated a numerical groundwater flow-and-transport model to support the management of brackish groundwater resources and wellfields [EL PASO COUNTY, TX]

Groundwater Flow Model • Lower Rio Grande Valley • Texas Water Development Board
Developed a conceptual hydrogeologic model, relational database, and geodatabase to provide input for a groundwater flow-and-transport model used to evaluate future desalination operations [SOUTHERN TX]

Groundwater Flow Model • Northern Portions of Queen City, Sparta, and Carrizo Wilcox • Texas Water Development Board
Developed a conceptual hydrogeologic model, relational database, and geodatabase to provide input for a groundwater flow model used to evaluate regional groundwater availability. [NORTHEASTERN TX]

Groundwater Flow Model • Kinney County • William R. Hutchison, Independent Groundwater Consultant
Supervised development of MODFLOW USG model grid using AlgoMesh software [KINNEY COUNTY, TX]

Groundwater Flow Model • Bluebonnet Groundwater Conservation District • William R. Hutchison, Independent Groundwater Consultant
Provided support for numerical model development: evaluated previous aquifer layer interpolations, updated aquifer layering using available well borehole geophysical logs, and supervised development of a geologic model that

Modeling Codes & Software

MODFLOW
FEFLOW
PEST
MODFLOW-SURFACT
MT3D
HEC-RAS
WINFLOW
THWELLS
Leapfrog Hydro
Leapfrog Geo
Groundwater Vistas
ArcView
ArcGIS
Spatial Analyst
3D Analyst

Additional Training

2017: Fundamental and Advanced Techniques of Leapfrog Geo

2015: Introduction to MineSight

2013: MODFLOW-USG workshop

2012: Fundamental and Advanced Techniques of Leapfrog Hydro

2010: Advanced Techniques for Aquifer Test Analysis Featuring AQTESOLV

2010: Fundamentals of Leapfrog Hydro

2009: HEC-RAS 3-Day Short Course

2008: Advanced Techniques for Aquifer Test Analysis Featuring AQTESOLV

2008: Calibration, Uncertainty Analysis, and Optimization — A Seminar

combines all aquifer layers from existing Groundwater Availability Models in vicinity of the District [NORTH-CENTRAL, TX]

Groundwater Modeling | Hydrologic Impact Analysis

Environmental Impact Analysis • Arivaca Groundwater Flow Model • Pima County Regional Flood Control District
Projected changes in groundwater levels and potential impacts to environmentally sensitive areas related to pumping in a hydrologically isolated basin [PIMA COUNTY, AZ]

Groundwater Modeling | Tailings Water Management

Water Balance • Sierrita Mine • Freeport-McMoRan Corporation
Developed and updated spreadsheet water budget models for tailings impoundments at the Sierrita open-pit copper mine [PIMA COUNTY, AZ]

Groundwater Modeling | Mine Dewatering

Dewatering & Impacts Modeling • Collahuasi Mine / Rosario Pit • Compañía Minera Doña Inés de Collahuasi SMC
Designed and constructed a groundwater flow model to support dewatering operations and predict the environmental impacts associated with a large, open-pit mine in a complex mountain aquifer system [NORTHERN CHILE]

Groundwater Modeling | Managed Aquifer Recharge

Water Level / Quality Projections • Tonopah Desert Recharge Project • Central Arizona Water Conservation District
Developed flow and solute-transport models to project changes in nitrate concentrations and groundwater levels associated with recharge and future recovery operations [WESTERN AZ]

Water Level / Quality Projections • Central Avra Valley Storage & Recovery Project • Central Arizona Water Conservation District
Updated flow and solute-transport models to project groundwater level rise and changes in concentrations of total dissolved solids resulting from recharge operations [PIMA COUNTY, AZ]

Water Level Projections • Superstition Mountains Recharge Project • Central Arizona Water Conservation District
Updated a groundwater flow model to evaluate recharge rates and predict the rise in groundwater levels associated with recharge operations [MARICOPA COUNTY, AZ]

Permit Support • Willow Springs South Ranch Village Project • ANAM, Inc.
Developed an analytical model to support regulatory permitting requirements for recharging treated effluent [PINAL COUNTY, AZ]

GIS & 3D Geologic Modeling

Geospatial Model Development • Various Sites • Various Clients
Developed or supervised the development of dozens of 3D geospatial models for hard-rock and basin-fill groundwater systems using Leapfrog® software [U.S., PERÚ, CHILE]

GIS Development & Application • Various Sites • Various Clients
Developed GIS inventories of wells, infrastructure, water use, land use, and other related features; prepared cartographically correct maps, figures, and 3D geologic models for many investigations and modeling projects [U.S., CHILE, PERÚ, ARGENTINA, BOLIVIA]

Managed Aquifer Recharge

Hydrogeologic Characterization • Recovery Wellfield Siting Study (Phase 1) • Central Arizona Water Conservation District
Conducted a hydrogeologic assessment, well inventory, and wellfield analysis for recovering stored CAP water [PINAL COUNTY, AZ]

Groundwater Modeling | Mine Water Supply

Groundwater Flow Model • Confidential Site • Confidential Client
As part of due diligence efforts, designed and implemented a model to project groundwater level impacts associated with potential future pumping for a new water supply; constructed a 3D geospatial model of an alluvial groundwater system using Leapfrog Hydro [WESTERN AZ]

Mine Water Supply

Aquifer Testing & Analysis • Proposed Copper Mine Reopening • Freeport-McMoRan Corporation
Planned and implemented an aquifer testing program; analyzed test data to evaluate groundwater resources [PIMA COUNTY, AZ]

Aquifer Testing & Analysis • Big Sandy Valley • Freeport-McMoRan Corporation
Analyzed long-term test data from a confined aquifer to evaluate potential groundwater resources, impacts to environmentally sensitive areas, and hydraulic connectivity between aquifers [MOHAVE COUNTY, AZ]

Water Policy & Planning

Hydrogeologic Characterization • Regional Water Plan • Confidential Client
Evaluated hydrogeologic data and supervised the development of a 3D data model to support the initial phases of a regional water plan [PIMA COUNTY, AZ]

Hydrogeologic Characterization • Various Sites • Pima County Regional Flood Control District
Conducted basic hydrogeologic investigations using publicly available data sources for Aguirre Valley, Altar Valley, and the Ajo-Why area to support an amendment to Pima County's Water Resources Comprehensive Plan [PIMA COUNTY, AZ]

Publications & Presentations

Development of conceptual plan for direct recovery of Central Arizona Project water stored at Tonopah Desert Recharge Project, Maricopa County, Arizona
Meyer, J.J., Cross, M.M., Schorr, S.W., Shipman, T.D., and Fuerst, D., 2009, National Groundwater Association 2009 Groundwater Summit, Tucson, AZ, April 19–23

Hydrogeologic conceptual model for the Collahuasi Mine area, Chile
Thomasson, M.J., Schorr, S.W., Davis, L.A., Rosko, M.J., Acosta, O.J., 2010, Water in Mining, Second International Congress on Water Management in the Mining Industry, Santiago, Chile, June 9–11

Conceptual model report: Lower Rio Grande Valley Groundwater Transport Model
Schorr, S., Hutchison, W.R., Panday, S., and Rumbaugh, J., 2017, prepared for Texas Water Development Board, June 30, 2017.

Conceptual model report: Groundwater Availability Model for northern portion of the Queen City, Sparta, and Carrizo-Wilcox Aquifers
Schorr, S., Hutchison, W.R., Panday, S., and Rumbaugh, J., 2018, prepared for Texas Water Development Board, draft report June 28, 2018.

Tab 12

No. 141, Original

In the

SUPREME COURT OF THE UNITED STATES

STATE OF TEXAS,

Plaintiff,

v.

STATE OF NEW MEXICO and
STATE OF COLORADO,

Defendants.

OFFICE OF THE SPECIAL MASTER

DECLARATION OF THERESA C. BARFIELD IN SUPPORT OF THE STATE OF TEXAS'S MOTION FOR PARTIAL SUMMARY JUDGMENT; MEMORANDUM OF POINTS AND AUTHORITIES IN SUPPORT THEREOF
FEDERAL RULE OF CIVIL PROCEDURE 56

Stuart L. Somach, Esq.*
Andrew M. Hitchings, Esq.
Robert B. Hoffman, Esq.
Francis M. Goldsberry II, Esq.
Theresa C. Barfield, Esq.
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**Counsel of Record*

November 5, 2020

I, Theresa C. Barfield, declare:

1. I am an attorney at law duly licensed to practice before all of the courts in the State of California. I am admitted to practice before the Supreme Court of the United States. I am a shareholder with Somach Simmons & Dunn and represent the Plaintiff State of Texas (Texas) in the above-captioned case. The following matters are within my personal knowledge and, if called as a witness, I can competently testify thereto.

2. Attached hereto as Exhibit 1 is a true and correct copy of the State of New Mexico's Objections and Witness Designations to the United States' Notice of Rule 30(b)(6) Deposition and to State of Texas' Cross-Notice, dated September 10, 2020.

3. Attached hereto as Exhibit 2 is a true and correct copy of the State of New Mexico's Objections and Supplemental Responses to the State of Texas's First Set of Requests for Admission to the State of New Mexico, dated October 30, 2020.

I declare under penalty of perjury that the foregoing is true and correct. Executed this 2nd day of November, 2020, at Folsom, California.

Theresa C. Barfield

Tab 13

No. 141, Original

IN THE
SUPREME COURT OF THE UNITED STATES

♦

STATE OF TEXAS,
Plaintiff,
v.
STATE OF NEW MEXICO and
STATE OF COLORADO,
Defendants.

♦

OFFICE OF THE SPECIAL MASTER

♦

STATE OF NEW MEXICO'S OBJECTIONS AND WITNESS DESIGNATIONS TO THE UNITED STATES' NOTICE OF RULE 30(b)(6) DEPOSITION AND TO STATE OF TEXAS'S CROSS-NOTICE

♦

HECTOR H. BALDERAS
Attorney General of New Mexico
TANIA MAESTAS
Chief Deputy Attorney General
CHOLLA KHOURY
Assistant Attorney General
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Special Assistant Attorney General
STATE OF NEW MEXICO
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*Counsel of Record

Pursuant to the Case Management Plan dated September 6, 2018, as amended (CMP), and Rule 30(b)(6) of the Federal Rules of Civil Procedure, the State of New Mexico objects to and provides witness designations for the United States' Notice of Rule 30(b)(6) Deposition of the State of New Mexico and the State of Texas's Cross-Notice (collectively, "United States' Notice") as follows:

GENERAL OBJECTIONS

1. New Mexico's objections and responses are based on information presently available. At present, New Mexico has not yet completed its investigation or preparation for trial, either of which may provide information responsive to this discovery request.

2. New Mexico objects to United States' Notice, including the instructions and definitions contained therein, to the extent that they impose obligations on New Mexico that exceed the possible scope of discovery as set forth in the Federal Rules of Civil Procedure. New Mexico reserves all objections and rights to which it is entitled under the Federal Rules of Civil Procedure and applicable law.

3. New Mexico objects to each and every instruction, definition and/or topic identified for examination to the extent the instruction, definition and/or topic is vague, ambiguous, unintelligible, compound, conjunctive, or disjunctive, and not full and complete in and of itself, so as to make a response impossible without speculation as to the meaning of the request.

4. New Mexico objects to each and every instruction, definition and/or topic for examination to the extent that the instruction, definition and/or topic seeks information protected by the attorney-client privilege, the work product doctrine, joint defense privilege, or any other applicable privilege. New Mexico's responses herein, and/or the witness' testimony, are not intended to, nor should they be construed as, a waiver or relinquishment of any part of the protections afford by the attorney-client privilege, the work product doctrine, the joint defense privilege, or any other applicable privileges or immunities. The inadvertent production of any such privileged information or document(s) is not a waiver of New Mexico's right to assert any

applicable privilege or doctrine relative to any such information or document(s), or any other information, document(s), or matter, pursuant to the terms of paragraph 7.2.3 of the CMP.

5. New Mexico objects to each and every instruction, definition and/or topic for examination to the extent that it seeks the legal analysis, legal conclusions, or the statutory basis supporting a factual conclusion.

6. New Mexico objects to each and every instruction, definition and/or topic for examination to the extent that they seek New Mexico's counsels', or any other counsel's, legal reasoning, theory, or statutory basis supporting a factual conclusion.

7. New Mexico objects to each and every instruction, definition and/or topic for examination to the extent it seeks expert analysis and/or testimony.

8. New Mexico objects to each and every instruction, definition and/or topic for examination to the extent the instruction, definition and/or topic is unduly and unreasonably oppressive, harassing, burdensome, overbroad, seeks information neither relevant to the subject matter of the action nor reasonably calculated to lead to the discovery of admissible evidence, is not proportional to the scope of this case, or constitutes an abuse of the discovery process.

9. New Mexico objects to definition number 12 in the United States' Notice to the extent it seeks information "from statehood to present" as unduly and unreasonably oppressive, harassing, burdensome, overbroad, seeks information neither relevant to the subject matter of the action nor reasonably calculated to lead to the discovery of admissible evidence, is not proportional to the scope of this case, and constitutes an abuse of the discovery process.

10. New Mexico objects to the form of each and every topic for examination to the extent that it is not full and complete in and of itself, and instead relies on preface and instructions.

11. New Mexico objects to each and every instruction, definition and/or topic for examination to the extent it seeks information or documents that are not in the possession,

custody, or control of New Mexico, its agents, or employees.

12. New Mexico's decision to provide information or documents, notwithstanding the objectionable nature of any of the discovery requests, should not be construed as a stipulation or admission that the information is relevant or admissible, a waiver of New Mexico's general or specific objections, or an agreement that requests for similar discovery will be treated in a similar manner.

13. To the extent New Mexico identifies witnesses, information, or documents as responsive to any of the United States' requests, it does not constitute an admission that New Mexico agrees with any characterizations, disputed facts, or other information contained in the specific request.

14. New Mexico and United States conferred in advance of United States' formal service of this notice of deposition, wherein counsel for New Mexico advised counsel for United States that witnesses would only be designated by New Mexico to provide testimony on the topics as identified below. New Mexico witnesses are not designated by New Mexico to provide testimony on any topics identified in United States' "Exhibit A," except as expressly identified herein, and the above General Objections are incorporated into each specific Topic.

NEW MEXICO'S SPECIFIC OBJECTIONS AND RESPONSES TO THE UNITED STATES' "EXHIBIT A"

UNITED STATES' TOPIC A: The responses, allegations, and affirmative defenses in New Mexico's answers to the complaint of the United States and to the complaint of Texas, including

- What is Texas' apportionment of water under the Compact?
- What amount of water is Texas entitled to receive to lands in Texas based on Texas' apportionment of water under the Compact?
- What is the relationship of the Project and Texas' apportionment of water under the Compact?
- What is New Mexico's apportionment of water under the Compact?
- What is the relationship of the Project and New Mexico's apportionment of water under the Compact?
- What are New Mexico's obligations to ensure Texas receives its full apportionment under the Compact?
- How does New Mexico ensure Texas receives its full apportionment under the Compact?

NEW MEXICO'S OBJECTIONS AND DESIGNATIONS AS TO TOPIC A:

New Mexico objects to the preface sentence in this Topic on the grounds that by using the term "including" it fails to describe the testimony sought with reasonable particularity as required by Rule 30(b)(6). A notice must avoid such terms as they put the responding party in the impossible task of preparing for an open-ended and theoretically infinite subject. *See, e.g., Reed v. Bennett,* 183 F.R.D. 689, 692 (D.Kan. 2000).

New Mexico objects to the preface sentence in that it impermissibly requires New Mexico to speculate as to the discovery being sought and to parse through hundreds of responses, allegations, and affirmative defenses in New Mexico's answers to the complaints of the United

States and Texas to infer the discovery sought by the United States. *See, e.g., Catt v. Affirmative Ins. Co.*, No. 08-CV-243, 2009 WL 1228605, at *6--7 (N.D. Ind. Apr. 30, 2009) (topics listed as allegations in the complaint, answers, affirmative defenses did "not identify the subject matter to be covered with 'reasonable particularity'"); *Smithkline Beecham Corp. v. Apotex Corp*., No. 98-C-3952, 2000 WL 116082, at *10 (N.D. Ill., Jan. 24, 2000) (finding Rule 30(b)(6) notice requesting designation of a witness to testify regarding responses to interrogatories and requests for production was overbroad, unduly burdensome, and inefficient).

New Mexico objects to the preface sentence in that it requires New Mexico to provide testimony as to legal conclusions and reveal privileged attorney work product and strategy.

New Mexico objects to the second bullet in that it fails to describe the testimony sought with reasonable particularity and forces New Mexico to speculate as to the discovery being sought in that the word "amount" is vague and ambiguous.

Subject to and without waiver of the foregoing objections, and to the extent New Mexico has knowledge, Estevan L. Lopez, former Director of the New Mexico Interstate Stream Commission, is designated by New Mexico to provide testimony as to the seven (7) specific bullet points following the preface sentence. Mr. Lopez is not designated by New Mexico to provide testimony on this Topic except as expressly identified herein.

UNITED STATES' TOPIC B: New Mexico's counterclaims against the United States and Texas, including the allegations pleaded in support of the same, and the remedies requested, related to:

- Counterclaim No. 1 - Compact violation by Texas caused by unauthorized depletions.
  - defining and providing scope of "unauthorized diversions" in Texas.

- Counterclaim No. 2 - Interference with Compact Apportionment against the United States was dismissed.
    - Questions under this counterclaim will be limited to what New Mexico was apportioned, and how Project operations are inconsistent with New Mexico's apportionment.
- Counterclaim No. 3 - Improper Release of Compact Credit Water against the United States was dismissed.
    - Questions under this counterclaim will be limited to New Mexico's understanding of the Compact's water accounting system for credit water, reservoir water evaporation and evaporation accounting.
- Counterclaim No. 4 - Compact Violation and Unjust Enrichment Against Texas.
    - questioning on Project lands receiving an equal amount of surface water per acre
- Counterclaim No. 5 - Violation of the Water Supply Act by the United States was dismissed.
    - Questions under this counterclaim will be limited to how an action pursuant to the Water Supply Act Pub. L. No. 85-500, 72 Stat. 297, 319 (July 3, 1958) violates the Compact.
- Counterclaim No. 6 - Improper Compact and Project Accounting against the United States was dismissed.
    - Questions under this counterclaim will be limited to how Project accounting is inconsistent with the Compact.
- Counterclaim No. 7 - Violation of the Miscellaneous Purposes Act and the Compact against Texas and the United States was dismissed.
    - Questions under this counterclaim will be limited to how any of the Miscellaneous Purposes Act contracts violate the Compact.
- Counterclaim No. 8 - Improper Project Maintenance against the United States was dismissed.
    - Questions under this counterclaim will be limited to the standards of Project maintenance the United States is subject to under the Compact, how the United States maintenance efforts violate the Compact, and how the alleged failure of the United States' maintenance has injured New Mexico.

- Counterclaim No. 9 - Failure to Enforce the 1906 Convention and Compact Violation against the United States was dismissed.
    - Questions under this counterclaim will be limited to how pumping of groundwater in Mexico and unauthorized surface diversions from the Rio Grande by Mexico have violated the Compact.

NEW MEXICO'S OBJECTIONS AND DESIGNATIONS AS TO TOPIC B:

New Mexico objects to the preface sentence in this Topic on the grounds that by using the term "including" it fails to describe the testimony sought with reasonable particularity as required by Rule 30(b)(6). A notice must avoid such terms as they put the responding party in the impossible task of preparing for an open-ended and theoretically infinite subject. *See, e.g., Reed v. Bennett,* 183 F.R.D. 689, 692 (D.Kan. 2000).

New Mexico objects to the preface sentence and the nine bullets in that they impermissibly require New Mexico to speculate as to the discovery being sought and to parse through hundreds of allegations and claims in New Mexico's counterclaims and requested remedies to the United States and Texas to infer the discovery sought by the United States. *See, e.g., Catt v. Affirmative Ins. Co.*, No. 08-CV-243, 2009 WL 1228605, at *6--7 (N.D. Ind. Apr. 30, 2009) (topics listed as allegations in the complaint, answers, affirmative defenses did "not identify the subject matter to be covered with 'reasonable particularity'").

New Mexico objects to the preface sentence and the nine bullets in that they require New Mexico to provide testimony as to legal conclusions and reveal privileged attorney work product and strategy. Specifically, as to the fifth sub-bullet, which requires New Mexico to provide a witness to interpret a statute and testimony as to legal conclusions and analysis, New Mexico is unable to prepare or provide a witness for this sub-Topic.

New Mexico objects to the use of the term "scope" is the 1st sub-bullet as vague and ambiguous such that New Mexico is unable to determine the discovery sought by the United States.

New Mexico objects to the fifth (5th) bullet, including the sub-bullet, as seeking testimony on a subject that is protected by privilege or the work product doctrine and as seeking testimony on a pure legal issue.

Subject to and without waiver of the foregoing objections, and to the extent New Mexico has knowledge:

(A) Estevan L. Lopez, former Director of the New Mexico Interstate Stream Commission, is designated by New Mexico to provide testimony as to seven (7) of the sub-bullets above, excepting the fifth (5th) and eighth (8th) sub-bullets.

(B) Rolf Schmidt-Petersen, current Director of the New Mexico Interstate Stream Commission, is designated by New Mexico to provide testimony on the eighth (8th) sub-bullet only.

Mr. Lopez and Mr. Schmidt-Petersen are not designated by New Mexico to provide testimony on this Topic except as expressly identified herein. New Mexico is not designating a witness to provide testimony on the 5th bullet.

UNITED STATES' TOPIC C: New Mexico's administration, implementation, and enforcement of its obligations under the Compact and under state laws, regulations, policies or actions in (1) delivery of Rio Grande Compact water to the State of New Mexico, (2) delivery of Rio Grande Compact water to the State of Texas, and (3) water released from storage to meet Compact irrigation demands below Elephant Butte Reservoir.

NEW MEXICO'S OBJECTIONS AND DESIGNATIONS AS TO TOPIC C:

New Mexico objects to this Topic on the grounds that it fails to describe the testimony sought with reasonable particularity and forces New Mexico to speculate as to the discovery being sought.

New Mexico objects to this Topic to the extent it calls for a witness to interpret laws and regulations and to the extent it seeks testimony as to legal conclusions and analysis.

Subject to and without waiver of the foregoing objections, and to the extent New Mexico has knowledge:

(A) Estevan L. Lopez, former Director of the New Mexico Interstate Stream Commission, is designated by New Mexico to provide testimony as to New Mexico's policies under the Compact relating to the three (3) identified subjects.

(B) Cheryl Thacker, Water Resources Manager for the New Mexico Office of the State Engineer, is designated by New Mexico to provide testimony as to New Mexico's administration, implementation, and enforcement as to the three (3) identified subjects.

Mr. Lopez and Ms. Thacker are not designated by New Mexico to provide testimony on this Topic except as expressly identified herein.

UNITED STATES' TOPIC D: New Mexico's policies relating to administration of surface water or groundwater below Elephant Butte Reservoir related to:

- New Mexico's policies relating to administration of water delivered to EBID pursuant to the 1938 contracts between the United States and the districts, the 1979/1980 operation and maintenance transfer contracts between the United States and the districts, and the 2008 Operating Agreement.

- New Mexico's policies on supplemental irrigation wells as defined by New Mexico.

- New Mexico's policies on conjunctive use of surface water and groundwater for irrigation purposes.

- New Mexico's policies, positions and actions in State of New Mexico ex rel. Office of the State Engineer v. EBID, et al., No. D-307-CV-96-888, County of Dona Ana, Third Judicial District related to:
  - water rights offered or consented to for the Project irrigation users, non-Project irrigation users, and municipal water right holders.
  - water rights offered for the United States' right to water for the Rio Grande Project and the determination of such rights in Stream System Issue No. 104.
  - Stream System Issue No. 101 and the determination of consumptive irrigation water amounts and farm delivery water requirements for all crops in the Lower Rio Grande Basin.

NEW MEXICO'S OBJECTIONS AND DESIGNATIONS AS TO TOPIC D:

New Mexico objects to the first bullet under this Topic to the extent it calls for legal interpretation of contracts to which it is not a party and to the extent it seeks testimony as to legal conclusions and analysis. New Mexico further objects to the terms "policies" and "policies, positions, and actions" as vague and ambiguous and as overly broad and unduly burdensome.

Subject to and without waiver of the foregoing objections, and to the extent New Mexico has knowledge, Cheryl Thacker is designated by New Mexico to provide testimony as to the first three (3) bullets.

New Mexico objects to the fourth bullet and the first sub-bullet thereafter in that they impermissibly require New Mexico to speculate as to the discovery being sought and to parse through thousands of subfiles, allegations, and claims in the referenced adjudication. Further, these subjects require New Mexico to provide testimony as to legal conclusions and reveal privileged attorney work product and strategy. New Mexico further objects to the fourth bullet and first sub-bullet thereafter in that they are vague, ambiguous, burdensome, overbroad, seek information neither relevant to the subject matter of the action nor reasonably calculated to lead to the discovery of admissible evidence, is not proportional to the scope of this case, and constitutes an abuse of the discovery process. *See, e.g., Catt v. Affirmative Ins. Co.*, No. 08-CV-243, 2009 WL 1228605, at *6--7 (N.D. Ind. Apr. 30, 2009) (topics listed as allegations in the complaint, answers, affirmative defenses did "not identify the subject matter to be covered with 'reasonable particularity'"). New Mexico is not able to prepare or provide a witness to testify as to these two (2) sub-topics.

Subject to and without waiver of the foregoing objections, and to the extent New Mexico has knowledge, John W. Longworth, Senior Engineering Executive of the New Mexico Office of the State Engineer and former Director of the New Mexico Interstate Stream Commission, is designated by New Mexico to provide testimony as to the last two sub-bullets.

Ms. Thacker and Mr. Longworth are not designated by New Mexico to provide testimony on this Topic except as expressly identified herein.

If the United States or Texas intend to ask questions about specific "policies" or documents, New Mexico requests that the United States and Texas provide copies of those specific policies or documents at least two days in advance of the deposition so that the witness may be adequately prepared.

UNITED STATES' TOPIC E: New Mexico's communications with the United States, its officers, employees, or agents, concerning complaints about Project operations and related water use, from 1938 to present, related to:

- wells drilled below Elephant Butte reservoir
- Project accounting for groundwater pumping in Texas
- Contracts for municipal use of water by El Paso
- management of Project facilities by the Districts after the transfer of operations and maintenance responsibility to the Districts

- allegations of Compact violations
- the Operating Agreement

NEW MEXICO'S OBJECTIONS AND DESIGNATIONS AS TO TOPIC E:

New Mexico objects to this Topic on the grounds that it fails to describe the testimony sought with reasonable particularity and forces New Mexico to speculate as to the discovery being sought in that the terms and phrases "communications" and "related water use" are vague, ambiguous, overbroad, seek information neither relevant to the subject matter of the action nor reasonably calculated to lead to the discovery of admissible evidence, and are not proportional to the scope of this case.

New Mexico objects to the time period designated in this Topic, "from 1938 to present", as overbroad, seeks information neither relevant to the subject matter of the action nor reasonably calculated to lead to the discovery of admissible evidence, and is not proportional to the scope of this case.

Subject to and without waiver of the foregoing objections, and to the extent New Mexico has knowledge, Rolf Schmidt-Petersen, current Director of the New Mexico Interstate Stream Commission, is designated by New Mexico to provide testimony as to complaints by New Mexico to the United States as to the six (6) specific bullets in this Topic. Mr. Schmidt-Petersen is not designated by New Mexico to provide testimony on this Topic except as expressly identified herein.

If the United States or Texas intend to ask questions about specific "communications," documents or "complaints," New Mexico requests that the United States and Texas provide copies of those specific communications, documents or complaints at least two days in advance of the deposition so that the witness may be adequately prepared.

UNITED STATES' TOPIC F: New Mexico's communications with the United States, its officers, employees, or agents, concerning complaints about maintenance of the Rio Grande channel.

NEW MEXICO'S OBJECTIONS AND DESIGNATIONS AS TO TOPIC F:

New Mexico objects to this Topic in that the term "the Rio Grande channel" is vague, ambiguous, overbroad, seeks information neither relevant to the subject matter of the action nor reasonably calculated to lead to the discovery of admissible evidence, is not proportional to the scope of this case, and constitutes an abuse of the discovery process. New Mexico further objects to the phrase "New Mexico's communications with the United States, its officers, employees, or agents" as vague and ambiguous and overly broad and unduly burdensome.

Subject to and without waiver of the foregoing objections, Rolf Schmidt-Petersen, current Director of the New Mexico Interstate Stream Commission, is designated by New Mexico to provide testimony on this Topic as it relates to the Rio Grande river channel below Elephant Butte dam and reservoir. Mr. Schmidt-Petersen is not designated by New Mexico to provide testimony on this Topic except as expressly identified herein.

If the United States or Texas intend to ask questions about specific "communications," documents or "complaints," New Mexico requests that the United States and Texas provide copies of those specific communications, documents or complaints at least two days in advance of the deposition so that the witness may be adequately prepared.

UNITED STATES' TOPIC G: New Mexico Interstate Stream Commission, Office of State Engineer, Attorney General Office and Governor's Office substantive communications related to the Operating Agreement and Compact litigation with other New Mexico entities, namely: The City of Las Cruces, its officers, employees, agents, or legal counsel; New Mexico State University, its officers, employees, agents, or legal counsel; the City of Albuquerque, its officers, employees, agents, or legal counsel; and the consortium of farmers in the lower Rio Grande collectively referred to as the New Mexico Pecan Growers or the Southern Rio Grande Diversified Crop Farmers Association, their officers, employees, agents, or legal counsel.

NEW MEXICO'S OBJECTIONS AND DESIGNATIONS AS TO TOPIC G:

New Mexico objects to this Topic in that it fails to describe the testimony sought with reasonable particularity and forces New Mexico to speculate as to the discovery being sought in that the phrase "substantive communications" is vague, ambiguous, overbroad, seeks information neither relevant to the subject matter of the action nor reasonably calculated to lead to the discovery of admissible evidence, is not proportional to the scope of this case, and constitutes an abuse of the discovery process.

New Mexico objects in that the request for communications between the personnel in four (4) New Mexico state agencies and the "officers, employees, agents, or legal counsel" of five (5) New Mexico entities – two of which are municipalities with hundreds of interactions annually with the designated state agencies -- is overbroad, burdensome, seeks information neither relevant to the subject matter of the action nor reasonably calculated to lead to the discovery of admissible evidence, is not proportional to the scope of this case, and constitutes an abuse of the discovery process.

New Mexico objects in that this Topic requires New Mexico to reveal privileged attorney work product and strategy and to violate applicable privileges.

Subject to and without waiver of the foregoing objections, John W. Longworth, Senior Engineering Executive of the New Mexico Office of the State Engineer and former Director of the New Mexico Interstate Stream Commission, is designated by New Mexico to provide testimony on this Topic. Mr. Longworth is not designated by New Mexico to provide testimony on this Topic except as expressly identified herein.

New Mexico will not be designating a witness to testify to "substantive communications related to the . . . Compact litigation," except to the extent that those communications took place in the presence of a third party and was therefore not protected.

If the United States or Texas intend to ask questions about specific "communications," documents or correspondence, New Mexico requests that the United States and Texas provide copies of those specific communications, documents or correspondence at least two days in advance of the deposition so that the witness may be adequately prepared.

Respectfully submitted this 10th day of September, 2020.

/s/ Jeffrey Wechsler
JEFFREY WECHSLER
Special Assistant Attorney General
MONTGOMERY & ANDREWS
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No. 141, Original

IN THE
SUPREME COURT OF THE UNITED STATES

♦

STATE OF TEXAS,

Plaintiff,

v.

STATE OF NEW MEXICO and
STATE OF COLORADO,

Defendants.

♦

OFFICE OF THE SPECIAL MASTER

♦

STATE OF NEW MEXICO'S CERTIFICATE OF SERVICE

♦

This is to certify that on the 10th of September, 2020, I caused a true and correct copy of the **State of New Mexico's Objections and Witness Designations to the United States' Notice of 30(b)(6) Deposition and to the State of Texas's Cross-Notice** to be served by e-mail upon all counsel of record and interested parties on the Service List, attached hereto.

Respectfully submitted this 10th day of September, 2020.

/s/ Michael A. Kopp
Michael A. Kopp
Attorney
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UNITED STATES

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Tab 14

No. 141, Original

IN THE
SUPREME COURT OF THE UNITED STATES

♦

STATE OF TEXAS,
Plaintiff,
v.
STATE OF NEW MEXICO and
STATE OF COLORADO,
Defendants.

♦

OFFICE OF THE SPECIAL MASTER

♦

STATE OF NEW MEXICO'S OBJECTIONS AND SUPPLEMENTAL RESPONSES TO THE STATE OF TEXAS'S FIRST SET OF REQUESTS FOR ADMISSION TO THE STATE OF NEW MEXICO

♦

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Pursuant to the Case Management Plan adopted on September 6, 2018, as amended ("CMP"), and Rule 36 of the Federal Rules of Civil Procedure ("FRCP"), the State of New Mexico ("New Mexico") hereby submits the following objections and responses to the State of Texas's ("Texas") First Set of Requests for Admission to the State of New Mexico.

GENERAL OBJECTIONS

In addition to the objections specifically noted in the responses to each individual Request for Admission, below, New Mexico incorporates the following General Objections into its responses to each and every Request for Admission:

1. New Mexico's responses are based on information presently available. At present, New Mexico has not yet completed its discovery, investigation, or preparation for trial, any or all of which may provide information responsive and/or relevant to these Requests.

2. New Mexico objects to Texas's Requests for Admission, including the Definitions and Instructions contained therein, to the extent that they impose obligations on New Mexico that exceed the scope of discovery as set forth in the FRCP. New Mexico reserves all objections and rights to which it is entitled under the FRCP and applicable law and procedure.

3. New Mexico objects to each Request for Admission to the extent the request is vague, ambiguous, unintelligible, compound, conjunctive, or disjunctive, and not full and complete in and of itself.

4. New Mexico objects to each Request for Admission to the extent that the request seeks information protected by the attorney-client privilege, the work-product doctrine, or any other applicable privilege. New Mexico's responses are not intended to, and should not be construed as, a waiver or relinquishment of any of the protections afforded by the attorney-client privilege, the work-product doctrine, or any other applicable privileges or immunities. The inadvertent disclosure of any such privileged information is not a waiver of New Mexico's right to assert any applicable privilege or doctrine relative to any such information, or any other information, document(s), or matter, pursuant to the terms of paragraph 7.2.3 of the CMP.

5. New Mexico objects to each Request for Admission to the extent that the request seeks a legal conclusion, which is improper under FRCP 36(a)(1).

6. New Mexico objects to each Request for Admission to the extent that the request seeks expert opinion or cannot be answered without the testimony of experts.

7. New Mexico objects to each Request for Admission to the extent the request is unduly and unreasonably oppressive, harassing, annoying, burdensome, overbroad, or constitutes an abuse of the discovery process.

8. New Mexico objects to each and every Request for Admission to the extent the request is overly broad and seeks information neither relevant to the subject matter of the action, nor reasonably calculated to lead to the discovery of admissible evidence.

9. New Mexico objects to the form of each Request for Admission to the extent that it is not full and complete in and of itself and, for example, instead relies on preface and instructions.

10. New Mexico objects to each Request for Admission to the extent the request seeks information that is not in the possession, custody, or control of New Mexico.

11. New Mexico objects to this definition of "Identify" with respect to a "person" or "entity" because the terms of the definition are overly broad with respect to "person," and because it seeks current contact information (including personal residences). Any employees of New Mexico or its contractors should be contacted through counsel for New Mexico. Further, New Mexico objects to seeking of "address" and "telephone number," as these seek disclosure of personal and private information that is irrelevant to the subject matter of this action. New Mexico objects to the instruction to provide "the person's present employer and occupation or business" as overbroad, unduly burdensome, irrelevant and exceeding the scope of New Mexico's discovery obligations under Rule 26 and 36 of the FRCP.

12. New Mexico also objects to the definition of "entity" as vague, ambiguous, and overbroad.

13. New Mexico objects to the definition of "Identify" with respect to a "document" because the definition is overly broad with respect to "each document," and to the extent that such definition demands "a brief description of the substance" of any document, and seeks disclosure of information and/or documents that are protected by attorney-client and work-product privileges. New Mexico objects to this definition because it imposes requirements beyond those found in Rule 33 of the FRCP. New Mexico also objects to this definition as overbroad, unduly burdensome, and unreasonably cumulative or duplicative.

14. New Mexico objects to the terms "Accretions," "Allocation," "Apportioned," "Apportionment," "Apportions," "Compact Apportionment," "Cumulative," "Downstream Contracts," "Return Flow," "Ground water tributary to the Rio Grande," "Lower Rio Grande," and "Unimpeded," "You" and "Yours" as vague, ambiguous and overbroad. New Mexico also objects to these terms to the extent they seek a legal conclusion, which is improper under FRCP 36(a)(1).

15. New Mexico's response to any Request for Admission, notwithstanding its objections should not be construed as a stipulation or admission that any information provided is relevant or admissible, or as a waiver of any of New Mexico's objections.

16. New Mexico objects to each Request for Admission on the ground that the request seeks information that is unduly burdensome and not proportional to the scope of this case.

SPECIFIC OBJECTIONS AND RESPONSES TO TEXAS'S FIRST SET OF REQUESTS FOR ADMISSION TO NEW MEXICO

REQUEST FOR ADMISSION NO. 1: Admit that the Compact Apportions Rio Grande water to Colorado.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "Rio Grande water" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that the Compact apportions surface waters of the Rio Grande to the State of Colorado ("Colorado").

REQUEST FOR ADMISSION NO. 2: Admit that the Compact Apportions Rio Grande water to New Mexico.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "Rio Grande water" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that the Compact apportions surface waters of the Rio Grande to the State of New Mexico, and that this apportionment includes 57% of the Rio Grande surface water annually allocated for delivery by the Rio Grande Project, subject to the United States' obligations to Mexico under the Convention for the Equitable Distribution of the Waters of the Rio Grande of May 21, 1906 Between the United States and Mexico, 34 Stat. 2953 ("Treaty") (the remaining 43% being apportioned under the Compact to Texas).

REQUEST FOR ADMISSION NO. 3: Admit that the Compact Apportions Rio Grande water to Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "Rio Grande water" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that the Compact apportions surface waters of the Rio Grande to the State of Texas, namely 43% of the Rio Grande surface water annually allocated for delivery by the Rio Grande Project, subject to the United States' obligations to Mexico under the Treaty (the remaining 57% being apportioned under the Compact to New Mexico).

REQUEST FOR ADMISSION NO. 4: Admit that Colorado's Apportionment pursuant the Compact is the depletions in the Rio Grande River in Colorado as of 1938 measured by the indexed relationship described in Article III of the Compact subject to the system of credits and debits described in the Compact.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "depletions" and "Rio Grande water" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that Colorado's apportionment of the surface waters of the Rio Grande on the mainstem at the Colorado and New Mexico state border is defined by Article III of the Compact. The Compact speaks for itself, and New Mexico denies any inference that is inconsistent with the Compact.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico admits the Compact allows Colorado the right to use the waters of the Rio Grande consistent with its Article III obligation, as modified by Article VI.

REQUEST FOR ADMISSION NO. 5: Admit that New Mexico's Apportionment pursuant to the Compact is the depletions in the Rio Grande River in New Mexico above Elephant Butte Reservoir as of 1938 measured by the indexed relationship described in Article IV of the Compact subject to the system of credits and debits described in the Compact.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "depletions" and "Rio Grande water," and to the phrase "as of 1938 measured by the indexed relationship described in Article IV of the Compact subject to the system of credits and debits described in the Compact" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that part of New Mexico's apportionment of the surface waters of the Rio Grande is defined by Article IV of the Compact. The Compact speaks for itself, and New Mexico denies any inference that is inconsistent with the Compact. New Mexico specifically denies that the apportionment identified in RFA No. 5 is the only apportionment of water it receives under the Compact, and affirmatively asserts that its Compact apportionment includes 57% of Project supply. Except as aforesaid, New Mexico denies RFA No. 5.

REQUEST FOR ADMISSION NO. 6: Admit that Texas's Apportionment under the Compact is the water delivered to Elephant Butte Reservoir by New Mexico pursuant to Article IV of the Compact plus Accretions to the Rio Grande River below Elephant Butte Dam subject to the United States's [sic] treaty obligation to New Mexico and EBID's Rio Grande Project contractual right.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "delivered" and to the phrase "pursuant to Article IV of the Compact plus Accretions to the Rio Grande River below Elephant Butte Dam subject to the United States's treaty obligation to New Mexico and EBID's Rio Grande Project contractual right" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico denies RFA No. 6.

REQUEST FOR ADMISSION NO. 7: Admit that Colorado's obligation to deliver water under the Compact is at the Colorado-New Mexico State line.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms “obligation,” “deliver,” and “water” as vague and ambiguous. New Mexico further objects to this request as seeking a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that Colorado’s obligation to deliver water under the Compact is set forth in Article III of the Compact. Specifically, New Mexico admits that under Article III, Colorado delivers surface water of the Rio Grande at the Colorado-New Mexico State line as measured at specified locations. The Compact speaks for itself, and New Mexico denies any inference that is inconsistent with the Compact.

REQUEST FOR ADMISSION NO. 8: Admit that New Mexico’s obligation to deliver water under the Compact is at Elephant Butte Reservoir.

RESPONSE: In addition to New Mexico’s General Objections, New Mexico objects to the terms “obligation,” “deliver,” and “water” as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that Article IV of the Compact includes an obligation to deliver water at Elephant Butte Reservoir. The Compact speaks for itself, and New Mexico denies any inference that is inconsistent with the Compact. Except as aforesaid, New Mexico denies RFA No. 8, and specifically denies that all surface water delivered to the Rio Grande Project is apportioned to Texas.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico rephrases its response as follows: New Mexico admits that New Mexico has an obligation to deliver water under Article IV of the Compact at Elephant Butte Reservoir.

REQUEST FOR ADMISSION NO. 9: Admit that Downstream Contracts promise Texas water districts an amount of water every year from the Project.

RESPONSE: In addition to New Mexico’s General Objections, New Mexico objects to the terms “promise,” “amount,” “Texas water districts,” “amount” and “water” as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that the U.S. Supreme Court stated that the: “Downstream Contracts . . . promised Texas water districts a certain amount of water every year from the Reservoir’s resources,” that “the Compact is inextricably intertwined with the Rio Grande Project and the Downstream Contracts,” and that “through the Downstream Contracts” the United States is “charged with assuring that the Compact’s equitable apportionment to Texas and part of New Mexico is in fact made.” *Texas v. New Mexico*, 138 S. Ct. 954 at 957, 959 (2018) (internal quotation marks omitted). The Downstream Contracts speak for themselves. Except as aforesaid, New Mexico denies RFA No. 9.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico rephrases its response as follows: New Mexico admits that, consistent with the Court’s 2018 opinion, the “Downstream Contracts . . . promised Texas water districts a certain amount of water every year from the Reservoir’s resources,” that “the Compact is inextricably intertwined with the Rio Grande Project and the Downstream Contracts," and that "through the Downstream Contracts" the United States is "charged with assuring that the Compact's equitable apportionment to Texas and part of New Mexico is in fact made." *Texas v. New Mexico*, 138 S. Ct. 954 at 957, 959 (2018) (internal quotation marks omitted).

REQUEST FOR ADMISSION NO. 10: Admit that New Mexico may not interfere with the delivery of Texas's Apportioned water under the Compact.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "interfere," "delivery," and "water," and to this request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). New Mexico is unable to admit or deny this request because it does not understand its meaning; in particular, New Mexico does not understand what Texas means by "interfere" in the context of RFA No. 10. Subject to its objections, and based in part on the ambiguity of the term "interfere," New Mexico denies RFA No. 10.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico rephrases its response as follows: New Mexico denies this request. The Project uses and reuses return flows and other sources of water to deliver apportioned water to Texas, and New Mexico denies that even if it "take[s] action, or refrain[s] from action, in a way that hinders, blocks, slows, impedes or depletes" specific molecules of water, which New Mexico does not admit, this does not necessarily constitute "inference" with delivery of Texas's Compact apportionment, as defined by Texas.

REQUEST FOR ADMISSION NO. 11: Admit that Return flows from irrigation of lands in the Lower Rio Grande are part of the water belonging to the Project.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "Return flows," "irrigation," "lands," "water" and "belonging" as vague and ambiguous. New Mexico objects to this request to the extent a response necessitates expert opinion. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that the Project captures and redelivers return flows. *See, e.g.,* Order Granting the State's Motion to Dismiss the United States' Claims to Groundwater and Denying the United States' Motion for Summary Judgment, LRG Adjudication (Aug. 6, 2012). Except as aforesaid, New Mexico denies RFA No. 11.

REQUEST FOR ADMISSION NO. 12: Admit that Return flows from irrigation of lands in the Lower Rio Grande are part of the water Apportioned to Texas under the Compact.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "Return flows," "irrigation," "lands," "part" and "water" as vague and ambiguous. New Mexico objects to this request to the extent a response necessitates expert opinion. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under

FRCP 36(a)(1). Subject to its objections, New Mexico admits that return flows may constitute a portion of the Project supply apportioned and delivered to both Texas and New Mexico under the Compact. Except as aforesaid, New Mexico denies RFA No. 12.

REQUEST FOR ADMISSION NO. 13: Admit that Groundwater tributary to the Rio Grande below Elephant Butte Reservoir is part of the water belonging to the Project.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "part," "water" and "belonging," and to the phrase "below Elephant Butte Reservoir" as vague and ambiguous. New Mexico objects to this request to the extent a response necessitates expert opinion. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico denies RFA No. 13.

REQUEST FOR ADMISSION NO. 14: Admit that Groundwater tributary to the Rio Grande below Elephant Butte Reservoir is part of the water Apportioned to Texas under the Compact.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "part" and "water," and to the phrase "below Elephant Butte Reservoir" as vague and ambiguous. New Mexico objects to this request to the extent a response necessitates expert opinion. New Mexico further objects to this request as seeking a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico denies RFA No. 14.

REQUEST FOR ADMISSION NO. 15: Admit that pumping of Groundwater tributary to the Rio Grande in New Mexico includes the pumping of Project Return flows that otherwise would reach Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "pumping" and "Return flows," to the phrase "that otherwise would reach," and to this request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico denies RFA No. 15.

REQUEST FOR ADMISSION NO. 16: Admit that groundwater pumping in New Mexico includes the pumping of Groundwater tributary to the Rio Grande that intercepts surface water flows in the Rio Grande that would otherwise reach Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "groundwater pumping," "pumping" and "intercepts," to the phrase "that otherwise would reach," and to this request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico denies RFA No. 16.

<u>REQUEST FOR ADMISSION NO. 17</u>: Admit that ground water pumping in New Mexico interferes with delivery of Project Return flows that would otherwise reach Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "groundwater pumping," "interferes," "delivery" and "Return flows," and to the phrase "that otherwise would reach" as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico denies RFA No. 17.

<u>REQUEST FOR ADMISSION NO. 18</u>: Admit that the Compact's geographic boundary extends to Fort Quitman in Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "extends" and to the phrase "Compact's geographic boundary" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that the Compact, in its preamble, states that it applies to "the use of the waters of the Rio Grande above Fort Quitman, Texas" and was entered "for the purpose of effecting an equitable apportionment of such waters." The Compact speaks for itself, and New Mexico denies any inference that is inconsistent with the Compact. Except as aforesaid, New Mexico denies RFA No. 18.

<u>REQUEST FOR ADMISSION NO. 19</u>: Admit that pumping of Groundwater tributary to the Rio Grande in the Lower Rio Grande interferes with deliveries of Project water Allocations to Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "pumping," "interferes," and "deliveries," and to this request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, the location, amount and timing of groundwater pumping and associated impacts, and the response of Project operations is the subject of expert testimony in this case, and New Mexico denies any inferences that are inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 19.

<u>REQUEST FOR ADMISSION NO. 20</u>: Admit that pumping of Groundwater tributary to the Rio Grande in the Lower Rio Grande interferes with deliveries of Texas's Compact Apportionment.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "pumping," "interferes," and "deliveries" as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. New

Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, the location, amount and timing of groundwater pumping and associated impacts, and the response of Project operations is the subject of expert testimony in this case, and New Mexico denies any inferences that are inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 20.

REQUEST FOR ADMISSION NO. 21: Admit that the amount of Rio Grande water that Colorado must deliver to the Colorado-New Mexico State line is based upon flow data and conditions that existed prior to 1938.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "amount," "Rio Grande water" and "deliver," and to the phrase "flow data and conditions that existed prior to 1938" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that to the extent Article III of the Compact uses data, it was necessarily available prior to the approval of the Compact. The Compact speaks for itself, and New Mexico denies any inference that is inconsistent with the Compact. Except as aforesaid, New Mexico denies RFA No. 21.

REQUEST FOR ADMISSION NO. 22: Admit that the amount of Rio Grande water that New Mexico must deliver into Elephant Butte Reservoir to satisfy the Texas Compact Apportionment is based upon flow data and conditions that existed prior to 1938.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "amount," "Rio Grande water," "deliver" and "satisfy," and to the phrase "flow data and conditions that existed prior to 1938" as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that Article IV of the Compact is based upon data that was necessarily available prior to the approval of the Compact. The Compact speaks for itself, and New Mexico denies any inference that is inconsistent with the Compact. Except as aforesaid, New Mexico denies RFA No. 22.

REQUEST FOR ADMISSION NO. 23: Admit that New Mexico, at least since 1985, has known that the pumping of Groundwater tributary to the Rio Grande in the Lower Rio Grande for use in New Mexico reduced the volume of water that absent such pumping would flow into Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "known" and "pumping," and to the phrases "at least since 1985," "in the Lower Rio Grande for use in New Mexico," "reduced the volume of water" and "would flow into" as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico denies RFA No. 23.

<u>REQUEST FOR ADMISSION NO. 24</u>: Admit that since 1985, the volume of groundwater pumping in the Lower Rio Grande is greater than the volume of ground water pumping in the Lower Rio Grande in 1938.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "volume," "groundwater pumping," "ground water pumping," "Lower Rio Grande" and "greater," and to the phrase "since 1985" as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico admits that the volume of groundwater pumping below Elephant Butte Reservoir since 1985 is generally higher than the volume pumped in 1938.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico rephrases its response as follows: New Mexico admits that, since 1985, the volume of groundwater pumping in the Lower Rio Grande is generally greater than the volume of ground water pumping in the Lower Rio Grande in 1938. New Mexico further asserts that, since 1985, the volume of groundwater pumping in the Compact area in Texas is generally greater than the volume of ground water pumping in the Compact area in Texas in 1938.

<u>REQUEST FOR ADMISSION NO. 25</u>: Admit that groundwater pumping consistent with state law in New Mexico in the Lower Rio Grande must be authorized or permitted by the State of New Mexico.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "groundwater pumping," "state law" and "Lower Rio Grande," and to the phrases "consistent with" and "must be authorized or permitted by," and to the request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent it seeks a legal conclusion, which is improper under FRCP 36(a)(1). Subject to its objections, New Mexico admits that the State of New Mexico has jurisdiction over the waters within the state, and admits that groundwater pumping in the Lower Rio Grande must be "consistent with state law." Except as aforesaid, New Mexico denies RFA No. 25.

<u>REQUEST FOR ADMISSION NO. 26</u>: Admit that the State of New Mexico has authorized ground water pumping in the Lower Rio Grande.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "authorized" and "ground water pumping" as vague and ambiguous. Subject to its objections, New Mexico admits that the State of New Mexico has jurisdiction over the waters within the state, and admits that groundwater pumping in the Lower Rio Grande must be consistent with state law. New Mexico further admits that since the declarations of the Lower Rio Grande Underground Water Basin, the New Mexico State Engineer has authorized certain groundwater pumping in that basin with appropriate conditions, subject to administrative rules, policies, and procedures. Except as aforesaid, New Mexico denies RFA No. 26.

__REQUEST FOR ADMISSION NO. 27__: Admit that the volume of pumping of Groundwater tributary to the Rio Grande in the Lower Rio Grande has increased since 1951.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "tributary," and to the phrases "volume of pumping" and "increased since 1951" as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico admits that the volume of groundwater pumping in the Rio Grande basin below Elephant Butte Reservoir has increased in certain years since 1951. The location, amount and timing of groundwater pumping and associated impacts, and the response of Project operations is the subject of expert testimony in this case, and New Mexico denies any inferences that are inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 27.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico admits that the volume of pumping of Groundwater hydrologically connected to the Rio Grande in the Lower Rio Grande in New Mexico, as well the volume of pumping of Groundwater hydrologically connected to the Rio Grande in Texas, has increased in certain years since 1951.

__REQUEST FOR ADMISSION NO. 28__: Admit that New Mexico, prior to May 22, 2018, did not provide notice to Texas of the allegations set forth in the First Claim for Relief in New Mexico's Counterclaims filed in This Case.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the phrases "prior to May 22, 2018" and "provide notice" as vague and ambiguous. Subject to its objections, New Mexico denies RFA No. 28.

__REQUEST FOR ADMISSION NO. 29__: Admit that New Mexico, prior to May 22, 2018, did not provide notice to Texas of the allegations set forth in the Fourth Claim for Relief in New Mexico's Counterclaims filed in This Case.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the phrases "prior to May 22, 2018" and "provide notice" as vague and ambiguous. Subject to its objections, New Mexico denies RFA No. 29.

__REQUEST FOR ADMISSION NO. 30__: Admit that well pumping of Groundwater tributary to the Rio Grande in the Mesilla and Rincon Valleys in New Mexico depletes Rio Grande surface flows.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "well pumping" and "depletes," and to the phrases "Groundwater tributary to the Rio Grande in the Mesilla and Rincon Valleys in New Mexico" and "Rio Grande surface flows" as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico admits that under certain conditions, in certain years, groundwater pumping in the Mesilla and Rincon Valleys in New Mexico, and in the Mesilla and El Paso Valleys in Texas, has the potential to deplete Rio Grande surface flows. The degree to which depletions occur in any given year is the subject of expert testimony in this case, and New Mexico denies any inferences that are inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 30.

<u>REQUEST FOR ADMISSION NO. 31</u>: Admit that between 1938 and 2020 the New Mexico Office of the State Engineer has never curtailed well pumping in the Lower Rio Grande to avoid depleting surface flows in the Lower Rio Grande.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "curtailed" and "well pumping," to the phrases "between 1938 and 2020," "has never" and "to avoid depleting surface flows," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico denies RFA No. 31.

<u>REQUEST FOR ADMISSION NO. 32</u>: Admit that groundwater pumping by the City of Las Cruces under LRG-430 has decreased the volume of Rio Grande surface water delivered to Texas below the volume of surface water that would have been present under pre-pumping conditions.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "delivered," to the phrases "groundwater pumping by the City of Las Cruces," "decreased the volume of Rio Grande surface water," and "below the volume of surface water that would have been present" and "under pre-pumping conditions," and to this request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, the location, amount and timing of groundwater pumping and associated impacts, the degree to which depletions occur in any given year, the volume of return flows and other offsets, whether pumping under LRG-430 has decreased or contributed to an increase in the volume of the flows of the Rio Grande, and the response of Project operations, is the subject of expert testimony in this case, and New Mexico denies any inferences that are inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 32.

<u>REQUEST FOR ADMISSION NO. 33</u>: Admit that pumping of Groundwater tributary to the Rio Grande in the Lower Rio Grande depletes drain flows within the Project Area.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "pumping," "depletes," "drain flows" and "within the Project Area" as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico admits that under certain conditions, in certain years, groundwater pumping in the Rio Grande basin below Elephant Butte Reservoir has the potential to deplete drain flows. The location, amount and timing of groundwater pumping, the effect, if any, on drain flows, and the response of Project operations is the subject of expert testimony in this case, and New Mexico denies any inferences that are inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 33.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico admits that, under certain conditions, in certain years, pumping of Groundwater hydrologically connected to the Rio Grande in the Lower Rio Grande, as well as pumping of Groundwater hydrologically connected to the Rio Grande in Texas, has the potential to deplete drain flows within the Project area.

REQUEST FOR ADMISSION NO. 34: Admit that pumping of Groundwater tributary to the Rio Grande in the Lower Rio Grande has decreased the volume of Rio Grande surface water in canals below the volume of surface water that would have been present under pre-groundwater pumping conditions.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "tributary," "pumping," "Lower Rio Grande" and "canals," and to the phrases "decreased the volume of" and "below the volume of surface water that would have been present under pre-groundwater pumping conditions," and to this request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico admits that under certain conditions, in certain years, groundwater pumping in the Rio Grande basin below Elephant Butte Reservoir has the potential to deplete surface water in canals. The location, amount and timing of groundwater pumping, the effect, if any, on Rio Grande surface water in canals, and the response of Project operations is the subject of expert testimony in this case, and New Mexico denies any inferences that are inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 34.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico admits that, under certain conditions, in certain years, pumping of Groundwater hydrologically connected to the Rio Grande in the Lower Rio Grande, as well as pumping of Groundwater hydrologically connected to the Rio Grande in Texas, has the potential to decrease the volume of Rio Grande surface water in canals below the volume of surface water that would have been present under pre-groundwater pumping conditions.

REQUEST FOR ADMISSION NO. 35: Admit that You were aware, by at least August 2005, that Texas was concerned about the impacts to Project supplies caused by New Mexico groundwater pumping.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "You," "concerned," "impacts" and "Project supplies," to the phrases "were aware," "by at least August 2005" and "New Mexico groundwater pumping," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico admits that Texas discussed potential impacts of groundwater pumping with New Mexico after 2000, and at that time New Mexico raised concerns with Texas regarding the potential impacts to Project supply caused by groundwater pumping in Texas. New Mexico expressed a willingness to discuss groundwater use in both States, but Texas indicated that it no longer desired to discuss the subject. Except as aforesaid, New Mexico denies RFA No. 35.

REQUEST FOR ADMISSION NO. 36: Admit that contract interpretation is a question of law.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the phrase "contract interpretation" as vague and ambiguous. New Mexico further objects to this request as seeking a legal conclusion, which is improper under FRCP 36(a)(1).

<u>REQUEST FOR ADMISSION NO. 37</u>: Admit that groundwater pumping in the New Mexico Mesilla Valley from 1900 to the present has decreased the volume of Project surface water delivered to farm headgates in Texas below the volume of Project surface water that would have been delivered under pre-groundwater pumping conditions.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the phrases "groundwater pumping in the New Mexico Mesilla Valley," "from 1900 to the present," "decreased the volume of Project surface water delivered to farm headgates" and "below the volume of Project surface water that would have been delivered under pre-groundwater pumping conditions," and to this request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, the location, amount and timing of groundwater pumping, the effect, if any, on Rio Grande surface water delivered to farm headgates, and the response of Project operations is the subject of expert testimony in this case, and New Mexico denies any inferences that are inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 37.

<u>REQUEST FOR ADMISSION NO. 38</u>: Admit that groundwater pumping in the New Mexico Mesilla Valley from 1900 to the present has decreased the volume of Project Return flows in drains below the amount of Project Return flows that would have been available under pre-pumping conditions.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the phrases "groundwater pumping in the New Mexico Mesilla Valley," "from 1900 to the present," "decreased the volume of Project Return flows in drains below the amount of Project Return flows" and "that would have been available under pre-pumping conditions," and to this request in its entirety as vague and ambiguous. New Mexico further objects to this request to the extent a response necessitates expert opinion. Subject to its objections, New Mexico admits that under certain conditions, in certain years, groundwater pumping in the Rio Grande basin below Elephant Butte Reservoir has the potential to decrease the volume of return flows in drains. The location, amount and timing of groundwater pumping, the effect, if any on the volume of return flows in drains, and the response of Project operations is the subject of expert testimony in this case, and New Mexico denies any inference that is inconsistent with its expert disclosures. Except as aforesaid, New Mexico denies RFA No. 38.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico admits that, under certain conditions, in certain years, groundwater pumping in the New Mexico Mesilla Valley, as well as in the Mesilla and El Paso Valleys in Texas, from 1900 to the present has decreased the volume of Project Return flows in drains below the amount of Project Return flows that would have been available under pre-pumping conditions.

<u>REQUEST FOR ADMISSION NO. 39</u>: Admit that You were aware in 1950-1960 of ground water pumping in the Project Area in Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "You," to the phrases "were aware," "in 1950-1960" and "ground water pumping in the Project Area in Texas," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico admits at least some person or entity within Texas's expansive definition of "You" was aware of groundwater pumping activity within Texas's definition of "Project Area" in Texas between 1950 and 1960. Except as aforesaid, New Mexico denies RFA No. 39.

<u>REQUEST FOR ADMISSION NO. 40</u>: Admit that You were aware in 1960-1970 of ground water pumping in the Project Area in Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "You," to the phrases "were aware," "in 1960-1970" and "ground water pumping in the Project Area in Texas," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico admits at least some person or entity within Texas's expansive definition of "You" was aware of groundwater pumping activity within Texas's definition of "Project Area" in Texas between 1960 and 1970. Except as aforesaid, New Mexico denies RFA No. 40.

<u>REQUEST FOR ADMISSION NO. 41</u>: Admit that You were aware in 1970-1980 of ground water pumping in the Project Area in Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "You," to the phrases "were aware," "in 1970-1980" and "ground water pumping in the Project Area in Texas," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico admits at least some person or entity within Texas's expansive definition of "You" was aware of groundwater pumping activity within Texas's definition of "Project Area" in Texas between 1970 and 1980. Except as aforesaid, New Mexico denies RFA No. 41.

<u>REQUEST FOR ADMISSION NO. 42</u>: Admit that You were aware in 1980-1990 of ground water pumping in the Project Area in Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "You," to the phrases "were aware," "in 1980-1990" and "ground water pumping in the Project Area in Texas," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico admits at least some person or entity within Texas's expansive definition of "You" was aware of groundwater pumping activity within Texas's definition of "Project Area" in Texas between 1980 and 1990. Except as aforesaid, New Mexico denies RFA No. 42.

<u>REQUEST FOR ADMISSION NO. 43</u>: Admit that You were aware in 1990-2000 of ground water pumping in the Project Area in Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "You," to the phrases "were aware," "in 1990-2000" and "ground water pumping in the Project Area in Texas," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico admits at least some person or entity within Texas's expansive definition of "You" was aware of groundwater pumping activity within Texas's definition of "Project Area" in Texas between 1990 and 2000. Except as aforesaid, New Mexico denies RFA No. 43.

<u>REQUEST FOR ADMISSION NO. 44</u>: Admit that You were aware in 2000-2010 of ground water pumping in the Project Area in Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "You," to the phrases "were aware," "in 2000-2010" and "ground water pumping in the Project Area in Texas," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico admits at least some person or entity within Texas's expansive definition of "You" was aware of groundwater pumping activity within Texas's definition of "Project Area" in Texas between 2000 and 2010. Except as aforesaid, New Mexico denies RFA No. 44.

<u>REQUEST FOR ADMISSION NO. 45</u>: Admit that You were aware in 2010-present of ground water pumping in the Project Area in Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "You," to the phrases "were aware," "in 2010-present" and "ground water pumping in the Project Area in Texas," and to this request in its entirety as vague and ambiguous. Subject to its objections, New Mexico admits at least some person or entity within Texas's expansive definition of "You" was aware of groundwater pumping activity within Texas's definition of "Project Area" in Texas between 2010 and the present. Except as aforesaid, New Mexico denies RFA No. 45.

<u>REQUEST FOR ADMISSION NO. 46</u>: Admit that the farm delivery requirement for farmers in the Lower Rio Grande established by the Adjudication Court in Stream System 97-101 was 4.5 acre-feet per acre.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "farm delivery requirement," and to the phrase "farmers in the Lower Rio Grande" as vague and ambiguous. Subject to its objections, New Mexico asserts that the Final Judgment in SS-97-101 speaks for itself. New Mexico denies any inference inconsistent with this judgment. Except as aforesaid, New Mexico denies RFA No. 46.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico denies that the final judgment in SS-97-101 approved a farm delivery requirement ("FDR") of 4.5 acre-feet per acre for all irrigated acres in the Lower Rio Grande. The final judgment approved an FDR of 3.024 acre-feet per acre for lands irrigated with surface water only, up to 4.5 acre-feet per acre for combined surface and groundwater acres, and up to 4.5 acre-feet per acre for groundwater-only acres.

REQUEST FOR ADMISSION NO. 47: Admit that under Stream System 97-101 pecan growers could establish a right to a farm delivery requirement of 5.5 acre-feet per acre by a date certain.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "pecan growers" and "farm delivery requirement" as vague and ambiguous. Subject to its objections, New Mexico asserts that the Final Judgment in SS-97-101 speaks for itself. New Mexico denies any inference inconsistent with this judgment. Except as aforesaid, New Mexico denies RFA No. 47.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico admits that the final judgment in SS-97-101 allowed certain farmers to submit evidence to support a farm delivery requirement of up to 5.5 acre-feet per acre. Few farmers took advantage of this process, and the window for making such submissions has closed.

REQUEST FOR ADMISSION NO. 48: Admit that the State of New Mexico's expert witness in Stream System 97-101, John Longworth, used a version of the Blaney-Criddle Method in determining a proposed farm delivery requirement of 3.0 acre-feet per acre.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the term "used," and to the phrases "a version of the Blaney-Criddle Method," "in determining a proposed farm delivery requirement" as vague and ambiguous. Subject to its objections, New Mexico admits that Mr. Longworth submitted an expert report in Case No. CV-96-888 that discussed the Modified Blaney-Criddle Method. Mr. Longworth's expert report speaks for itself. New Mexico denies that Mr. Longworth "proposed [a] farm delivery requirement of 3.0 acre-feet per acre." Except as aforesaid, New Mexico denies RFA No. 48.

REQUEST FOR ADMISSION NO. 49: Admit that the farm delivery requirement of 3.0 acre-feet per acre as proposed by the State of New Mexico in Stream System 97-101 was selected in part because of concerns about the effect of groundwater pumping on Compact deliveries to Texas.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the terms "farm delivery requirement," "concerns," "effect" and "groundwater pumping," and to the phrases "as proposed by the State of New Mexico," "was selected in part," and "Compact deliveries" as vague and ambiguous. New Mexico further objects to this request as improperly seeking information protected by attorney-client privilege. Subject to its objections, New Mexico denies RFA No. 49.

REQUEST FOR ADMISSION NO. 50: Admit that attached hereto as Exhibit B is a true and correct copy of the September 13, 1935 report of the Board of Review of the National Resource Committee Relating to water projects on the Rio Grande above El Paso.

RESPONSE: The document at Exhibit B was not authored or created by New Mexico. In addition, Exhibit B is not a document produced by New Mexico, and New Mexico does not have a copy in its records. Accordingly, New Mexico is unable to authenticate the same or to say whether this document is a true and correct copy.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico further asserts that the information New Mexico knows or can readily obtain is insufficient to enable it to admit or deny Texas's request.

REQUEST FOR ADMISSION NO. 51: Admit that attached hereto as Exhibit C is a true and correct copy of the Proceedings of the Rio Grande Compact Commission meetings of March 3 through March 18, 1938 (Including appendices).

RESPONSE: Admit.

REQUEST FOR ADMISSION NO. 52: Admit that attached hereto as Exhibit D is a true and correct copy of the Engineers Report to the Rio Grande Compact Commission dated December 27, 1937.

RESPONSE: Admit.

REQUEST FOR ADMISSION NO. 53: Admit that attached hereto as Exhibit E is a true and correct copy of the U.S. Geological Survey, Preliminary memorandum on ground-water supplies for Elephant Butte Irrigation District, New Mexico, September 1947 (known as the "Conover Report") (at NM_00124167-193.)

RESPONSE: Admit.

REQUEST FOR ADMISSION NO. 54: Admit that the U.S. Geological Survey, Preliminary memorandum on ground-water supplies for Elephant Butte Irrigation District, New Mexico, September 1947, (NM_00124167-193) (i.e., the Conover Report) is part of the official records of the State of New Mexico Office of the State Engineer.

RESPONSE: In addition to New Mexico's General Objections, New Mexico objects to the phrase "official records of the State of New Mexico Office of the State Engineer" as vague and ambiguous. New Mexico is unable to determine what Texas means by the phrase "official records of the State of New Mexico Office of the State Engineer." Subject to its objections, New Mexico admits that the Office of the State Engineer has a copy of the document marked as Exhibit E.

However, New Mexico is unaware whether this Office maintains “official records” within the meaning intended by Texas. Therefore, New Mexico is unable to admit or deny whether Exhibit E “is part” of such “official records.” Except as aforesaid, New Mexico denies RFA No. 54.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico admits that, under the expansive definition of “official records” proffered by Texas, the Office of the State Engineer has a copy of Exhibit E in its “official records.” New Mexico denies this has any legal significance.

REQUEST FOR ADMISSION NO. 55: Admit that the U.S. Geological Survey, Preliminary memorandum on ground-water supplies for Elephant Butte Irrigation District, New Mexico, September 1947, (NM_00124167-193) (i.e., the Conover Report) was made a part of the official records of the State of New Mexico Office of the State Engineer in or before 1950.

RESPONSE: In addition to New Mexico’s General Objections, New Mexico objects to the phrases “was made a part of,” “the official records of the State of New Mexico Office of the State Engineer,” and “in or before 1950” as vague and ambiguous. New Mexico has made a reasonable inquiry, and based on the information known or presently available to New Mexico, New Mexico is unable to admit or deny this request.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico further asserts that the information New Mexico knows or can readily obtain is insufficient to enable it to admit or deny Texas’s request.

REQUEST FOR ADMISSION NO. 56: Admit that attached hereto as Exhibit F is a true and correct copy of the 1954 USGS Water-Supply Paper 1230, Ground-Water Conditions in the Rincon and Mesilla Valleys and Adjacent Areas in New Mexico (WSP 1230).

RESPONSE: New Mexico denies that the comment embedded on Page 1 of Exhibit F is a part of the true and correct copy of the 1954 USGS Water-Supply Paper 1230, Ground-Water Conditions in the Rincon and Mesilla Valleys and Adjacent Areas in New Mexico (WSP 1230). New Mexico admits that the remainder of Exhibit F is a true and correct copy of that document.

REQUEST FOR ADMISSION NO. 57: Admit that attached hereto as Exhibit G is a true and correct copy of “Rio Grande, Elephant Butte Dam to El Paso, TX,” authored by the State of New Mexico Office of the State Engineer.

RESPONSE: The document at Exhibit G is not a document produced by New Mexico. New Mexico has made a reasonable inquiry, and based on the information known or presently available to New Mexico, New Mexico is unable to admit or deny this request.

SUPPLEMENTAL RESPONSE: Subject to its objections, New Mexico further asserts that the information New Mexico knows or can readily obtain is insufficient to enable it to admit or deny Texas’s request.

Respectfully submitted this 30th day of October 2020,

/s/ Jeffrey Wechsler
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No. 141, Original

IN THE
SUPREME COURT OF THE UNITED STATES

♦

STATE OF TEXAS,

Plaintiff,

v.

STATE OF NEW MEXICO and
STATE OF COLORADO,

Defendants.

♦

OFFICE OF THE SPECIAL MASTER

♦

STATE OF NEW MEXICO'S CERTIFICATE OF SERVICE

♦

This is to certify that on October 30th, 2020, I caused a true and correct copy of the **State of New Mexico's Supplemental Responses to the State of Texas's First Set of Requests for Admission to the State of New Mexico** to be served by e-mail upon all counsel of record and interested parties on the Service List, attached hereto.

Respectfully submitted this 30th day of October 2020.

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Tab 15

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

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REMOTE ORAL AND VIDEOTAPED DEPOSITION OF
JOHN D'ANTONIO
JUNE 24, 2020
VOLUME 1

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION of JOHN D'ANTONIO, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on June 24, 2020, from 9:03 a.m. to 12:51 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the offices of HEATHER L. GARZA, CSR, RPR, The Woodlands, Texas, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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Peggy Barroll
Arianne Singer
Al Blair
Gary Esslinger
Susan Barela
Ian Ferguson
Michelle Estrada-Lopez
Greg Ridgley
Jeff Clark
Jonathan George
Erek Fuchs
Kyler Rayden
Rolf Schmidt-Petersen
Estevan Lopez

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WITNESS: JOHN D'ANTONIO

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THE VIDEOGRAPHER: The time is 9:03 a.m. We're on the record.

(The witness was sworn.)

MR. SOMACH: I guess we should start with some appearances. This is Stuart Somach. I'm the attorney for the State of Texas. On the phone or on the Zoom, I guess, is Rich Deitchman, Theresa Barfield, Mac Goldsberry from my office, also appearing on behalf of the State of Texas. I'm not sure if anybody else is on the phone. There is -- I have a list, but I can't entirely scroll through it right now so if anybody else for Texas is on the phone, just make your appearance.

(No response.)

MR. SOMACH: Then Jeff, for New Mexico?

MR. WECHSLER: Good morning. Jeff Wechsler for the State of New Mexico, and we also have or will have throughout the day John Draper, Greg Ridgley, Arianne Singer, Shelly Dalrymple, Susan Barela, Rolf Schmidt-Petersen, Peggy Barroll, and Estevan Lopez.

MR. SOMACH: And for the United States?

MR. LEININGER: Good morning. This is Lee Leininger for the United States, and we're joined with Jim Dubois from Department of Justice, Chris Rich and Shelly Randel from the solicitor's office, Ian Ferguson, Michelle Estrada-Lopez, Bureau of Reclamation.

MR. SOMACH: And for the State of Colorado?

MR. WALLACE: Good morning. This is Chad Wallace, along with Preston Hartman, for the State of Colorado.

MR. SOMACH: And EP No. 1.

MR. HICKS: Renea Hicks for El Paso County Water Improvement District No. 1, and also on the Zoom, I believe, is Dr. Al Blair.

MR. SOMACH: Anybody on behalf of the Elephant Butte Irrigation District?

MR. ESSLINGER: Gary Esslinger.

MR. SOMACH: Okay.

MR. FUCHS: Erek Fuchs.

MR. SOMACH: Okay. What about -- I'll just go down through the service list here if I could. What about for Albuquerque?

MR. BROCKMANN: Yes, Stuart, this is Jim Brockmann on behalf of Albuquerque. I'll also sit in for Jay for the City of Las Cruces.

MR. SOMACH: Okay. City of El Paso?

MR. CAROOM: Good morning. Doug Caroom for the City of El Paso.

MR. SOMACH: Hudspeth County Conservation Reclamation District?

(No response.)

MR. SOMACH: New Mexico pecan growers?

(No response.)

MR. SOMACH : New Mexico State?

MR. UTTON: Good morning. This is John Utton.

MR. SOMACH: Anybody else? Okay. Now, Jeff, my -- is someone else -- want to say something?

MR. GEORGE: Good morning. This is Jonathan George on behalf of Texas. I was -- I missed my cue to speak.

MR. SOMACH: Okay. Who else? Anybody else?

(No response.)

MR. SOMACH: Okay. Jeff, my understanding is we'll go to -- I'm trying to think when my time -- 1:00 your time, and if necessary, we'll -- we'll move into tomorrow, and we have Friday, and heaven forbid that we need another half day, but I do appreciate your accommodating me. I did have a conflict arise yesterday and because it was a family conflict as opposed to a business conflict, I put the priority there, so I appreciate your accommodation.

JOHN D'ANTONIO,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. SOMACH:

Q. Mr. D'Antonio, you've been sworn in, and I know that you've had your deposition taken before; is that correct?

A. That's correct.

Q. A few times?

A. A couple of times as far as I can remember, yes.

Q. Have you ever -- you've never done one of these remote depositions, have you?

A. I have not.

Q. Okay. I -- I don't know if they're easier or harder, to be honest with you. This is the first one I've taken so we'll experience this together. Jeff's an old hand at it, so he can help us out where we -- we run into problems. But in general, this is just like any other deposition, so I want to make certain that you understand that you're under oath and that by agreement of the parties and involvement of the Special Master, an oath is the same as if we were in the same room taking an in-person deposition. Do you

understand that?

A. I do.

Q. And you know that the deposition could, under various circumstances, be utilized in the courtroom during the trial of this case or elsewhere in this case. Do you understand that?

A. Yes.

Q. You can see me okay?

A. I can if I look up.

Q. Well, that's -- as it should be.

A. Yep.

Q. And you can see your attorney, Mr. Wechsler, okay; is that correct?

A. I can see him, yes.

Q. All right. Then without much further ado, let's get started. I -- because you're -- you're not a -- testifying as a expert in the sense of -- of being a retained consultant or even a non-retained expert, I don't have any background information for you, so I want to start there just to kind of get some context. I do have an exhibit I'm going to put up. And, of course, I lost my list of exhibits somewhere in the shuffle. Let me grab it. This would be what is -- is marked as the John D'Antonio Bio. So if you could put that up for me. Again, I've never done this

before so I'm not sure entirely how this works, but let's give it a try. There you go.

MR. SOMACH: Now, does the deponent have control of that screen, so he can scroll through that?

THE VIDEOGRAPHER: I'll give that to him right now.

MR. SOMACH: Okay.

THE VIDEOGRAPHER: And just whenever you -- you have to click on the screen to start the control.

THE WITNESS: Yes.

Q. (BY MR. SOMACH) Okay. John, do you know what it is --

MR. SOMACH: And let's mark this as Exhibit 1.

THE VIDEOGRAPHER: Okay.

(Exhibit No. 1 was marked.)

Q. (BY MR. SOMACH) And, John, do you know what that is?

A. Yes. It's my bio that I used when I was with the U.S. Army Corps of Engineers from two thousand -- the end of 2011 to about March of 2019.

Q. All right. I don't -- you know, I'm only using this particular exhibit as an anchor to kind of run down through -- through your background. I notice

statutorily the chair of the water quality control commission, part of the mining commission, and so I got into some of the other aspects of -- of New Mexico water associated with those particular areas, also air -- air quality, DOD controls, so some of the Los Alamos programs and clean up hazardous and toxic waste. Several others that escape me right now.

Q. What -- what's the role -- that's the wrong choice of words, but as a cabinet secretary, do you have agencies that are below you in terms of your responsibility that you're responsibility -- responsible for those state agencies?

A. You have programs and bureaus, which are headed by directors and bureau chiefs, but no, there's just one agency. New Mexico Environmental Department is one agency. New Mexico Office of the State Engineer is one agency, so there's no agencies underneath those.

Q. So is it a -- is it a -- a parallel -- correct me if I'm describing this wrong. Is it a parallel agency to the Office of State Engineer?

A. I would say yes. It just has different -- a different mission but same -- same reporting to the governor. It's a -- it's an executive agency that reports directly to the governor.

Q. As is the Office of State Engineer?
A. Yes.
Q. All right. Now, how -- you said you were in that job for a year, the last year of the governor's --
A. It was about five or six months. No, it was just closing out Governor Johnson's last -- last term.
Q. And what -- what was -- when -- when that was done, what did you do then?
A. Well, I thought I had to look for another job based on working for a Republican governor and -- and Governor Richardson was coming in as a -- as a Democrat. Everybody knew that. Typically what happens is all those agency heads are wiped clean, and they start fresh. In my particular case, I was -- I worked with their transition team to help them come up to speed. They asked me if I was interested in staying on as secretary of the environment department, and I said no, but I -- I said I'd rather be state engineer, and they asked me if I had put in for that position, and I said no, and they asked me to go ahead and put in for that position, which I did interview for the -- for the position and was appointed by Governor Richardson.
Q. How long -- I'm sorry?

A. Go ahead.

Q. I -- I interrupted you. Go ahead and finish.

A. I was just appointed for immediately Governor Richardson took office?

Q. What -- I want to come back to the role of state engineer in a little bit and spend a little time on it so I can understand it, but how long were you in the job of state engineer -- state engineer at that point in time?

A. So at that point in time, that was my first appointment to the state engineer position. As I had stated earlier, I worked for the agency since 1998, but that was the -- my first time when I got appointed in 2003 state engineer, and I worked for Governor Richardson for his eight years, both his admin -- both of his terms of office. So from 2008 to 2011, I worked for -- for him.

Q. In -- in your opinion, was Governor Richardson actively involved in New Mexico water issues?

A. Yes.

Q. So you met with him often; is that correct?

A. Yes.

Q. And all these things are relative and so you can qualify this in any way you want to, but -- but

did he have a knowledge of -- of water and water resources in -- in New Mexico?

A. I would say he had general knowledge. He was a New Mexico Congressman in northern New Mexico for 16 years, so he dealt with a number of really complicated issues, acequia issues, tribal issues, water issues. He's very astute with respect to water, and he -- he went to the trouble of putting together a 22-member task force to find the state engineer and so the -- the candidates for the state engineer office had to do at least two interviews in hotel ballrooms with a U-shaped table with 22 stakeholder groups asking questions regarding the appropriateness of becoming state engineer. So he -- he did a lot of -- he put a lot of effort into it. I think he wanted some political, you know, backing that there was a -- there was knowledgeable people, all stakeholders within the state that were participative in selecting the state engineer's office to make sure it was not a political buyer.

Q. And you -- I assume you kept him informed throughout the eight years of significant water issues within the state?

A. Yes.

Q. And that included issues in -- I want to come

back to this, also, but below Elephant Butte on the -- on the Rio Grande; is that correct?

A. Yes.

Q. So you were a state engineer, and we're going to come back. I want to talk about what that job entails, but move me forward. You were there for the entire term of Governor Richardson, and then what?

A. Then Governor Martinez was -- was elected. I stayed on for Governor Martinez -- almost her first year, and I decided to leave in November. So she was elected at the end of -- so 2011 was her first year. I -- I was state engineer until November of that first year and decided to leave and take a job back with the U.S. Army Corps of Engineers.

Q. And what job was that with the -- the Corps of Engineers?

A. It was the -- the lead civilian position in the Albuquerque district. The title for it is Deputy District Engineer for Programs and Project Management.

Q. And how long were you in that -- that job?

A. About seven-and-a-half years.

Q. And is that the job that immediately preceded your -- your coming back to the state engineer's office?

A. It is, but let me qualify it. I had -- you know, I had three developmental assignments as a deputy district engineer for programs and project management, so I had two acting positions in senior executive service, one in San Francisco, South Pacific Division, one in Atlanta, Georgia, South Atlantic Division, which were the -- they had two senior executives that headed both those big division offices, and I was in those two division offices. And then I decided to take a developmental assignment as the western state's water council -- well, actually, Western Federal Agency Support Team, which is comprised of 12 federal agencies that deal with water in -- in the western United States. They needed a liaison to those 12 federal agencies. I went ahead and put in for that because I was interested in staying in -- in western water, and so I was working in that capacity with the -- with -- with high-level federal agency personnel in looking at water policy and setting water policy for the western United States.

Q. And what was the name of that organization again that --

A. WestFAST so Western Federal Agency Support Team. Works with the western state's water council as the -- as the liaison to all the federal agencies. I did that for a few months before Governor Lujan Grisham's folks came in and asked me to come back as state engineer for New Mexico.

Q. How did that occur? Was that similar to your selection as state engineer with Governor Richardson?

A. A little bit different. I -- I had answered questions. The transition team was searching for candidates. They wanted to interview me. I told them I was not interested in the position, but they -- I interviewed with them to give them my view on things that were going on, and they were -- they were still in search and then they asked me if I would consider coming back as state engineer. My immediate response was no. After a few weeks that went by, they -- they asked me again, and I said, well, if -- if she needs a fallback position, I might consider it, and then they sort of put a full court press on me, and she called me directly to see if I would come back.

Q. Is -- is the current governor as involved in water issues as was Governor Richardson?

A. It's a little bit different. Her organization structure is somewhat different. Governor Richardson had a specific water policy person who I could use as a -- as a conduit to the governor's office very quickly. Governor Lujan Grisham does not have just a specific water policy person, although we do meet in what we call natural resource huddles, so we meet with the natural resource groups, but I think her plate -- and she's been focusing on healthcare issues, education issues, and obviously this COVID-19 is taking all the oxygen in the room. So she's -- she's concerned with it. She -- but she's not as directly involved as Governor Richardson was but under obviously different circumstances.

Q. Who was the liaison with -- for water issues with Governor Richardson?

A. The -- the liaison that -- he was the policy person on water was Mr. Bill Hume, H-U-M-E.

Q. What -- I notice in this Exhibit 1 that there's a couple of Blue Ribbon Task Force that you were a member of, one in 1998 to 2011 -- I guess maybe they're the same. They're just simply, on my sheet, repeated. But what are those or what was that? I assume they're the same thing, right?

A. They're -- they are the same thing, but they were comprised of different personnel. From 2008 to 2011, it was an organization that was stood up by Governor Johnson. I was asked by Tom Turney, who was the state engineer at that time, to attend those meetings for him, which I did, and it was more of the business farming communities that -- that were interested in water policy within the State of New Mexico. I worked very closely with them for those three years. Governor Richardson stood up his own Blue Ribbon Task Force when he became governor and appointed different personnel. There -- there was a little bit of overlap with -- with the first Blue Ribbon Task Force, but it was a bigger group, more diverse with Governor Richardson, and so it was -- that was in place for the eight years under Governor Richardson.

Q. I notice on that very last paragraph in Exhibit 1, there's some -- I assume these are specific roles that you had or jobs or tasks that you had, however you want to describe them, while you were state engineer. Can you run through those and kind of explain what those were?

A. Sure. The first one, Secretary of the Interstate Stream Commission, statutorily the state engineer, is the Secretary of the Interstate Stream Commission. Chairman of the Water Trust Board, that is a -- that's also -- in the statutes, the Chairman is elected to a 15-member board. The Chairman is elected by his order of peers. That's -- ten of those board members are other cabinet secretaries within --

Grande at the Colorado/New Mexico state line," and then it refers to -- to further define that obligation. But -- but it begins, "The obligation of Colorado to deliver water in the Rio Grande at the Colorado/New Mexico state line measured at or near Lobatos" and so forth. Did I read that correctly?

A. Yes.

Q. Okay. Take a look at Article 4. Article 4 begins with this statement, "The obligation of New Mexico to deliver water to the Rio Grande at San Marcial." We know that one's changed. Let me stop there and say: Did I read that clause correctly?

A. Yes.

Q. Is the obligation imposed on Colorado and New Mexico, are those obligations, at least the way they're described, that clause that I read -- that I recognize that after the clause, things are different, but the initial clause, are they the same in Article 3 as in Article 4?

A. Well, the same in what respect? The clause in the first requires a state delivery, this one requires a delivery at San Marcial, so I'm not sure what you mean.

Q. Well, the delivery is to two different obligations, but is the language the obligation of New

Mexico to deliver water in the Rio Grande, is that language that begins Article 4 identical with the use of the word Colorado instead of New Mexico, is it identical in both clauses --

A. Yes.

Q. -- in both articles?

A. Yes.

MR. WECHSLER: Object to form.

Q. (BY MR. SOMACH) Do you have any reason to believe, as state engineer and commissioner for New Mexico, that those two clauses should be interpreted differently?

MR. WECHSLER: Object to the extent it calls for a legal conclusion.

MR. SOMACH: Not looking for a legal conclusion.

Q. (BY MR. SOMACH) Your -- your views, Mr. D'Antonio.

A. Can you please ask it again?

Q. The language that I'm talking about with the exception of New Mexico and Colorado in Articles 3 and 4 reads the same. Is there any reason you can think of in your -- your -- your understanding of the Compact as commissioner why that language should be interpreted differently in Article 3 than it is

interpreted for Article 4?

MR. WECHSLER: Object to form.

A. No.

Q. (BY MR. SOMACH) Okay. And presumably, as the commissioner for New Mexico, you're concerned about the interpretation and obligations in both Articles 3 and 4; is that correct?

A. Yes.

Q. Once Colorado delivers water pursuant to Article 3, may it intercept that water for use in Colorado?

A. I'm sorry. I missed that -- the question. Please ask it again.

Q. Once Colorado delivers water to -- to the Colorado/New Mexico state line, can Colorado intercept that water for use in Colorado?

MR. WECHSLER: Object to form.

A. I'm (unintelligible).

Q. (BY MR. SOMACH) It may not. Is that what you're saying?

A. Yes. It may not.

Q. Once it gets into New Mexico, it becomes New Mexico's water; is that correct?

A. Correct.

Q. Now, we touched on this earlier, and I want

to get more specific on the question now, but was Texas apportioned water under the Compact?

A. Yes. According to the Compact, yes.

Q. What water was Texas apportioned under the Compact?

A. Percentage of the natural flow that goes to the Otowi gage index.

Q. And when you say a percentage, what is that percentage?

A. It's based on the quantity that's -- that passes the -- the gage. There's a prescribed amount that -- that's shared between New Mexico and Texas, and then once it gets to a certain level, the remainder goes, again, into the project to Texas essentially, but it's shared by EBID down there.

Q. What -- what about the water that's delivered into Elephant Butte reservoir, is that apportioned to Texas?

A. A part of it is. 43 percent is supposed to go to Texas, and 57 percent is to remain for use by the EBID farmers.

Q. Is that -- is that split that you made pursuant to the Compact or pursuant to the downstream reclamation contracts involving EBID and EP No. 1?

A. It's pursuant to the historical operation of the Compact, as well as to the 1938 contracts that -- that the federal government had with the districts.

Q. That historic operation that you refer to, is that historic operation consistent with or in furtherance of the downstream contracts?

A. It's consistent with.

Q. So -- and I'm just trying to understand. In terms of understanding what water is apportioned to Texas, it is -- it is the water that's in Elephant Butte reservoir subject to EBID's contract with the United States is -- and let's exclude from this discussion. Let's assume that 60,000 acre feet is going to Mexico so of the residual, is the water in the reservoir apportioned to Texas subject to EBID's downstream contract rights? Is that a way of -- of phrasing it? Is that a proper phraseology?

MR. WECHSLER: Objection; ambiguous; compound; misstates prior testimony.

MR. SOMACH: I'm not relying on prior testimony.

Q. (BY MR. SOMACH) Did you understand what I asked?

A. Can you break it down into specific questions, please?

Q. Well, is the water that is in Elephant Butte

reservoir all apportioned to Texas except for the amount of water that goes to EBID under its downstream contract with Reclamation?

MR. WECHSLER: Object to form.

A. Yes. Minus any credit water that's in there and minus any San Juan-Chama water that's in there. So it's taken into consideration the total of what's in Elephant Butte.

Q. (BY MR. SOMACH) And I want to talk a little bit about all the water in Elephant Butte. I think probably what -- to clarify for now because I want to talk about what other water is in Elephant Butte, but usable water is what you're talking about; is that correct?

A. That's correct.

Q. Okay. Okay. We're at -- I'm about to move into another little area here. I notice that in California, it's 11:50. In New Mexico, it's, now, 12:50. I'm wondering if this is a good place to break, and we'll pick up again at 8:00 my time and 9:00 -- does anybody have any objection to doing that?

MR. WECHSLER: No objection.

MR. SOMACH: Okay. Then if that's the case, let's go off the record, and we'll resume in -- I was going to say 12 hours, but that's not right.

Whatever. We'll resume in the morning, 9:00
Mr. D'Antonio's time, and -- and 8:00 my time.

THE WITNESS: Very good. Thank you.

THE VIDEOGRAPHER: The time is 12:51
p.m. We're off the record.

(The deposition concluded at 12:51 p.m.)

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
14/ 24	change "Hydrology" to "Hydraulic"	Correction
15/ 3 &13	change "Hydrology" to "Hydraulic"	Correction
15/ 10	change "Core" to "Corps"	Correction
18/ 6	change "TRC" to "T or C"	Correction
22/ 3	change "for immediately" to "when"	Correction
22/ 16	change "2008" to "2003"	Correction
23/ 19	delete " 's office"	Correction
23/ 20	change "buyer" to "hire"	Correction
27/ 22	change "2011" to "2003"	Correction
28/ 24	change "order of" to "other"	Correction
29/ 4	change "Indian - There's a Tribal Person" to "New Mexico Indian Affairs Representative"	Correction
29/ 12	change "governor's got a" to "Governor appointed a drought"	
30/ 11	change "on" to "I'm"	Correction
34/ 34	change "placement" to "place and purpose"	Correction
46/ 14	change "allocations" to "applications"	Correction
48/ 1	change "Playa" to "Plata"	Correction
49/ 11	change "on" to "by"	Correction

John R. D'Antonio Jr.

JOHN D'ANTONIO, VOLUME I

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
51/ 15	change "there being" to "they're"	Correction
52/ 7	add "the" after "within"	Correction
64/ 14	change "Petersen" to "Lopez"	Correction
89/ 5	change "can" to "can't"	Correction
101/ 13	change "those" to "low"	Correction
108/ 19	change "ratifications" to "ramifications"	Correction

John R. D'Antonio Jr.

JOHN D'ANTONIO, VOLUME I

SIGNATURE OF WITNESS

I, JOHN D'ANTONIO, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

John R. D'Antonio, Jr.

JOHN D'ANTONIO, VOLUME I

Job No. 63558

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. SOMACH - 03:11:39
MR. WECHSLER - 00:00:00
MR. LEININGER - 00:00:00
MR. WALLACE - 00:00:00
MR. HICKS - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, this, the 21st day of July, 2020.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 04-30-22

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Tab 16

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

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REMOTE ORAL AND VIDEOTAPED DEPOSITION OF
JOHN D'ANTONIO
JUNE 25, 2020
VOLUME 2

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION of JOHN D'ANTONIO, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on June 25, 2020, from 9:15 a.m. to 12:57 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the offices of HEATHER L. GARZA, CSR, RPR, The Woodlands, Texas, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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Shelly Dalrymple
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Peggy Barroll
Estevan Lopez
Ken Knox
Rolf Schmidt-Petersen
Al Blair
Gary Esslinger
Erek Fuchs
Ian Ferguson
Michelle Estrada-Lopez

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PAGE

EXHIBIT NO.3 178
Active Water Resource Management in the Lower Rio Grande Tools for a New Era in Water Management PowerPoint Presentation

EXHIBIT NO.4 210
United States Department of the Interior Geological Survey Report Dated October 23, 1947

THE VIDEOGRAPHER: Today is Thursday, June 25th, 2020. The time is 9:15 a.m. We're on the record.

JOHN D'ANTONIO,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. SOMACH:

Q. Good morning, Mr. D'Antonio.

A. Good morning.

Q. How are you this morning?

A. Fine. Thank you. How are you?

Q. Good. And you've got all of your -- your various electronic equipment functioning at this point in time; is that correct?

A. I do, yes. It's -- I can see the realtime going on now, so thank you.

Q. Good.

MR. SOMACH: Let's do some appearances here for the record. This is Stuart Somach, attorney of record for the State of Texas in this litigation, and with me also on behalf of the State of Texas are Francis Goldsberry, Theresa Barfield, Rich Deitchman, and Robert Hoffman. Those are the names that I see on the screen that I have in front of me. If there's anybody else for Texas, why don't you make your appearance now.

(No response.)

MR. SOMACH: Okay. And for New Mexico, Jeff?

MR. WECHSLER: Good morning. Jeff Wechsler for the State of New Mexico. We're joined by John Draper, Greg Ridgley, Arianne Singer, Shelly Dalrymple, Susan Barela. We will be joined at some point today by Rolf Schmidt-Petersen, Peggy Barroll, Estevan Lopez, and Ken Knox.

MR. SOMACH: Okay. And for the United States?

MR. LEININGER: Good morning. This is Lee Leininger, Department of Justice. We're joined today with Jim Dubois, Department of Justice; from the solicitor's office, Chris Rich and Shelly Randel; also from the Bureau of Reclamation, Ian Ferguson, and I can't tell if Michelle has joined us.

MS. ESTRADA-LOPEZ: I'm here.

MR. LEININGER: Oh, there she is. Thank you. Michelle Estrada-Lopez is also here.

MR. SOMACH: And, Chad, for Colorado?

MR. WALLACE: Good morning, Stuart. This is Chad Wallace along with Preston Hartman for Colorado.

MR. SOMACH: And is there anyone here from EP No. 1? I see Renea but --

MR. HICKS: Renea Hicks for El Paso County Water Improvement District No. 1, and also on is Dr. Al Blair.

MR. SOMACH: Okay. EBID?

MR. ESSLINGER: Good morning. This is Gary Esslinger.

MR. SOMACH: Good morning, Gary. Let's go down then through the -- the list of other intervenors. Let's go to -- I'm sorry -- Albuquerque.

MR. BROCKMANN: Yeah, Stuart, this is Jim Brockmann. I'll be on for Albuquerque and Las Cruces, and I appreciate you granting us intervenor status in this.

MR. SOMACH: Oh, I said intervenors, right? Well, you know --

MR. BROCKMANN: Take it.

MR. SOMACH: -- you can take my authority and put it in a thimble probably, so I'll let you explain that I've granted you that to the Special Master and to the Court. On the other hand, I can also grant intervenor authority to the City of El Paso. Who's on for the City of El Paso? Anybody?

MR. BROCKMANN: We might as well have documents. Obviously, we're still in discovery. I would say, yeah, they were a proponent of the operating agreement.

Q. (BY MR. SOMACH) Are you familiar with what is known as the D2 line?

A. Yes.

Q. Can you describe what the D2 line is, just so the record is clear? I'm sure the United States and you will talk about this later, but -- but I just want to make sure that you understand or -- what -- what the D2 line is for the purposes of my limited questions now.

A. Well, I understand it in -- in regards to the D1/D2 concept, which is project -- essentially project diversions over releases. So the -- so if you take EBID, distributions to EBID, to El Paso No. 1, and to Mexico in relation to the total diversions from Caballo, that gives you the -- the D1/D2 ratio.

Q. And that's based upon a -- a time period, isn't it?

A. Yes, it is.

Q. And do you know what that time period is?

A. Approximately 1950 to 1978.

Q. Do you know whether or not Texas believes that that's a appropriate time period to utilize for

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determining how much water should be apportioned or allocated -- and I'll use both terms, you can -- you can use whichever one you want -- to Texas?

A. Well, the -- they and New Mexico both acquiesced to that timeline in how the project was operated all the way up into 2005.

Q. When you say "acquiesced," what does that mean?

A. That's how the -- the project was -- was managed, the deliveries, the allocations were managed based on that -- that relationship since -- since that time, since the '50s.

Q. Are -- are you aware of what -- and only if you're aware of what Texas' position is with respect to what deliveries should be under the Compact?

A. No, I'm not aware of this.

Q. About -- we talked about this a bit ago, but when -- when about did New Mexico learn that wells were being pumped in the Hueco?

A. I can't answer that question. I'm sure it was in the -- in the drought of the '50s, but I have no knowledge of that time period on who knew when.

Q. Is there a hydrologic or physical interconnection between the groundwater basin, the Hueco groundwater basin, and the Mesilla/Rincon

groundwater basins?

MR. WECHSLER: Objection; foundation.

A. If there is, it's very slight or else they'd be the same basin, so -- and honestly, I'm probably not qualified to answer that so I would say I don't know.

Q. (BY MR. SOMACH) You'd say you don't know?

A. I don't know.

Q. Okay. If I could have put up the Bates No. US0539807. It's a August, 2005, PowerPoint presentation. There we go. And let's mark this the next exhibit in line. I think it's 3; is that right?

(Exhibit No. 3 was marked.)

Q. (BY MR. SOMACH) I'm being parsimonious with my exhibits. Can you take a look and scroll through this document, Mr. D'Antonio? Let me know when you're ready. I'd like to talk a little bit about it.

A. Not very responsive on my scrolling here.

Q. Take your time. We'll suffer through the technology.

A. I think I have the general idea of what it is and I can refer to specific slides based on your question.

Q. Okay. Well, first question about Exhibit 3 is what is it?

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A. It's a PowerPoint presentation on Active Water Resource Management in the Lower Rio Grande and the tools that are required in order to implement active water resource management, and it looks like it's a presentation to the Lower Rio Grande Water Users Association in August of 2005.

Q. Is this a PowerPoint presentation that you made?

A. Likely, yes.

Q. That -- at least it says that on the cover; is that correct?

A. Yeah.

Q. By John D'Antonio; is that correct?

A. Yes.

Q. Okay. And what is the Lower Rio Grande Water Users Association?

A. Well, it's a -- it's a group of water users that are within that basin. Some of them -- the makeup of them, as far as I know, and I may miss a few, but it's -- it consists of pecan growers and row croppers, which are the farming groups, and it also includes City of Las Cruces, New Mexico State University, the Camino Real Water User District and Public Service Company of New Mexico and there are maybe one or two others that escapes me right now.

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Q. Let's take a look at the first slide after the cover, which is at US0539808. Are you there? You do -- you describe about midway through the existence of downstream pressure. Do you see that?

A. I do see that.

Q. Okay. And what -- what is that pressure? What was that pressure back in 2005?

A. It -- it looks like it's a quote from somebody, and I don't remember who that quote is from. That's been 15 years ago. But there's always been some discussion with downstream -- with the downstream and Texas. I mean, I can go back to -- to 1997 when there was a discussion of a pipeline being built to Elephant Butte by Texas water. I've seen their senate bills that have appropriated a billion dollars to look at and evaluate supplies from the Rio Grande. So there -- there's been an ostensible threat always, and if you -- if you understand western water law, there's a lot of litigation that ensues from a downstream state that ensues an upstream state, so I think there's always an awareness that something could happen. I think I was always comfortable that we were -- we were doing the things we needed to do in New Mexico in managing our water resources that -- that could answer and -- and stay out of litigation

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with the State of Texas. So, again, it's just a -- it's just an awareness thing downstream pressure. Texas sues us on the Pecos. Texas has always been in the minds of new Mexicans -- in 1974, Texas sued New Mexico on the Pecos for a billion dollars and so there's always been downstream pressures, and it happens in -- in most western states.

Q. You were aware of this pressure in 2005 then, I assume?

A. Apparently.

Q. And I think you also said that that pressure existed prior to 2005; is that correct?

A. Well, the knowledge of -- of actions in Texas, we were aware of. Like I said before, the -- the pressure that I felt was in managing our water in the entire State of New Mexico with the droughts -- the drought that was happening in -- in 2002, and I would say through the -- the last probably 15 years, we suffered severe droughts. So, yeah, it was -- I think it was in that regard that the pressure to be able to manage and have the tools in place necessary, not only to manage the lower Rio Grande, but all the other priority basins that we had at the State of New Mexico that were subject to prior -- priority administration.

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that -- is that accurate?

A. Yeah. According to this slide, it is.

Q. Okay. And the second bullet says, "The Supreme Court could require offsets for all post-Compact groundwater pumping." And you cite a precedent for that; is that correct?

A. I did in this presentation, yes.

Q. And in our case, post-Compact groundwater pumping would include anything after 1938. That's correct, isn't it?

MR. WECHSLER: Object to form.

A. Based on your question, yes.

Q. (BY MR. SOMACH) Okay. And -- and the last bullet point is interesting. It says, "Loss of the use of aquifer as a drought reserve." That kind of goes to the conjunctive use of surface and groundwater that you were talking about earlier, doesn't it?

A. Yes, it does.

Q. Okay. If you can turn to the next slide, which for the record is US0539817, can you see that? Well, you had it. There it is.

A. This one? Okay.

Q. Uh-huh. The -- the -- there appears to be -- what you're saying here is that it's not just your concern, it's the governor and the legislature's

concern; is that correct?

A. Yes.

Q. Okay. And then the second bullet point there says, "Legislators have admonished the State Engineer not to let the Pecos River history repeat itself anywhere, including on the Lower Rio Grande." What is that -- what is that referring to?

A. The Supreme Court action that Texas took against New Mexico, I believe, in -- when they filed in 1974, but that was a different case, and there were -- there were measured under deliveries at the state line there. This is not the case in the same case in the Rio Grande, and the whole idea behind this presentation is to get the legislature and the governor behind giving me funding so that we could put the tools in place to preclude Texas from filing a lawsuit against New Mexico under some of those same -- some of those same concerns. And, again, my -- my feeling was we were managing the Lower Rio Grande in a way that would allow us to stay out of litigation by taking care of and administering water rights based on this active water resource management initiative. So I know what the slides say, but the intent -- the intent was to keep it in control and -- and the corrections within New Mexico and -- and I think we definitely would have been able to do that, and I think the operating agreement flipped that strategy on its head because it so exacerbated the need for New Mexico to pump additional groundwater before we could put this active water resource management initiative in place.

Q. Turn to Slide No. 0539815, which I think is the next slide. Oh, you went past it. There you go. Here, you're talking about the action that is needed; is that correct?

A. Yes.

Q. So let's -- let's start with the first bullet point, "Improved regulation of groundwater pumping is imperative." What -- what has been done to improve the regulation of groundwater pumping in the Lower Rio Grande?

A. I put a metering order in place in December of 2004, requiring all groundwater pumping to be metered and followed up with two additional -- I think an extension of the orders and two additional orders in subsequent years to make sure there was compliance with -- with that order.

Q. Is that it?

A. Well, no -- well, there was some other things that happened. Obviously in prior -- and I believe it was in 1999, there was some Mesilla -- Mesilla guidelines, administrative guidelines, that were put in place, that the state engineer put in place that was the intent of managing groundwater pumping, but you really -- you really can't put -- you really can't manage what you don't measure, so it was necessary to put -- put the -- you know, the -- the meters in place and require the meters to be there. I also established a water master district not only there but other areas of the state and set up a water master within the Lower Rio Grande to start taking control and -- and quantifying the water that was being -- that was being pumped and -- and so that's -- that happened. We even provided -- the State provided low-interest loan funding, because I got sued by Elephant Butte Irrigation District on them not wanting me to impose metering to them. We even provided low-interest loan money for them to get into compliance with that cost so the metering was not imperative. So when you look at improved regulation of groundwater pumping, we were -- we were putting that action in place through -- through those -- through those efforts.

Q. Let's turn to the -- to the next slide. It's actually two slides down. For the record, the one I'm

talking about the US0539820. It's the one that says, "What LRGWUO can do."

A. Okay.

Q. What is LRGWUO? Is that the association; is that right?

A. Yes. The Lower Rio Grande Water Users Organization, I think.

Q. So have the cooperative agreements that are talked about in the diamond bullet for shortage sharing, have they been developed?

A. No, they have not been developed yet.

Q. Okay. What about the second diamond bullet, "Strengthen water leasing mechanisms, implement special water users associations," has that occurred?

A. Not yet.

Q. "Develop alternative methods to ensure seniors are kept whole." What -- what alternative methods have been developed since 2005?

A. Well, we've -- we've teed -- we've teed these issues up. Obviously we got -- we got challenged in -- in district court on trying to establish the district-specific regulations. We got -- we got sued on -- on those particular regulations. We wound up actually prevailing after the case went through district court, court of appeals in New Mexico Supreme

Court in 2012 that New Mexico Supreme Court affirmed all of the actions that the state engineer took previously to put the active water resources management tools in place, but that's also about the time of the lawsuit. And so I think -- I think some of the activities that we've been trying to do have been hampered by -- by the lawsuit, obviously, and by -- by other things beyond the state engineer's control. Stuart, your mic is off. I can't hear you.

Q. I did that because the gardeners were outside and I couldn't hear, let alone I'm sure you can't. On that second -- on that slide -- that first bullet says, "Participate in developing different district-specific regulations." Do you see that? Have district-specific regulations been promulgated or developed?

MR. WECHSLER: What page are you looking at?

A. What page are you on now, Stuart? Yeah.

Q. (BY MR. SOMACH) It's -- it's the next page. Says, "In addition." And that, for the record, is US0539821?

A. Yes. So draft district-specific regulations have been put -- have been drafted. I mean, we drafted the -- the -- but they haven't been formalized based on a lot of these other issues that have gotten in the way.

Q. So they've been drafted, but they haven't been actually promulgated; is that correct?

A. That's correct.

Q. And so they obviously haven't also been implemented; is that correct?

A. That's correct.

Q. What about AWRMs for the Lower Rio Grande, have they been promulgated?

A. I'm not sure I understand that question. AWRMs aren't things that need to be promulgated. Active water resource management is -- is a -- there's a statute that was passed. Are you talking about district-specific regulations?

Q. Yes. So how you would actually implement the AWRM, a state statute, would be through district-specific regulations; is that -- is that correct? Am I understanding that correct?

A. Yeah. Each -- each particular basin would have its own district-specific regulations that would be put together by input and from input from all the stakeholders within that particular basin.

Q. That hasn't been done yet is what I understood you to say?

A. No, it has not been done yet.
Q. Okay. Has there been a reduction in groundwater pumping in New Mexico in the Rincon and Mesilla valleys since 2005?
MR. WECHSLER: Objection; vague.
A. I don't know.
MR. SOMACH: Okay. Let's -- let's -- we've been at this now for maybe an hour and a half so let's take a break. Let's come back at 11:05, 12:05. I will say that I'm not sure how much longer I'll go and whether we'll finish with me today, but in any event, the United States is going to follow. But I'll -- I'll try to get as much done as I can do in the next hour before we have to break today.
THE WITNESS: Okay.
MR. SOMACH: If I do the time right, 11:55 means -- 10:55 means it's 11:55 so it's almost 12:00. So that's -- what I did say is accurate. I'll try to get wrapped up in terms of my questions before we break for the day, but if I can't, we'll trickle over into tomorrow and then U.S. will -- will pick up. Just to let you know my plans. Okay. That's it. Let's -- let's talk about ten after.
THE VIDEOGRAPHER: The time is 10:56 p.m. We're off the record. I'm sorry. 11:56 a.m.

(Break.)

THE VIDEOGRAPHER: The time is 12:14 p.m. We're back on the record.

Q. (BY MR. SOMACH) Mr. D'Antonio, is the Office of State Engineer, does it administer water rights in the Middle Rio Grande differently than it does in the Lower Rio Grande?

A. Conceptually, no, waterline basically is waterline in New Mexico, and we still have the basic attendance of, you know, administering permits, requiring permits, conditioning those permits, and, and then on new applications for -- for use or change of place in purpose of use or new appropriations of water, we have to do an analysis and impairment analysis and look at the public welfare issues of the State of New Mexico and whether or not it's contrary to conservation within the State of New Mexico. So water management is water management, and they're all based on New Mexico waterline.

Q. What about these regulations under AWRM, are -- are there regulations that have been propounded and implemented in the Middle Rio Grande under the AWRM statutes?

A. Not under the AWRM statutes, but we do have Middle Rio Grande guidelines that were put in place in about -- about 20 years ago that are still -- that are still in force and in place so, no, not under AWRM.

Q. But otherwise, is that what you're saying? Are other regulatory mechanisms in place in the Middle Rio Grande that are not in place in the Lower Rio Grande?

A. Well, there -- there are guidelines. We're still -- we still have to comply with the same law and the same parameters that I look at as state engineer, but there are guidelines associated, like there's Mesilla guidelines in the Lower Rio Grande to give instruction to our water rights staff on how an application processing would take place. Same thing in the Middle Rio Grande. There are guidelines associated with how water rights applications are -- are administered.

Q. You, several times over the last couple days, referred to conjunctive use of surface and groundwater. Could you describe what you mean when you are talking about conjunctive use of surface and groundwater?

A. Well, just that. I can use the example in the Lower Rio Grande. Some parcels of land down there have a combined right of both surface and groundwater. They're conjunctively managed. When surface supply

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
51/ 24	change "account" to "accounted"	Correction
57/ 20	change "ensues" to "sued"	Correction
58/ 4	capitalize "n" in "new"	Correction
60/ 25	change "was" to "were"	Correction
70/ 8	change "a" to "an"	Correction
73/ 7&8	delete "you know don't adjudicate interstate compact variable supply where it's --"	Correction
76/ 11	change "there" to "they"	Correction
76/ 12	delete "case in the"	Correction
78/ 7	change "metering to" to "metering on"	Correction
78/ 19	delete "that cost so"	Corection
78/ 19	change "was" to "so that cost was"	Correction
78/ 20	change "imperative" to "a factor"	Correction
79/ 25	change "in" to "and in the"	Correction
80/ 1	change "that New Mexico Supreme Court" to "they"	Correction
83/ 8,9 & 19	change "waterline" to "water law"	Correction
83/ 10	change "attendance" to "obligation"	Correction
83/ 13	change "in" to "and"	Correction

John R. D'Antonio Jr.

JOHN D'ANTONIO, VOLUME II

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
83/ 14	change "add" to "an"	Correction
91/ 14	change"a few" to "to"	Correction
91/ 15	change "than" to "that"	Correction
96/ 13	change "that" to "that need to"	Correction
96/ 17	change "full" to "whole"	Correction
100/ 16	change "nonuse" to "nonuse an issue"	Correction
100/17	change "issued" to "issues"	Correction

John L. D'Antonio

JOHN D'ANTONIO, VOLUME II

SIGNATURE OF WITNESS

I, JOHN D'ANTONIO, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

John R. D'Antonio Jr.

JOHN D'ANTONIO, VOLUME II

Job No. 63559

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS)
)
Plaintiff,)
) Original Action Case
VS.) No. 220141
) (Original 141)
STATE OF NEW MEXICO,)
and STATE OF COLORADO,)
)
Defendants.)

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, JOHN D'ANTONIO, to the interrogatories as indicated were made before me by the said witness after being first remotely duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. SOMACH - 03:07:40
MR. WECHSLER - 00:00:00
MR. LEININGER - 00:00:00
MR. WALLACE - 00:00:00
MR. HICKS - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, this, the 21st day of July, 2020.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 04-30-22

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Tab 17

Active Water Resource Management in the Lower Rio Grande

Office of the State Engineer
nm
Interstate Stream Commission

TOOLS FOR A NEW ERA IN WATER MANAGEMENT

presented by

John D'Antonio, PE
New Mexico State Engineer

Lower Rio Grande Water Users Association
8/19/05

Agreement:

A Need for Groundwater Administration:

" In order for junior ground-water users to continue to pump, they will have to acquire … offsets to their effect on senior water right holders through a mechanism like a Special Water Users Association (SWUA)"

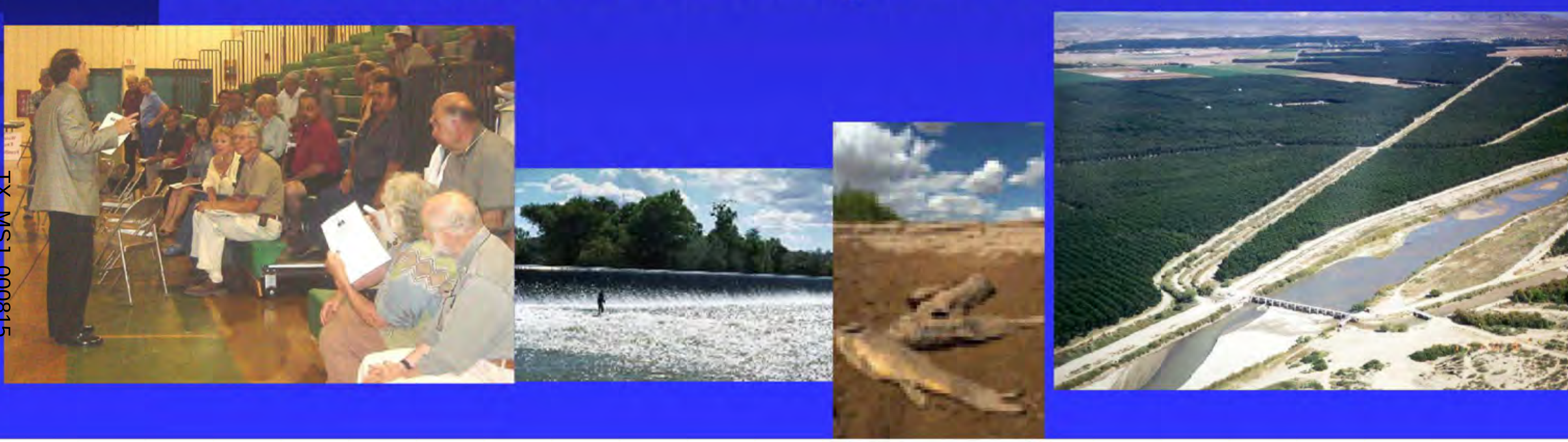
The Existence of Downstream Pressure:

" Texas entities have alleged that the New Mexico portion of the Project is taking more than their share and seek a larger portion of the allocation of Project supply."

Lower Rio Grande Regional Water Plan, Executive Summary, Page 4

Purpose of Today's Talk

- Describe the water problem in the Lower Rio Grande
- Begin discussion of Alternative Administration plans
  - Suggestions of actions area water users can take
  - Requirements for approval of an Alternative Administration Plan
  - Begin discussions for structuring the cooperation of area water users with the State Engineer
  - Your thoughts and ideas
- Brief description of LRG Regulations and implementation



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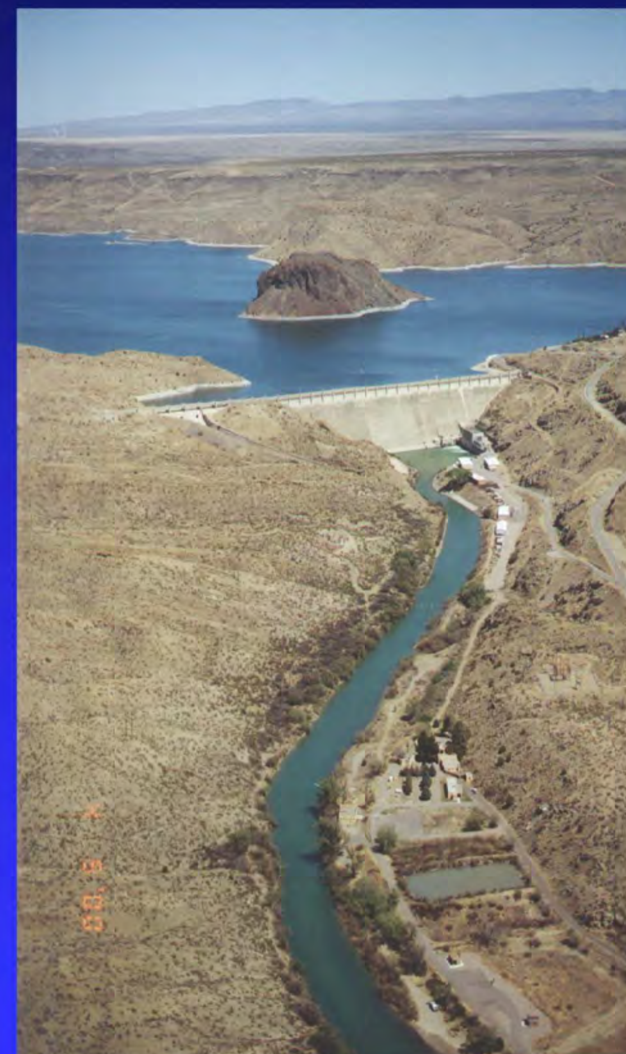
US0539809

What is Active Water Resource Management?

- Proactive statewide program to ensure New Mexicans have a predictable water supply
- Set of water management tools customized to each district
- The means for keeping control of our water and protecting our water rights and our economy



Drought Opened Our Eyes

- When drought hits, it’s too late to put tools in place to manage shortages
- The supply is always variable and droughts are inevitable
- Water will always be scarce in New Mexico

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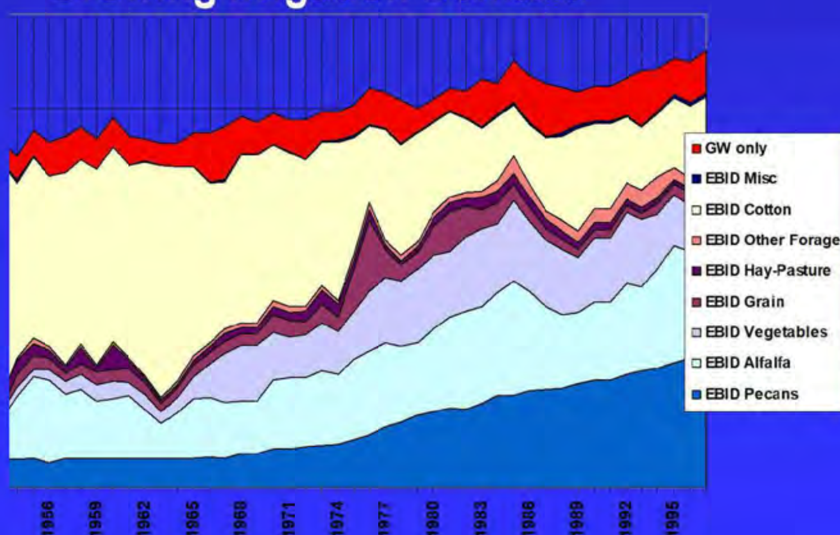
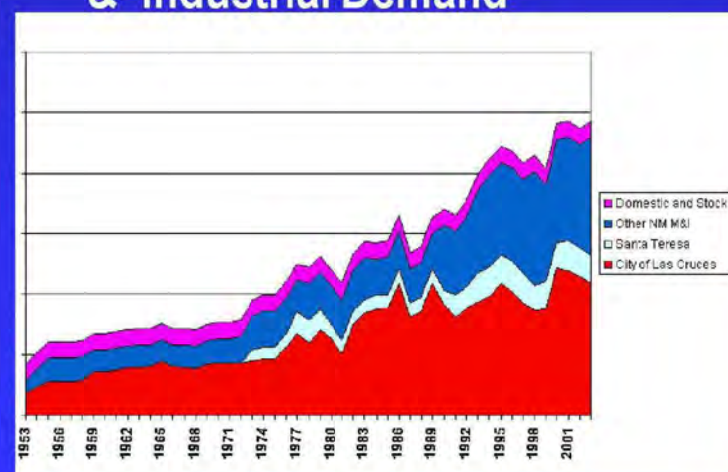
Competition for Water Keeps Growing

- Among New Mexico users & downstream
- Surface water is fully appropriated,
- Groundwater and surface water are interconnected
- We must ensure senior water rights are protected & accommodate needs of junior water rights holders

Growing Irrigation Demand



Growing Municipal
& Industrial Demand

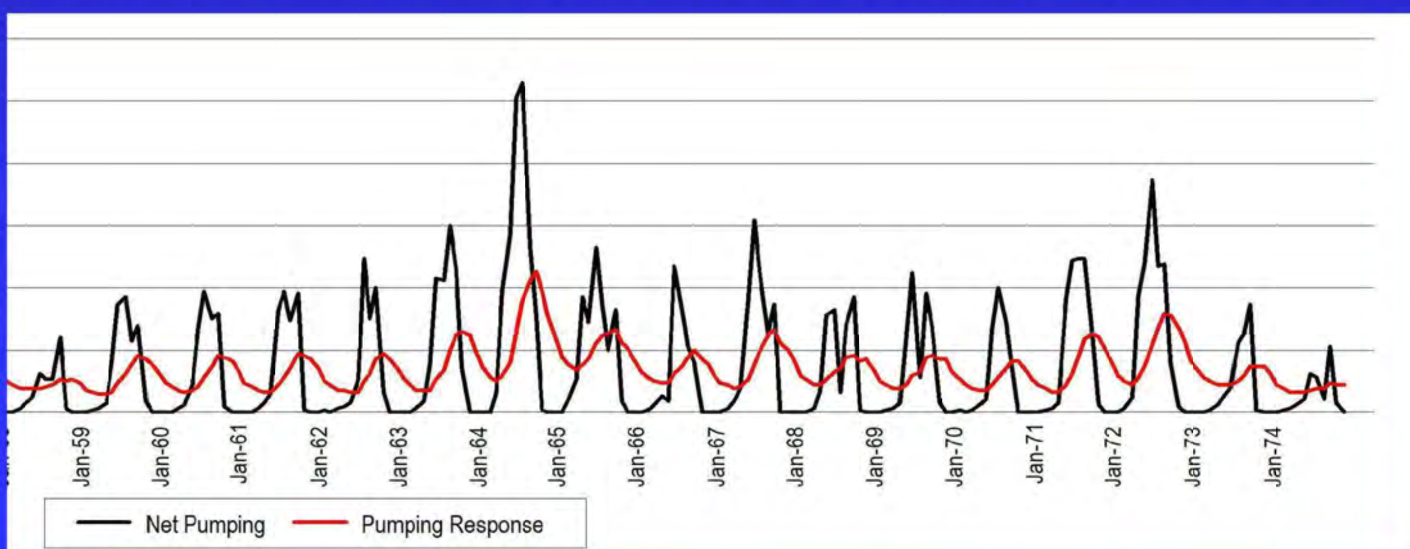


The Facts We Must Deal With

- Groundwater use has increased in the LRG
- Groundwater pumping for irrigation use alone may be as high as:
  - 50,000 -100,000 AFY in full project supply years
  - 200,000 - 300,000 (?) AFY in low project supply years

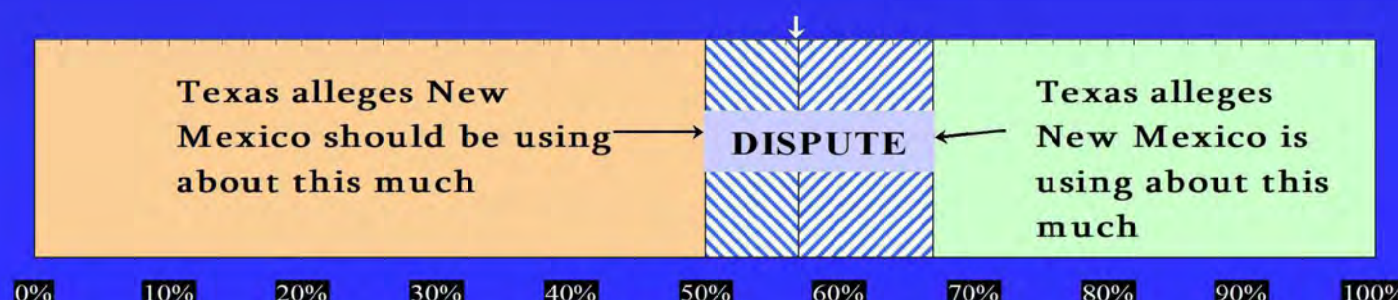
The Problem: Heavy Reliance on Groundwater While Instituting Few Controls on it

- Groundwater and surface water are closely linked
- Pumping reduces river flow
- Surface water rights are generally senior



The Problem: Claims that New Mexico Groundwater Pumping is Affecting Surface Water Flows

The Rio Grande Project Holds a Senior Surface Water Right



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US0539815

Risks to the State and New Mexico Water Users

- Interstate stream disputes are decided by the U.S. Supreme Court
- The Supreme Court could require offsets for <u>all</u> post-Compact groundwater pumping (as happened in *Kansas v. Colorado*).
- Loss of the use of the aquifer as a drought reserve

TX_MSJ_000822

US0539816

The Governor and Legislature have Recognized the Urgent Need for Administration

- *Administer NOW! Law:* 72-2-9.1 (2003)
  - "The need for water administration is urgent, compliance with interstate compacts is imperative"
- Legislators have admonished the State Engineer not to let the Pecos River history repeat itself anywhere, including on the Lower Rio Grande

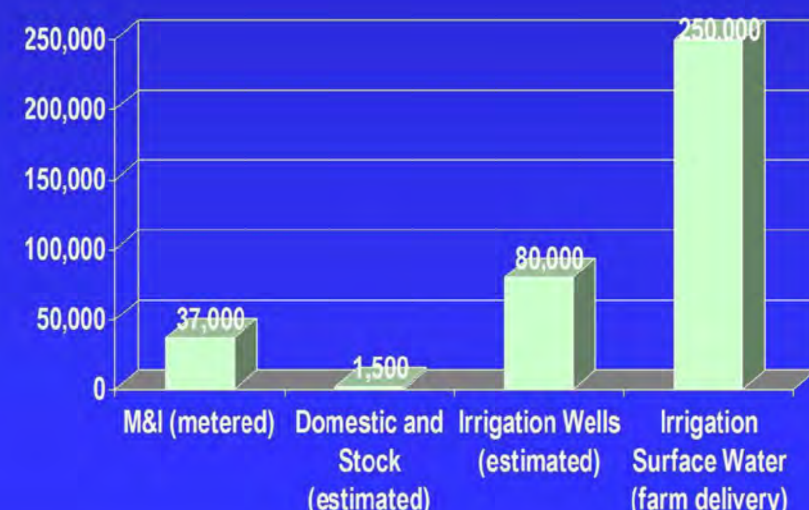
Action is needed

- Improved regulation of groundwater pumping is imperative
- Priority Administration is the State Engineer's only tool to address water demand in excess of water supply
- We need your cooperation on developing an alternative administration tool

The State Engineer Much Prefers to Administer Based on Alternative Administration Plans

- Priority administration is an inflexible tool, but the only one the law provides to the State Engineer
  - Seniors get a full supply before juniors get any
  - Only seniority counts (except domestic uses)
  - Groundwater rights are generally junior
  - The burden imposed by shortages is not shared

We hope water right owners will develop alternatives for managing shortages so the State Engineer can avoid strict priority administration



What LRGWUO Can Do

First and Most Important:

- Develop alternatives to priority administration
  - Set up cooperative agreements for shortage sharing
  - Strengthen water leasing mechanisms -- implement Special Water Users Associations
  - Develop alternative methods to ensure seniors are kept whole
  - Other measures . . ?

TX_MSJ_000826

What LRGWUO Can Do

In addition:

- Participate in developing district-specific regulations
- As you requested, you will have an exclusive opportunity to review our first draft
- At least two drafts will follow

Benefits of Your Participation

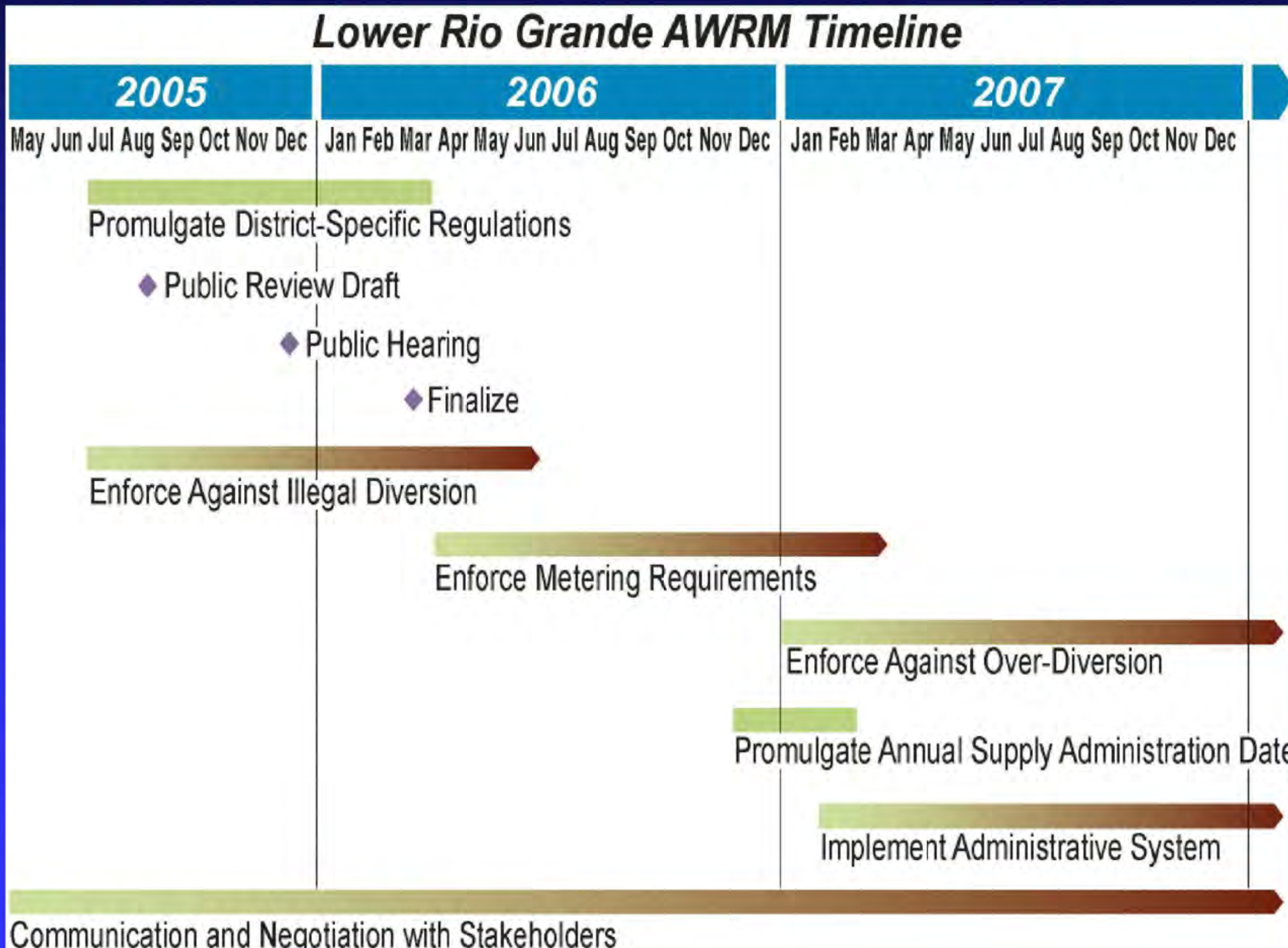
- Alternative Administration means: local solutions to maintain local control
- Minimize impacts on local economy that would result from priority administration
- More certainty and steadiness of supply
- Ensure that the State Engineer's district-specific regulations are workable and fair

TX_MSJ_000828

Concurrently:

The State Engineer is preparing and will promulgate District Specific Regulations that will provide for both priority administration and allow for the implementation of alternative administration

We Are Taking it Step by Step



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US0539824

State Engineer Tools

- Requirement for Meter installation for all wells (except domestic)
- Declaration of water master district
- Appointment of water master
- Enforcement against illegal uses
- Promulgation of district-specific regulations
- Curtailment of over-diversions
- Administration by priority date as necessary (unless an acceptable alternative is agreed to by local users)

TX_MSJ_000831

The State Engineer does not intend to oversee or regulate EBID's distribution of surface water to farmers

" That is EBID's responsibility by law, and I have no intention of duplicating that responsibility."

--John D'Antonio Jr., February 2, 2005

We Encourage Your Participation

- My staff is available to work with you on developing workable alternative administration plans
- We pledge to provide ample opportunity for you to review and provide input on the District Specific Regulations
- The time to start working together is NOW

Tab 18

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION OF
JOHN D'ANTONIO
JUNE 26, 2020
VOLUME 3

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION of JOHN D'ANTONIO, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on June 26, 2020, from 9:02 a.m. to 12:59 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the offices of HEATHER L. GARZA, CSR, RPR, The Woodlands, Texas, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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Shelly Dalrymple
Susan Barela
Peggy Barroll
Estevan Lopez
Ken Knox
Rolf Schmidt-Petersen
Al Blair
Gary Esslinger
Ian Ferguson
Michelle Estrada-Lopez

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EXHIBIT NO.11 332
Suggesting Speaking Points Lower Rio Grande Interstate Issues and Federal Involvement November 3, 2006

EXHIBIT NO.12 338
Active Water Resource Management Protecting Our Water Future Office of the State Engineer Lower Rio Grande Water Master District State of New Mexico June 28, 2006, PowerPoint Presentation

EXHIBIT NO.13 339
First Public Draft Proposed Rules and Regulations Providing for Active Water Resources Administration of the Waters of the Lower Rio Grande Water Master District dated June 28, 2006

THE VIDEOGRAPHER: Today is Friday, June 26th, 2020. The time is 9:02 a.m. We're on the record.

MR. SOMACH: All right. Why don't we start by making appearances? This is Stuart Somach on behalf of the State of Texas. Also on the Zoom call is Francis Goldsberry, Theresa Barfield, Richard Deitchman, and Robert Hoffman, all representing Texas all from my office. Jeff?

MR. WECHSLER: Jeff Wechsler on behalf of the State of New Mexico and, again, today either on already or will be on will be John Draper, Arianne Singer, Shelly Dalrymple, Susan Barela, Rolf Schmidt-Petersen, Peggy Barroll, Estevan Lopez, and Ken Knox.

MR. SOMACH: And the United States?

MR. LEININGER: Good morning. This is Lee Leininger for the United States, and I'm joined by Jim Dubois for the Department of Justice, and with the Solicitor's Office, Chris Rich, Shelly Randel, and for the Bureau of Reclamation, Ian Ferguson and Michelle Estrada-Lopez.

MR. SOMACH: And Colorado?

MR. WALLACE: Good morning. This is Chad Wallace for the State of Colorado.

MR. HARTMAN: Also, Preston Hartman for Colorado is on the line.

MR. SOMACH: Did you get that, Heather and Pete? It's a phone number there. You've got that?

THE REPORTER: Yes.

MR. SOMACH: Okay. Albuquerque?

MR. BROCKMANN: Good morning. It's Jim Brockmann both for Albuquerque and Las Cruces again.

MR. SOMACH: City of El Paso?

(No response.)

MR. SOMACH: EP No. 1?

MR. HICKS: Yes, Renea Hicks for El Paso County Water Improvement District No. 1, and Dr. Blair is on. For some reason, the gallery view is only showing a few people, I can't tell who all is on, but Dr. Blair tells me he's on the text, so I take him at his word.

MR. SOMACH: Elephant Butte Irrigation District?

MR. ESSLINGER: Good morning. This is Gary Esslinger.

MR. SOMACH: And Hudspeth County?

(No response.)

MR. SOMACH: New Mexico pecan growers?

MS. DAVIDSON: Good morning. Tessa Davidson for New Mexico pecan growers.

MR. SOMACH: New Mexico State?

(No response.)

MR. SOMACH: Anybody else?

(No response.)

MR. SOMACH: So we've got it all covered.

JOHN D'ANTONIO,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. SOMACH:

Q. Good morning, Mr. D'Antonio.

A. Good morning.

Q. Are you all ready to go?

A. I am.

Q. Let me remind you that you're still under oath and you have been the last two days before today. Now, the way I assume we'll proceed today is a little bit as we discussed yesterday. I'll finish up within the next little while. I don't obviously know exactly how long it'll take. And then Mr. Leininger will -- will pick up on behalf of the United States and then before we're done, we'll just confirm that we'll need another -- another half day somewhere down the road

to -- to finish up the deposition. Mr. D'Antonio, you're familiar with the operating agreement, I assume?

A. Yes, I am.

Q. We talked on and off about it over the last couple of days. What do you understand Texas' role to be in the negotiation of the operating agreement?

A. Well, they -- they were present. The commissioner, Mr. Pat Gordon was present and acting to my knowledge as a facilitator between the two districts and Bureau of Reclamation.

THE REPORTER: Mister who? I'm sorry?

MR. SOMACH: I'm sorry, Heather?

THE REPORTER: Mister who? Who did you say was present?

THE WITNESS: Mr. Pat Gordon.

THE REPORTER: Thank you.

Q. (BY MR. SOMACH) Do you know -- first of all, was New Mexico involved in those negotiations?

A. Not to my knowledge.

Q. Do you have any opinion as to why New Mexico was not involved?

A. Well, the opinion, what I heard after the fact essentially was that the operating agreement was between the two districts and the Bureau of payback of water. We have different provisions that we use, and we can settle these things through our administrative litigation unit, but every once in a while, somebody that's illegally diverting will -- will challenge even our administrative control and -- and we'll -- we'll have to go to a district court judge to make a decision before they comply. But for the most part, yeah, we've got the authority through the administrative processes and through our ALU process, through alternate dispute resolution, if it were to get to that point. But, yeah, we have -- we have -- we take care of most of those things internally, but once in a while, we've got to have the Court enforce some -- some actions.

Q. Let's -- let's go to another exhibit. This is --

MR. LEININGER: Pete, I'm sorry. This is the February 5, 2020, Barroll deposition testimony transcript, and I have it as Letter E.

Q. (BY MR. LEININGER) John, this is a -- this is a transcript -- I'm sorry. Let's get the sticker on here.

(Exhibit No. 10 was marked.)

Q. (BY MR. LEININGER) John, this is -- this is the transcript of Dr. Barroll's deposition on February

5th of 2020. If we go to Page 56, and I think it's also PDF 56, and down to Lines 19 and 20.

A. Okay.

Q. Do you see where Dr. Barroll says, "So far in the lower Rio Grande, we have not done active curtailment of any water rights"? Do you see that?

A. Yeah, I see it.

Q. So this is a -- this is a 2020 statement. We were talking about your earlier PowerPoint, which was January, 2005, and here in 2020, Dr. Barroll is saying "we," and I think she's referring to the state engineer's office -- "has not done any active curtailment of water right." Do you agree with that or not?

MR. WECHSLER: Objection; foundation.

A. Well, you've got to understand what active curtailment is, and if you go back up to her answer, she's talking about -- so the question is how water use is administered by the state engineer prior to 2005, and she's talking about water rights -- let's see. Standard administration of water rights versus active administration of water rights, active administration being more related to some sort of priority call or other curtailment of water rights. So what she's talking about here is actually putting in district-specific regulations under the active water resource management initiative and looking at how you would curtail uses or come to an agreement on an alternative needs of administration. That's not the same -- curtailment there is not the same as enforcing against illegal uses. So, yeah, I agree with her statement that she has in here, but there are two different issues that -- that I think you're trying to ask.

Q. (BY MR. LEININGER) Okay. So your -- your understanding of her statement is that there's not been a active water resource management plan that's been put into effect to curtail water rights?

A. No. The active water resource management plan has been put in place, and that's the tools, the water master's, the metering, the databases that we're doing, that's the active water resource management initiative. What she's talking about here is essentially how we would administer, which would be through district-specific regulations, and those were challenged, those aren't in place yet, so any active curtailment with respect to water administration, that piece is not in place yet.

Q. Okay. If you go to Page 57, next page. And I'm just trying to understand this testimony further

and your explanations are helpful. So if you look on Lines 1 through 4, she's also explaining that -- sorry. Page 57. You have to go down a little bit.

A. Right. I didn't want to just pick it up in the middle of -- of a sentence, but go ahead and ask your question and see if I have to go back up and read the context that it was stated in. So go ahead and ask your question.

Q. Okay. So the question here is just she's talking about permits are being issued with conditions, which would be fulfilled in enforcement by the office of these conditions.

A. Right.

Q. And she describes that as part of the active -- early active water resource management. So those conditions that are put onto permits that are then enforced, can you describe any examples of those?

A. Sure. Let me just look at the prior page a little bit, what the question was. I think this goes to your last line of questioning before our break. She's talking about permits that are filed for new appropriations, and we -- we conditioned those -- those applications, those -- those permit applications, we always condition them, and -- and obviously they cannot impair, they cannot -- they can't be detrimental to the public welfare of the State of New Mexico, they can't be contrary to conservation. The impairment piece is where we require offsets, so -- so in this particular case, if there was a new appropriation, somebody would have to acquire a water right and transfer that water right in before they could -- that permit would be accepted. So -- so there's -- there's different conditions. There's metering conditions depending on the use, if it's a commercial use. So there -- there's various conditions associated with any permits that gets applied for, and if it gets granted, it can't cause impairment. It can't be detrimental to public welfare or contrary to conservation with the State of New Mexico. So there's -- there's a process that happens that prevents impairment to other water users.

Q. Are you using the ILRGM model to evaluate those impairments, the -- I believe it's Integrated Lower Rio Grande Model?

A. I don't know what my district office uses down there. They -- they definitely use a -- a conjunctive management model that they use, and they use the Mesilla Valley guidelines. If it's within the Mesilla Valley that's a -- the process they use to evaluate applications.

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
14/ 24	change "hot' to "how"	Correction
19/ 14	change "or" to "and"	Correction
27/ 13	change "a" to "an"	Correction
27/ 14	change "operations" to "apportionment"	Correction
30/ 12	change "ask" to "answer"	Correction
30/ 13 & 14	change "western states, a lot of council" to	
	"Western States Water Council"	Correction
30/ 21	change "could discuss" to "could have discussed"	Correction
37/ 11	change "log" to "water"	Correction
44/ 4	change "appropriate" to "unappropriated"	Correction
51/ 15	change "was" to "wasn't"	Correction
74/ 8	change "continuum" to "continual"	Correction
77/ 3	change "2" to "$200"	Correction
80/ 22	change "the Antonio" to "D'Antonio"	Correction
87/ 19	delete "away"	Correction
89/ 24	change "back" to "bad"	Correction
103/ 9	change "limitation" to "interpretation"	Correction

John R. D'Antonio Jr.

JOHN D'ANTONIO, VOLUME III

SIGNATURE OF WITNESS

I, JOHN D'ANTONIO, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

John R. D'Antonio Jr.

JOHN D'ANTONIO, VOLUME III

Job No. 63560

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS)
)
Plaintiff,)
) Original Action Case
VS.) No. 220141
) (Original 141)
STATE OF NEW MEXICO,)
and STATE OF COLORADO,)
)
Defendants.)

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, JOHN D'ANTONIO, to the interrogatories as indicated were made before me by the said witness after being first remotely duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. SOMACH - 01:07:48
MR. WECHSLER - 00:00:00
MR. LEININGER - 02:11:41
MR. WALLACE - 00:00:00
MR. HICKS - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, this, the 21st day of July, 2020.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 04-30-22

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Tab 19

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS,	§	
	§	
Plaintiff,	§	
	§	
vs.	§	ORIGINAL ACTION
	§	CASE NO.: 220141
STATE OF NEW MEXICO,	§	(ORIGINAL 141)
and STATE OF COLORADO,	§	
	§	
Defendants.	§	

****

REMOTE VIDEOCONFERENCED DEPOSITION OF

JOHN D'ANTONIO, P.E.

AUGUST 14, 2020

****

REMOTE VIDEOCONFERENCED DEPOSITION OF JOHN D'ANTONIO, P.E., produced as a witness at the instance of the United States Department of Justice, and remotely duly sworn by agreement of all counsel, was taken in the above-styled and numbered cause on August 14, 2020, from 9:03 a.m. to: 3:06 p.m. before Karen L. D. Schoeve, RDR, CRR, reported remotely by computerized machine shorthand, pursuant to Section 5.4 of Appendix C of the September 6, 2018 Case Management Plan, as amended (CMP) and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

This deposition is being conducted remotely regarding the COVID-19 State of Disaster status of the world.

REPORTER'S NOTE: Please note that due to the quality of the transmission data for a Zoom video-conference, overspeaking causes audio distortion in the testimony when preparing a videoconference transcript.

Please be advised that an UNCERTIFIED ROUGH DRAFT version of this transcript exists. If you are in possession of said rough draft, please replace it immediately with this CERTIFIED FINAL TRANSCRIPT.

Quotation marks are used for clarity and do not necessarily reflect a direct quote.

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Aryian Singer
Ian Ferguson
Fred Cortez
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ALSO PRESENT:

Christian Barrett, Videographer

THE COURT REPORTER:

Karen L. D. Schoeve
Certified Realtime Reporter
Registered Diplomate Reporter
Realtime Systems Administrator

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NO.	DESCRIPTION	PAGE
Exhibit JD-014		13
Deposition of John D'Antonio, P.E. dated 05/11/11 (92 pages)		
Exhibit JD-015		43
First Public Draft, Proposed Rules and Regulations Providing for Active Water Resources Administration of the Waters of the Lower Rio Grande WaterMaster District, dated 06/28/06 Bates stamped NM_00075441 - 75500		
Exhibit JD-016		61
State of New Mexico's Counterclaims in the matter of State of Texas v. State of New Mexico, et al. Dated 05/22/18 (30 pages)		

P R O C E E D I N G S

THE VIDEOGRAPHER: The time is 9:03 a.m., and we are on the record.

JOHN D'ANTONIO, P.E.,

having been previously sworn to tell the truth, the whole truth, and nothing but the truth, so help him God, testified further:

EXAMINATION

BY MR. LEININGER:

Q. Good morning, Mr. D'Antonio. My name's Lee Leininger. You may recall at the end of your last three days of deposition, I was continuing to ask you questions. So you are still under oath.

You understand that?

A. I do.

Q. Okay. And basically, the same rules and procedures apply. We'll go for about an hour here, take a break, or we can take a break whenever you request, you or your attorney.

Is that okay?

A. That's fine.

Q. And just as a last matter, I think at the end of the last deposition, there were a number of other attorneys representing various parties that also wanted to ask you questions, so I'm going to

proceed and hopefully finish this morning and then turn it over to those guys, okay?

A. Okay.

Q. Did you review your transcript of the previous three days of deposition?

A. Yes.

Q. Okay. So you recall that we ended your deposition on June 24th discussing the FDR, the form delivery requirement that the State of New Mexico stipulated to for irrigation use in the Lower Rio Grande?

A. Yes.

Q. And that was the stream system issue Number 101 in the Lower Rio Grande adjudication, correct?

A. That's correct.

Q. Do you recall having your deposition taken in that case?

A. Yes, I do recall that.

MR. LEININGER: Let's -- Christian, if we could go to what should be identified as the deposition transcript for that case. And I apologize. I didn't look back at our numbering, so does anyone know what number this next exhibit is going to be?

THE VIDEOGRAPHER: It should be 14.
MR. LEININGER: 14, okay.
MR. WALLACE: Lee, this is Chad. Do you want to take appearances before we get too far down the line?
MR. LEININGER: Oh, I'm sorry, Chad. I didn't mean to skip right over that. Certainly. So --
THE COURT REPORTER: Before you do, I'll have to have you put the document down so that I can see the screen, please, then we can do it. Thank you.
MR. LEININGER: Yeah, my apologies everyone.
So for the United States, this is Lee Leininger with the U.S. Department of Justice.
We also have from the Department of Interior Solicitor's Office, Chris Rich.
And I'm looking for Shelly Randel. No, Chris Rich.
And then from the Bureau of Reclamation, we have Ian Ferguson, Fred Cortez and Michelle Estrada Lopez.
Let's proceed with Texas.
MR. SOMACH: Yes. This is Stuart

Grande. For the portions of the lower -- of the Rio Grande project below Elephant Butte, can BOR contract with New Mexico, or can New Mexico contract with BOR for the distribution of the project water in New Mexico?

A. I suppose so. I think the contracts now are with EBID and with El Paso Number 1 and then I think there's a contract between El Paso 1 and EBID.

Q. So New Mexico can have authority to administer a Reclamation -- federal Reclamation project?

MR. WECHSLER: Objection; form.

A. That's a different question.

Q. (BY MR. LEININGER) Well, let me understand the answer to your last question. The question is, can New Mexico contract with the Bureau of Reclamation for that distribution and allocation of project water within New Mexico?

A. I suppose they could. I mean, I don't -- I'm not sure -- I don't understand the line of questioning here, but I think the Bureau and any federal agency and the state agency could enter into a contract for project water. In the Lower Rio Grande, I think the projects -- the contracts are already in place and the water is spoken for, so those -- those contracts speak for themselves that are in place now, so I'm not sure exactly what you're asking.

Q. Well, this line of questioning, John, stems from your statement about New Mexico utilizing its apportionment under the Compact below Elephant Butte, okay?

A. Okay.

Q. All right. So you've stated that the surface water apportionment to New Mexico below Elephant Butte is 57 percent of the project supply, correct?

A. Yes.

Q. Okay. My question goes to how New Mexico can utilize 57 percent of the project water, okay?

A. Did you mean to --

Q. Do you understand my line of questioning? So now -- so the next question from that is, what is New Mexico's authority to either contract with the Bureau of Reclamation to utilize that water, or what is New Mexico's authority to administer the project water?

A. Well, I guess --

Q. Is that a compound question? I'll break that down for you. Let's just do the first one.

What is New Mexico's authority to contract with BOR to utilize project water below Elephant Butte?

MR. WECHSLER: Form and foundation.

A. Well, I think it's somewhat of a moot point, isn't it? Don't you already have a contract. The contracts are in place, the project is under Reclamation law and it runs. So no, New Mexico does not have authority to contract with BOR on this particular project. It's already under contract. I guess that's what you're asking.

Q. (BY MR. LEININGER) Okay. So there's no express federal authority for New Mexico to administer that project water for the Rio Grande project?

MR. WECHSLER: Form and foundation.

MR. WALLACE: Objection; form.

A. No, I just want to be clear that New Mexico still has administrative authority on surface and groundwater below Elephant Butte. And so -- and I mentioned, I mean, the State is involved in permitting processes all the time. And we've got a bunch of questions on that.

But New Mexico's not involved to administer the contract water, no.

Q. (BY MR. LEININGER) Okay. In New Mexico -- and just a couple more questions. So New Mexico cannot administer the surface water that's under contract to BOR, correct?

MR. WECHSLER: Object to form.

A. No, New Mexico does not administer the surface water that's under contract, other than we still permit the points of diversion and the places of use as an overall project permitting with the federal government, that's still something that's required. But, no, we don't administer on a day-to-day basis any of the water that's meant for the project.

Q. (BY MR. LEININGER) Okay. Sorry, but we need some clarity here. You said with regard to overall project permitting with the federal government, what are you referring to? How does the OSE permit project water use with the federal government?

A. Well, there are applications that were filed, even when the federal government filed for all the unappropriated surface water in the State of New Mexico in 1903 or '5, or whatever that was, and it would require a permit from then the territory or application to the territorial engineer at the same time.

And same with the project was built and constructed. There were applications that were filed for the points of diversion and for storage, the storage of the -- within, you know, behind Elephant Butte Dam required a permit from the State Engineer's office, the points of diversions on the three main diversion structures all required a permit from the State Engineer's office.

So it worked ancillary. They were involved in the day-to-day administration with respect to those points of diversions; and so that's what, I mean, New Mexico is still in the administrative scheme, even though we're not managing every molecule of water within the project under the contract that the Bureau of Reclamation does.

So I hope I was clear on that.

Q. We're getting there. Just a couple more questions.

So when you talk about, with respect to points of diversion, can New Mexico manage project points of diversion in the quantity of water diverted within the project?

MR. WECHSLER: Form and foundation.

A. Well, can New Mexico manage? I think we can observe and make sure there's compliance with what's going on -- or at least taking information and data to make sure that the diversions are within compliance in quantity of water. But, no, we don't manage project points of diversion in the way I think you're stating it and going for the project.

Q. (BY MR. LEININGER) Let's go back to the last exhibit. Right. This is Exhibit 16 again. It's the counterclaims, rather, from New Mexico. Let's go to .pdf 25. And you'll see a heading, I hope, that says "Improper Project Maintenance Against the United States." You may have to page down.

A. (Complied.) Okay.

Q. So you've reviewed the counterclaims. Are you familiar with this claim against the United States?

A. (Examined exhibit.) Well, just based on the reading of it, I wouldn't say I've reviewed them in-depth lately, so . . .

Q. Do you know what the complaint is?

A. Well, from my understanding there was project maintenance that the Bureau of Reclamation is responsible for doing, and a lot of it's not being done. And so it translates into project inefficiencies based on vegetation within the channel. I think that's part of it.

Q. Who's the person with the most knowledge at the OSE on U.S. operation of maintenance of the project facilities?

MR. WECHSLER: Foundation.

A. Well, it's handled -- most of that's handled with the -- I would say through the Interstate Stream Commission based on the fact that we have a -- nearly a $750,000 to a million dollar contract a year to help dredge out the channel right above Elephant Butte to make sure we get our Compact deliveries into the lake there. And so the Interstate Stream Commission is constantly reviewing channel efficiencies.

And, in fact, during our Rio Grande Compact Commission meetings, we have reports from the Bureau of Reclamation annually that talks about maintenance and talks about efficiencies and answers questions that we have. And those questions are usually given to me through our Interstate Stream Commission staff to address some of these inefficiencies within the channel.

Q. (BY MR. LEININGER) And my question's a

little broader than that. I mean, you have an allegation here that United States has allowed growth of water consuming vegetation around the reservoirs and along the channel. And allowed the channel, in the next paragraph, to fill with silt and other debris. Who is the person in New Mexico who has the most knowledge regarding these allegations?

MR. WECHSLER: Same objection.

A. Well, again, are we looking at the same -- so the counterclaims document that was filed in 2018, you know, when this was written and put together, I would just go back to our experts that were with New Mexico at that time and it would go back to Raul Schmidt-Peterson. Peggy Barroll, probably, was doing some work down there, although she's more of the hydrologist. But it would be them and their staffs or immediate staffs that deal with Rio bed operations.

Q. (BY MR. LEININGER) Right. I mean, we have not seen an expert report from New Mexico specifically addressing this question of channel maintenance and the impacts of efficiency in project operations. Peggy Barroll had touched upon it, but we didn't see any studies attempting to quantify

you to interpret the contract. I'm just asking you whether it is the contract that defines the apportionment New Mexico gets below Elephant Butte Reservoir, no matter what's in the contract?

MR. WECHSLER: Object to form.

A. Well, I think the Compact itself and the originators of the Compact, they always talk about that acreage split, you know, the 88,000 acres that could go up by 3 percent in New Mexico and the 67,000 for a total of 155,000 and they had that 3 percent of variance that they would allow.

So I think the Compact -- when the Compact was set up, it contemplated that split and I think the operating, or the -- not the operating agreement, but the contracts with the districts are consistent with the understanding of the Compact. That's the best I can answer to your question.

Q. (BY MR. SOMACH) Yeah. Let me just ask: Is there any daylight between what's in the contracts and what New Mexico is apportioned under the -- under the Compact?

MR. WECHSLER: Form and foundation.

A. And I'm not familiar with the contracts, Mr. Somach. So I'm not sure if there's any daylight between what's in the contract and what New Mexico's apportioned.

Q. (BY MR. SOMACH) Well, the Compact, Article 4, any other article, doesn't talk about 57/43, does it?

A. I don't believe so. The Compact just talks about how the water's gonna get delivered.

So, no, I don't think it -- but I know the Compact founders, everything that I've seen, always contemplated that split based on the acreage and operating the project as a single unit, equal project water to each project acre. And then -- so, again, I'm getting back to my understanding of the project supply that the Compact actually apportions the water to New Mexico and Texas. So I'm just saying the contracts that the Bureau of Reclamation has is part of that overall picture that helps identify that acreage split.

Q. Well, actually, you framed my next question, perhaps inadvertently.

But what else besides the contracts frame what New Mexico gets in terms of a apportionment below Elephant Butte Reservoir?

A. Well, obviously the understanding of the historical operation of the Compact is how the project supply essentially is used by both states.

And the project supply, like I'd said before, it includes those return flows, and it also includes any of the flood flows or extra flows that come in downstream.

Q. And that's how the project is operated and what the entitlements are under the contracts; isn't that true?

A. Again, I'm not really familiar with the contract -- the specific aspects of the contract other than I know it apportions the water in those amounts. But I've really never looked or studied the contract terms.

Q. In your opinion, can New Mexico use the water that's apportioned to it under the Rio Grande Compact below Elephant Butte Reservoir in a manner that's inconsistent with Elephant Butte Irrigation District's contracts with the United States?

A. Well, not the surface water apportionment.

Q. It had been my understanding that New Mexico doesn't believe groundwater was apportioned under the Compact. Is that an incorrect understanding?

A. No, that's true. Groundwater is not apportioned under the Compact.

Q. Well, all the Compact deals with is

surface water, and the question is: Can New Mexico utilize the water apportioned to it under the Compact in a manner that's inconsistent with the Elephant Butte Irrigation District contract with the United States?

MR. WECHSLER: Object to form. Foundation.

A. Well, I think it's consistent with the Elephant Butte Irrigation District's use of the water.

Q. (BY MR. SOMACH) The question I had, though, was couldn't Mexico utilize the water that's apportioned under the Compact below Elephant Butte Reservoir in a manner that is inconsistent with the Elephant Butte Irrigation District contract with the United States?

A. Well, again, it's -- I don't think we would use it inconsistently with it, but it is apportioned to New Mexico for the benefit of Elephant Butte. So I don't think we -- I don't think we look at it to do anything with it in a manner that's inconsistent with Elephant Butte who needs water.

But, again, I just want to be clear. It apportioned to the State of New Mexico.

Q. Yes. I'm trying to understand what that means, by understanding whether there's a difference between what's provided for in the Elephant Butte Irrigation District contract and what New Mexico was apportioned under the Compact. Are they the same or are they different things?

A. (Examined realtime screen.) Well, they're the same -- the quantity is the same. And I think the -- I just -- so the difference, as I see it is, you know, I think, Texas is of the opinion that, you know, that their water is used as a -- within the terms of that particular contract. And New Mexico's opinion is that it's apportioned to the State of New Mexico, we're gonna -- we recognize that contract and we -- we're not going to do anything that's inconsistent with Elephant Butte being able to use that water under those contract terms.

But just from my perspective on, as the New Mexico Commissioner, that water's apportioned to New Mexico, and it's subject to that contract.

Q. And I'm not -- I'm not quibbling with that. And I think you may have just answered the question. You've said that whatever the apportionment -- and I don't mean to put words in

your mouth, so correct me if I say this wrong.
But whatever was apportioned to New Mexico below Elephant Butte Irrigation District is subject to the contract with the Elephant Butte Irrigation District, and I've said that.
Whatever was apportioned to New Mexico below Elephant Butte Reservoir is subject to the contract that Elephant Butte Irrigation District has for the United States. Is that what you said?
A. That's what I said.
Q. And I recognize that there is a legal argument about whether there's an apportionment to New Mexico or whether it was something else.
Is there a functional difference between what New Mexico believes was apportioned to New Mexico below Elephant Butte Reservoir and what is subject to the contract with the Elephant Butte Irrigation District?
MR. WECHSLER: Form and foundation.
Q. (BY MR. SOMACH) In other words, there may be a legal distinction, and I don't want to argue the legal issue with you. I'm trying to figure out if there's a functional difference.
Is what functionally New Mexico got below Elephant Butte Irrigation -- Elephant Butte

Reservoir equal to the Elephant Butte Irrigation District's contract with the United States, functionally?

A. Well, I would say functionally in the quantity of the apportionment.

Q. So the quantity apportioned to New Mexico is defined by the Elephant Butte Irrigation District contract?

MR. WECHSLER: Object to form.

A. Yes, you could say that. That is consistent.

Q. (BY MR. SOMACH) Beyond quantity is the -- does the Elephant Butte Irrigation District define where New Mexico can utilize its apportioned water below Elephant Butte Reservoir?

A. (Examined realtime screen.)

Well, I think within a contract there's contract lands, project lands that are subject to the contract. Again, I have not seen the contract itself; but, yeah, I'm supposing that the place of use is identified within that contract.

Q. And that would define where the apportioned water to New Mexico below Elephant Butte Reservoir could be used -- area that could be used; is that correct?

A. (Examined realtime screen.)
Yeah. I'd say that's correct.
Q. And what about the purpose of use or the things that the water could be utilized for? Is that also defined in the contract, in other words, is the use of water -- the purposes of use of water apportioned to New Mexico below Elephant Butte Reservoir, is that also defined in the Elephant Butte Irrigation District's contract with the United States?
MR. WECHSLER: Foundation.
A. Again, Mr. Somach, I'm not familiar with the contract itself. I'm assuming that it's in there; but, again, I'm not familiar with the contracts.
Q. (BY MR. SOMACH) Let's assume for the sake of the question that there is a specified use for the water contract with Elephant Butte Irrigation District.
With that assumption, would New Mexico's use of water apportioned to it below Elephant Butte Reservoir under the Compact be also limited to the uses within the Elephant Butte Irrigation District contract with the United States?
A. Well, I think it would be limited and

subject to other contracts under the Multiple Purposes Act -- am I saying that right? I don't know. The MPA, the act that allows for other water to be used by, say, the City of Las Cruces or others Miscellaneous Purpose Act. That's what it is.

Q. Are you aware of Miscellaneous Use Purpose -- Purpose Use Act contract that Las Cruces has with the United States?

A. No, I'm really not, but I think most of the Bureau of Reclamation has that ability to enter into both types of contracts.

Q. And that presumably would be consistent with and pursuant to the contract that EBID has with the United States for use of water below Elephant Butte Reservoir; is that correct?

A. Yeah, I think that's correct.

Q. Let me ask quickly a couple of other questions that came out of some earlier questioning.

I had asked you about the -- you're the Secretary of the Interstate Stream Commission, correct?

A. That's correct.

Q. And you're also the State Engineer for the State of New Mexico, that's correct, right?

A. That's correct.

Q. And I think you said that the Interstate Stream Commission will protest if it feels that an application might affect an interstate stream. Is that a correct statement?

A. Well, protest what? Protest an application?

Q. If it feels it will affect an interstate stream.

A. Mr. Somach, what I'm asking is you said that the Interstate Stream Commission will protest, and I'm asking what will they protest?

Q. An application.

A. An application, okay. I just want to make sure you're -- yeah, they have the ability to lodge a protest, based on effects -- any detrimental effects that could happen to a -- regarding the Compact.

Q. Okay. Now, let's assume for a moment that an application's been granted. Does the Interstate Stream Commission monitor an interstate stream to ensure that ongoing operations on that stream do not adversely effect New Mexico's ability to meet its obligations to a downstream state?

A. Well, the State Engineer's office and staff is the one that monitors the permits. They're

CHANGES AND SIGNATURE

WITNESS NAME: JOHN D'ANTONIO, P.E.

DATE: AUGUST 14, 2020

PAGE/LINE	CHANGE	REASON
18/15	change "basis" to "beneficial use"	Correction
18,15	change "basis to" to "basis, the"	Correction
18/18	change "FOPS" to "crops"	Correction
30/7	change "breaker" to "FDR"	Correction
35/15	change "there tells" to "there's"	Correction
41/1	change "travel" to "Tribal"	Correction
41/20	change "short-sharing" to "shortage sharing"	Correction
41/21	change "Galenas" to "Gallinas"	Correction
41/22	change "Nimbus" to "Mimbres"	Correction
43/13	change " at the" to "active"	Correction
44/5	change "it" to "I"	Correction
49/8	change "combat" to "compact"	Correction
56/6	change "AWR" to "AWRM"	Correction
56/7	delete "and the"	Correction
59/24	change "based on" to "place"	Correction
70/6	delete "monthly"	Correction
74/23	change "general" to "engineer"	Correction
90/6	change 'legal" to "an illegal"	Correction
98/15	change "Raul" to "Rolf"	Correction
98/19	change "Rio" to "River"	Correction"
103/3	change "apply" to "comply"	Correction

Page/Line	Change	Reason
107/18	Change “form” to “forum”	Correction
107/ 23 & 24	Change “I wouldn’t - -“ to “it would”	Correction
123/4	Change “forcing” to “enforcing”	Correction
134/25	Change “floor on” to “for”	Correction
154/25	Change “and” to “to”	Correction
155/11	Change “governor” to “manager”	Correction
155/18	Change “with” to “that”	Correction
156/5	Delete “to an”	Correction

I, JOHN D'ANTONIO, P.E., solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction pages(s).

JOHN D'ANTONIO, P.E.

Job No. 65060

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS,	§	
	§	
Plaintiff,	§	
	§	
vs.	§	ORIGINAL ACTION
	§	CASE NO.: 220141
STATE OF NEW MEXICO,	§	(ORIGINAL 141)
and STATE OF COLORADO,	§	
	§	
Defendants.	§	

****

REPORTER'S CERTIFICATE

REMOTE VIDEOCONFERENCED DEPOSITION OF

JOHN D'ANTONIO, P.E.

AUGUST 14, 2020

****

I, Karen L. D. Schoeve, Registered Diplomate Reporter, Certified Realtime Reporter, and Realtime Systems Administrator, residing in the State of Texas, do hereby certify that the foregoing proceedings were reported by me and that the foregoing transcript constitutes a full, true, and correct transcription of my stenographic notes, to the best of my ability and hereby certify to the following:

That the witness, JOHN D'ANTONIO, P.E., was duly remotely sworn by the officer and that the transcript of the oral deposition is a true record of the testimony given by the witness;

I further certify that I am neither counsel for, related to, nor employed by any of the parties in the action in which this proceeding was taken, and further that I am not financially or otherwise interested in the outcome of the action.

That the amount of time used by each party at the deposition is as follows:

R. Lee Leininger - 02:41
Stuart L. Somach - 00:28
Chad Wallace - 00:01
Jeffrey Wechsler - 00:00
Renae Hicks - 00:58
James Brockmann - 00:00
John W. Utton - 00:00

Subscribed and sworn to on this the 29th day of August, 2020.

Karen L.D. Schoeve, CSR, RDR, CRR
Realtime Systems Administrator
Texas CSR No. 3354, Exp.: 10-31-2021
NCRA Exp. Date: 09-30-21
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Job No. 65060

Tab 20

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****

ORAL AND VIDEOTAPED DEPOSITION OF
PEGGY BARROLL
FEBRUARY 5, 2020
VOLUME 1

****

ORAL AND VIDEOTAPED DEPOSITION of PEGGY BARROLL, produced as a witness at the instance of the Plaintiff, and duly sworn, was taken in the above-styled and numbered cause on February 5, 2020, from 9:39 a.m. to 5:29 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the DRURY PLAZA HOTEL - SANTA FE, 828 Paseo De Peralta, Santa Fe, New Mexico, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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ALSO PRESENT:

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Mr. Jeff Wechsler
Mr. Estevan Lopez
Mr. John Utton
Mr. Gary Esslinger
Mr. Phil King
Mr. Al Blair
Mr. Gilbert Bart (via telephone)

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WITNESS: PEGGY BARROLL

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New Mexico Office of the State Engineer, Hydrology Bureau, Printout Labeled How Much Water Is There? Lower Rio Grande

BARROLL EXHIBIT NO.10 170
Active Water Resource Management, Protecting Our Water Future, Office of the State Engineer, Lower Rio Grande Water District, Water Master District, State of New Mexico June 28th, 2006, PowerPoint

BARROLL EXHIBIT NO.11 181
First Public Draft Proposed Rules and Regulations Providing for Active Water Resources Administration of the Waters of the Lower Rio Grande Water Master District dated June 28, 2006

BARROLL EXHIBIT NO.12 188
Second Public Draft Proposed Rules and Regulations Providing for Active Water Resources Administration of the Waters of the Lower Rio Grande Water Master District dated November 14, 2006

THE VIDEOGRAPHER: Good morning. We are now going on the record. The time is 9:39 a.m., and today's date is February 5th, 2020. Please note that the microphones are sensitive and may pick up whispering, private conversations, and cellular interference. Please turn off your cellphones and place them away from the microphones as they can interfere with the deposition audio. This is Media Unit No. 1 in the video deposition of Peggy Barroll taken by the plaintiff in the matter of Texas versus New Mexico filed in the Supreme Court of the United States, Case No. 141. This deposition is being held at the Drury Plaza Hotel Santa Fe located at 828 Paseo de Peralta. My name is Gary Goldblum, certified legal video specialist with The Video Department. I am not related to any party in this action nor am I financially interested in the outcome. Counsel all present in the room and everyone attending remotely will now state their appearances and affiliations for the record.

MR. LEININGER: I'll start there. This is Lee Leininger for the U.S. Department of Justice.

MR. ROMAN: David Roman on behalf of the State of New Mexico.

MR. WECHSLER: Jeff Wechsler for the New

Mexico State Engineer.

MS. DALRYMPLE: Shelly Dalrymple for the New Mexico Interstate Stream Commission.

MS. BARNCASTLE: Samantha Barncastle for the Elephant Butte Irrigation District.

MR. WALLACE: Chad Wallace for the State of Colorado.

MS. O'BRIEN: Maria O'Brien for El Paso County Water Improvement District No. 1.

MR. SOMACH: Stuart Somach for the State of Texas.

THE REPORTER: On the telephone?

MR. GOLDSBERRY: Francis Goldsberry for the State of Texas.

MR. RICH: Chris Rich, Solicitor's Office United States.

THE VIDEOGRAPHER: The court reporter is Heather Garza with Veritext.

MR. BARTH: Gil Barth.

MR. LEININGER: Sorry. There's a few more.

THE VIDEOGRAPHER: Okay.

MR. LEININGER: Who else is on the phone?

MR. KOPP: Michael Kopp for the State of

New Mexico.

MR. UTTON: This is John Utton. I represent New Mexico State University, Public Service Company of New Mexico, and the Camino Real Regional Utility Authority.

MR. LEININGER: Is that it? Will you please swear in the witness?

PEGGY BARROLL,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. LEININGER:

Q. Will you please state your full name for the record?

A. Margaret Wethered Barroll.

Q. And we've known each other for a long time, so if I slip and call you Peggy, forgive me, but I'll try to stick with the formal Ms. Barroll.

MS. DALRYMPLE: Dr. Barroll.

MR. LEININGER: Dr. Barroll. Thank you. Dr. Barroll.

Q. (BY MR. LEININGER) So let me introduce myself. My name is Lee Leininger with the U.S. Department of Justice. I'll be asking questions. Other attorneys will likely be asking questions so when I finish, we're not -- we're not finished, and I may reserve the opportunity to come back and ask follow-up questions. Okay?

A. Okay.

Q. Okay. And who's representing you today?

A. David Roman.

Q. From --

A. The New Mexico State's Attorney General's Office.

Q. Okay. Thank you. Have you had your deposition taken before?

A. Yes, I have.

Q. How many times?

A. I'm not sure. Probably around ten.

Q. Oh, okay. So you're very familiar with it. When was the last time you had your deposition taken?

A. Oh, it's been several years. I'm not sure when.

Q. All right. And basically, you know, if you can just give me the list and -- and what your depositions were in reference to?

A. Okay. I've done, I think, three or four that were related to actual court cases as opposed to hearings. I was deposed in the Pecos settlement litigation. I was deposed in a water rights hearing that went to trial for the Santa Fe ski area and then one for the Pegasus gold mine and then a bunch of them that were just water rights hearings like the Hideout Golf Course case and a couple of times for various ski areas. More of the Pegasus Gold Mine and Lone Mountain.

Q.   So they were all in the context of your professional expertise?

A.   I -- yeah. And I was deposed once for -- it was -- involved a traffic accident.

Q.   Okay. And how about testimony, have you testified in trial?

A.   I -- I think I only went to actual trial once for the Santa Fe ski area. The other once settled or summary judgment before trial.

Q.   And these hearings, the administrative hearings or --

A.   I testified at a lot of administrative hearings.

Q.   Okay. So you're familiar with the ground rules of a deposition, correct?

A.   Yes, I am.

Q.   Let's just go through those very quickly. You're under oath, subject to penalty of perjury so it's just like testifying. You understand your answers are sworn testimony?

MR. LEININGER: Okay. All right. Why don't we take a break now.

THE VIDEOGRAPHER: We're going off the record. The time is 10:52.

(Break.)

THE VIDEOGRAPHER: We are going back on the record. The time is 11:12.

Q. (BY MR. LEININGER) Let's go ahead and mark the next exhibit, so we'll put your CV aside.

(Exhibit No. 4 was marked.)

Q. (BY MR. LEININGER) Dr. Barroll, you've been handed exhibit marked No. 4?

A. Yes.

Q. And it's a slides taken from a PowerPoint with the title slide reading, "Active Water Resource Management in the Lower Rio Grand." Then it has the Office of the State Engineer and the Interstate Stream Commission logo and states, "Tools For New Era in Water Management, presented by Peggy Barroll, Hydrologist, New Mexico Office of the State Engineer, Lower Rio Grande Water Users Association 8/19/05," August 19, 2005. Did I read that correctly?

A. Yes.

Q. Do you recognize this document?

A. Yes.

Q. Did you compile this document?
A. Yes, I did.
Q. Why don't we start with just the first page. And I'll probably use the acronym AWRM. Are you familiar with that?
A. Yes, I am.
Q. Is that stands for active water resource management?
A. That's correct.
Q. Briefly tell me, what was -- what is the AWRM?
A. AWRM originated with the -- a piece of legislation in which the state legislator instructed the state engineer to administer water rights in the absence of an adjudication in order to improve interstate stream management and for other reasons, I guess, and the state engineer wrote some framework rules on how administration -- priority administration or otherwise in the absence of a completed adjudication would occur.
Q. So when you say, "Instructed the state engineer to -- the state legislator instructed the state engineer to administer water rights in the absence of an adjudication," what water rights or what uses of water are you talking about?

A. I think it would include any use of water in New Mexico.

Q. Okay. So this is essentially for the administration of any use of water in New Mexico, and this, in particular, for the Lower Rio Grande?

A. Yes.

Q. How was --

A. This presentation is related to the Lower Rio Grande.

Q. So this is dated 2005, year 2005. How were water uses administered by the OSE prior to 2005?

A. So at that time, we had -- we would sort of talk amongst ourselves as to sort of normal or standard administration of water rights versus active administration of water rights, active administration being more related to some sort of priority call or other curtailment of water rights, if necessary, in times of shortage. And so prior to -- and, actually, you know, so far in the Lower Rio Grande, we have not done active curtailment of any water rights. The normal administration has been, you know, the requirement of anyone who's drilling a well or appropriating water for use to come to the state engineer's office and get a permit, go through the application process, allow for protests or objections, may have to go to hearing, and then permits would be issued with conditions, which would have to be fulfilled and enforcement by the office of these conditions and then, again, we have -- as part of the early active water resource management, that was the declaration of the water master district appointment of water master and water master staff and the metering order.

Q. And when was that? When was the appointment of the water master?

A. I think 2004 would have been when the first water master was appointed.

Q. Okay. So prior to that, administration was limited to metering, and that metering was only M&I?

A. Prior to that time, there was not comprehensive metering of irrigation uses. I think some of them were, in fact, metered before that time, but there was no comprehensive metering of irrigation uses. I -- I believe all M&I was metered.

Q. And with regard to administration, beyond metering -- and we talked about the metering orders, correct?

A. Yes.

Q. Beyond that, what actively did the OSE do to administer water uses?

MR. ROMAN: Object to form; foundation.
But you can answer.
A. The administration consisted of all new uses or new wells or changes in water use aside from surface water within the project, but all other changes in use, they'd have to -- water users would have to come to the state engineer, file a permit, and it would be evaluated for impairment, might go to hearing. There'd be opportunity for protests. There would be conditions and then enforcement of those conditions.
Q. (BY MR. LEININGER) Okay. And outside of that, how -- how about administration for quantities of water use?
A. Water users who had permits with quantities listed, there would -- state engineer's office, those users would be limited to the amounts listed on their permits.
Q. Okay. And -- and I'm sorry. For "permits," what are you referring to?
A. The permit from the state engineer's office to divert groundwater say.
Q. So the permitting process, let's go ahead and talk a little bit about that. When did that begin?
A. I believe in 1980 with the declaration of the

Q. Okay. Do you -- do you recall -- you say it was a settlement. Do you recall what the OSE position was prior to settlement, what the FDR should have been?
A. I think the reports -- our reports had different figures in them. John Longworth was taking the lead on this rather than myself. I think we had some numbers in the high 3s and a number around 4.
Q. Not more than 4?
A. I don't believe so. I don't remember all of the things that were in our exhibits.
Q. So these are -- these are estimates then for amount of water pumped for agricultural purposes during a full supply year of 3 acre feet per acre, which is related to usable water in storage, correct?
A. Yeah. Except these are -- I mean, the -- the bars are the limits of what groundwater could be pumped if the FDRs were set to these levels.
Q. And you're calculating limits based upon total number of acres or -- or what for the F -- for this calculation of what the limits would be with these FDRs?
A. I don't remember what I threw in for acreage in that calculation, whether I -- oh, I think I was throwing in 75,000 acres.

Q. Oh, is that on here?
A. That's in that table.
Q. Okay. You have the magnifying glass so --
A. Yeah.
Q. -- I'll take your word for it. Okay. So let's jump over to the sustainable -- sustainable system column. You have a bullet point here from this 2005 document that says, "If the aquifer system continues to operate in this way, it will continue to be a sustain -- it will continue to be a sustainable system. Draw downs from drought will recover in intervening good years." So that's the conclusion in 2005, correct?
A. Yeah. That's what I -- that's what we thought -- that's what I thought in 2005, yeah.
Q. Okay. And then you go onto say, "If groundwater pumping regularly exceeds recharge, the LRG aquifer system will cease to be a sustainable system and turn into a mined aquifer."
A. Yes.
Q. Is that the situation we're in now?
A. Yes.
Q. And when did the LRG aquifer system, in your view, become a mined aquifer?
A. I'd say in the years following the adoption

of the operating agreement when EBID's allocation in full supply years was decreased by over a hundred, 150,000 acre feet so that in full supply years, the amount of surface water applied and available for recharge is now significantly lower and then EBID farmers pump more groundwater to make up for that lack in surface water and so all together, the farm -- the aquifer budget is changed in such a way that we are probably largely in a mined condition, though it's possible we may be able to get some recovery in some of the wet years.

Q. Okay. Let's break that down a little bit. What -- what year do you think you would define pumping -- and, again, I guess we're talking the Mesilla and Rincon -- Rincon valleys as being a mined aquifer?

MR. ROMAN: Object to form.

A. So I think that we started -- so D3 allocation was initiated in 2006. 2006 through 2010, the project had close to a full supply. EBID's allotments were close to two. I think we were -- the aquifer was holding its own then, and then we went into drought, very low surface water supply. In 2011, groundwater levels declined, and they have never really since recovered. I could say we started a little earlier, because we -- there was the groundwater level drop in 2003/2004, and it never really recovered from even that drop so maybe the mining started in 2003.

Q. (BY MR. LEININGER) Okay. So you -- you used the term here sustainable system. So sustainable system would be prior to 2001?

A. Prior to 2003, I guess.

Q. Prior to 2003. And then just for definition purposes, how do you define a mined aquifer?

A. One in which the -- on a long-term average basis, pumping exceeds recharge and so groundwater levels continue to decline.

Q. Okay. You can put that one away.

A. Here, you can have this.

Q. Oh, thanks.

A. My mother had one of those.

Q. I wish I could keep this, but it's actually Department of Justice property.

Okay. So we're back to our favorite Exhibit 4, and here on this Page 12 -- I'm sorry, the next page, it says, "This effect has been evident in the recent drought." Just for foundation, I think you're referring to the effect on groundwater pumping as having on drains; is that right?

A. Yeah.
Q. Okay. So as of -- as of 2005, your statement here, "The drains have dried up rapidly and have not yet recovered." You think that was a result of the -- of the early 2000s drought?
A. Yeah. That was the 2003/2004 drought, dried up the drains.
Q. Okay. And you say "have not yet recovered," so when you wrote this, was there a full supply year?
A. I -- I'm not sure. Let's see. 2005 was sort of technically speaking a full supply year. There was a full supply allocation made, but I think that it was only -- it only got up to a full supply allocation late in the year, so EBID and EP No. 1 didn't really take a full supply delivery.
Q. Okay.
A. So it's questionable as to whether -- then, of course, once you get to 2006, D-3 allocation, so EBID doesn't get the same full supply allocation as it used to get.
Q. So would you expected the drains to recover after the drought in 2001 --
A. 2003/2004. So this was written in 2005, so would it have recovered?
Q. Okay. I'm sorry. I thought you said the

drought years were 2002/2003?
A. If I said that, I was -- I misspoke.
Q. Okay.
A. It was 2003 and 2004 were the years where the project had a very low supply, very low allocation in allotments.
Q. They had not recovered by the time you'd --
A. The drains had not come back by the time I wrote this report.
Q. Gotcha.
A. This PowerPoint.
Q. Okay. That finally gets us to the title of this presentation, which is the AWRMs. Slide 14, you've got a slide titled, "In addition, the district specific regulations will include priority administration."
A. So two slides ahead, and it says "in addition" is the title of it?
Q. Right.
A. Yeah, okay. "In addition, the district specific regulations will include priority administration"? That's the one?
Q. Yeah.
A. Okay. Yes.
Q. So let's start in a nutshell. What --

explain the AWRMs and -- well, let's start there. Explain the AWRMs and their goal, what they were trying to accomplish?

A. The AWRM rules are -- including the framework rules were to give the state engineer a regularized official documented way to curtail water rights and priority if necessary, even in the absence of a completed adjudication.

Q. Okay. The reasons are stated on this slide, "To protect the historical operations of the Rio Grande project." So how was curtailment of junior groundwater rights necessary to protect historical operations of the Rio Grande project?

A. Well, it -- the regs -- the idea of the regs was to provide a mechanism to provide the means by which junior groundwater rights would be curtailed in priority if necessary to protect the historical operations of the Rio Grande project. So I believe those draft regs had, like, a provision for the U.S. to do a priority call on behalf of the project. So if the U.S. viewed the historical -- that the operations of the Rio Grande project were being impaired by junior groundwater use, the U.S. had this -- the -- the regs would have given the U.S. this mechanism to ask the state engineer to make a call, and because junior groundwater pumping -- or groundwater pumping, in general, can affect reduced groundwater levels, increase river seepage, making it more difficult to deliver project water, deplete drain flows, which reduces project supply, et cetera.

Q. The next page talked about a priority administration target?

A. Yes.

Q. So to protect the historical operating efficiency of the Rio Grande was -- that was the purpose of the AWRMs?

A. That was the target that we had developed in the -- that those draft district specific regs.

Q. Okay. The D2 curve?

A. Yeah.

Q. And we -- we can pull up that when we take a look at the -- the AWRMs, but just briefly, what was the D2 curve?

A. The D2 curve was an analysis developed by Bureau of Reclamation staff probably during the early 1980s in which they compared historical data from 1951 to 1978 from the monthly water data distribution reports on comparing release from storage -- release from project storage versus how much project water was diverted from stream by the districts in Mexico during that time period. It's -- can be used as a measure of project performance or efficiency.

Q. That time period was what?

A. 1951 to 1978.

Q. So the AWRMs were intended to ensure the same amounts of delivery at these downstream head gates from a given release at Caballo?

A. They were intended to maintain the same level of project efficiency. There were some downstream targets, I believe, in the -- in the regs. They -- I don't think they were necessarily river head gate diversions.

Q. Okay. So what were they?

A. I don't remember, but I -- I don't want to say they were down head gate diversions, because I don't recall that they were, but I haven't read them lately.

Q. Okay. So I understood your -- your conception of D2 was a certain amount of release generated a certain amount of diversion downstream?

A. Yeah.

Q. And these diversions were at the head gates or elsewhere?

A. The diversions in the D2 curve were at, yeah, river -- river heading -- canal headings on -- on the river, pretty much.

Q. Well -- so this is important. Are the diversions you're referring to diversions at the major head gates for the districts --

A. Yes.

Q. -- downstream?

A. Yes.

Q. Okay.

A. They were.

Q. Okay. And that was for that period between '52 and '78?

A. '51 and '78.

Q. Sorry. '51 and '78. Right. So the AWRMs were being generated to continue to produce that amount of diversions given the historic '51 to '78 time period for a release of water from storage?

A. It was intended to attempt to maintain the level of efficiency -- project efficiency from that period, and there was -- I know there was understanding there would be adjustments in it, for example, Canutillo pumping would be explicitly accounted for. So it's -- you know, it's not as exactly the same diversions as in the D2 period. It's -- it would have -- there was understanding that there'd have to be adjustments made for changes in conditions --

Q. Okay. So --

A. -- and diversions since that point.

Q. So the Canutillo well field is a well field that's in Texas in the lower Mesilla valley, correct?

A. That's correct.

Q. Okay. So other than adjustments for Canutillo pumping and effects on delivery -- surface water delivery, what other adjustments were considered in the AWRMs?

A. I don't know that we have any others listed in there.

Q. Okay. Let's go to Page 22 on this.

MR. ROMAN: Can you give the title?

MR. LEININGER: Yeah. I'm sorry. 22 is titled, "Why administer to the historical operating conditions?"

Q. (BY MR. LEININGER) You give four reasons here. First gives a quantified target for surface water delivery; second, documented in US BOR Rio Grande project water supply allocation procedures; three, it has been the basis of Rio Grande project operations for 50 years; four, it is generally favorable to New Mexico. Let's just look at that last bullet point. How is it generally favorable to New

Mexico?

A. Well, at the time I believed it was -- our team believed it was because it incorporated pumping that was occurring during the 1951 to 1970 period.

Q. Okay. So explain to me how that's generally favorable to New Mexico if you're basing a target on pumping that was impacting surface flows?

A. It's -- it was considered generally favorable to New Mexico to not cause a great disruption in the irrigation district and to allow and to ensure that the groundwater necessary to supply the project during times of drought is included in the consideration of what the efficiency of the project should be.

Q. All right. So by saying "not disruptive," you mean it grandfathers in a certain amount of ground -- groundwater pumping in that --

A. That is what we believed at the time, yes.

Q. -- in that period prior to 1978?

A. Yes.

Q. Okay. So it's generally -- you say it's generally favorable compared to what? What -- what were you concerned about that would be the alternative?

A. We did not want to implement a kind of any administration that would make agriculture untenable in the Lower Rio Grande by preventing groundwater pumping during times of low surface water supply.

Q. Okay. Any other reasons?

A. That we regarded as -- any other reasons of what?

Q. Well, we'll get -- I'm going to pull out one more PowerPoint that you generated or the OSE generated, and it talked about concerned about lawsuits from Texas. So was that a consideration?

A. Well, that was a consideration in doing AWRM all together in the Lower Rio Grande. I mean, the fact that we were doing AWRM was, I believe -- I mean, I believe the AWRM statute in itself was, again, motivated by the possibility of interstate litigation.

Q. Okay. So how'd it go? What happened to AWRMs?

MR. ROMAN: Object to form.

MR. LEININGER: Yeah. Let me -- I'll restate that question.

Q. (BY MR. LEININGER) The AWRMs were not adopted, correct?

A. That's correct.

Q. Okay.

MR. ROMAN: And I'd just like to clarify. You've been using the term AWRMs, but if --

if I'm mistaken, correct me, but I believe you're referring to the district specific regulations under the active water resource management statute, but if I'm mistaken, that's fine.

MR. LEININGER: Yeah, that's correct. As they applied to the Lower Rio Grande.

A. Right.

Q. (BY MR. LEININGER) That's been your understanding?

A. The district specific regs have not been adopted.

Q. Okay. All right. So to the -- to the best of your knowledge, why were they not adopted?

A. There's been a lot of things that happened, and I -- I can't really say for sure. The framework regs were in litigation for a long time, and a lot of facts on the ground changed shortly after the -- we put out these drafts.

Q. So you recall that the AWRMs were subject to litigation that was -- went all the way up to the New Mexico Supreme Court, correct?

A. That's right.

Q. All right. And the Supreme Court found that the AWRMs were legally authorized under New Mexico statute and laws?

A. That the framework was constitutional.
Q. It was constitutional. Thank you. Yeah. It was a constitutional question. So after AWRMs were found to be constitutional and consistent with the law of New Mexico, was there any attempt by the State of New Mexico, the OSE office, to revisit AWRMs in the --
MR. ROMAN: Object --
Q. (BY MR. LEININGER) -- Lower Rio Grande?
MR. ROMAN: Object to form and foundation.
A. The topic has come up. It's come up in the forum of the users group, which I guess is covered by confidentiality. We have not issued -- the state engineer has not issued completed or issued another draft of the district specific rules and regulations.
Q. (BY MR. LEININGER) Okay. There's -- there was two drafts, correct, in --
A. Yeah, yeah, I believe so.
Q. All right. How are we doing? Let's -- let's push on until 5:00, and then we'll decide what to do from there. Are you doing okay? Do you need a break?
A. I'm okay.
Q. You can put this away.
A. Some water.
MS. DALRYMPLE: I'll get it.

(Exhibit No. 10 was marked.)

Q. (BY MR. LEININGER) You've been handed what's been labeled Exhibit 10. It appears to be another PowerPoint slide series, and this one on the cover sheet says, "Active Water Resource Management, Protecting Our Water Future, Office of the State Engineer, Lower Rio Grande Water District, Water Master District, State of New Mexico June 28th, 2006." Did I get that right?

A. Yes. I think so.

Q. Were you -- did you generate these slides?

A. Looks -- some of them are mine.

Q. Okay. So you're familiar with this slide show?

A. Yes.

Q. So this is about a year after the prior slide show dated June 28th, 2006. The other one, which we've been talking about, was dated August 19, 2005. So let's go Page 6. And the purpose of this slide show is to still roll out the draft active water resource management regulations and to promote them, the OSE was promoting them; is that correct?

A. Yes. I believe so, yes.

Q. Let's go to the slide that -- or I believe it's 6. It says, "Population growth."

A. Yes.
Q. And it states, "Fact, water demand is growing, supply is not. Regional population growth projections," and you've got a bar chart with four -- five years, two thousand -- sorry, five decades, 2000, 2010, 2020, 2030, and 2040. So are these projections still reasonably accurate?
A. I don't know. I'm not -- this isn't my field.
Q. Oh, okay. So you didn't participate -- you didn't assist in the generation of this slide?
A. I didn't generate these, and I don't know.
Q. Okay. Okay. Let's go to the slide, I believe it's the 12th page, it says, "Fact, as a result, total consumption of irrigation water has increased." Do you see that slide?
A. Yes. That was a conclusion based on the -- the data and analysis we had at that time. The CIRs were probably generated using that modified Blaney-Criddle by the -- by Bryan Wilson from water use and report. It's -- I mean, this is -- this is what we thought -- this is how we viewed the picture at the time.
Q. Okay. And it's slightly different from your previous slides the year earlier. You have a -- a

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
46/5	"I used Blaney-Criddle estimates in."	I misspoke
62/11+12	"Water use and reports people had made a calculation, and sent it to Water Rights who started using that value	Transcription makes my meaning unclear
140/2	"kriged" not "creed"	error in transcription
161/6	"curtail water rights in priority"	transcription error
190/9	"probably" not "proudly"	transcription error
104/8	"one water" should be "One Rain"	misspoke
106/21	"1 water" should be "One Rain"	misspoke

PEGGY BARROLL, VOLUME I

Job No. TX3852882

S I G N A T U R E   O F   W I T N E S S

I, PEGGY BARROLL, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

Peggy Barroll 5/4/2020

PEGGY BARROLL, VOLUME I

Job No. 3995820

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS)
)
Plaintiff,)
) Original Action Case
VS.) No. 220141
) (Original 141)
STATE OF NEW MEXICO,)
and STATE OF COLORADO,)
)
Defendants.)

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, PEGGY BARROLL, to the interrogatories as indicated were made before me by the said witness after being first duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. LEININGER - 05:07:04
MR. ROMAN - 00:00:00
MR. SOMACH - 00:00:00
MR. WALLACE - 00:00:00
MS. O'BRIEN - 00:00:00
MS. BARNCASTLE - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 24th day of February, 2020.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 04-30-22
VERITEXT LEGAL SOLUTIONS
Firm Registration No. 571
300 Throckmorton Street, Suite 1600
Fort Worth, TX 76102
1-800-336-4000

droman@roblesrael.com

February 24, 2020

RE: Texas v. New Mexico

DEPOSITION OF: Peggy Barroll (# 3852882)

The above-referenced witness transcript is available for read and sign.

Within the applicable timeframe, the witness should read the testimony to verify its accuracy. If there are any changes, the witness should note those on the attached Errata Sheet.

The witness should sign and notarize the attached Errata pages and return to Veritext at errata-tx@veritext.com.

According to applicable rules or agreements, if the witness fails to do so within the time allotted, a certified copy of the transcript may be used as if signed.

Yours,

Veritext Legal Solutions

Tab 21

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****

ORAL AND VIDEOTAPED DEPOSITION OF
PEGGY BARROLL
FEBRUARY 6, 2020
VOLUME 2

****

ORAL AND VIDEOTAPED DEPOSITION of PEGGY BARROLL, produced as a witness at the instance of the Plaintiff, and duly sworn, was taken in the above-styled and numbered cause on February 6, 2020, from 8:41 a.m. to 3:24 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the DRURY PLAZA HOTEL - SANTA FE, 828 Paseo De Peralta, Santa Fe, New Mexico, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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ALSO PRESENT:

Mr. Ian Ferguson
Mr. Jeff Wechsler
Mr. Estevan Lopez
Mr. John Utton
Mr. Gary Esslinger
Mr. Phil King
Mr. Al Blair
Mr. Gilbert Barth (via telephone)

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WITNESS: PEGGY BARROLL

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BARROLL EXHIBIT NO.14 D2, D3 and Rio Grande Project Operations New Mexico Office of the State Engineer, Hydrology Bureau, April, 2007	231
BARROLL EXHIBIT NO.15 Rio Grande Project Operation Agreement - A State of New Mexico Perspective, Presented by Peggy Barroll PhD, dated August 5, 2010	240
BARROLL EXHIBIT NO.16 New Mexico Perspective on the 2008 Rio Grande Project Operations Agreement by Estevan Lopez, P.E., Director, New Mexico Interstate Stream Commission, dated March 9, 2011	248

BARROLL EXHIBIT NO.17 250
Rebuttal Expert Report Revised Comparison of 2009 Farm Deliveries with Farm Delivery Requirement Calculations for the Lower Rio Grande dated April 2011

BARROLL EXHIBIT NO.18 256
Expert Report of Margaret Barroll, Ph.D., dated October 31, 2019, Prepared for State of New Mexico

BARROLL EXHIBIT NO.19 270
Evaluation of Annual Operational Allocations and Deliveries Rio Grande Project and the Republic of Mexico, 1951 to 1978, dated July 30, 1981

THE VIDEOGRAPHER: Today's date is February 6th, 2020, and we are going on the record. The time is 8:41 a.m. This begins DVD No. 4 in the continuation of Dr. Peggy Barroll. The witness has been sworn in, and you may proceed.

PEGGY BARROLL,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. LEININGER:

Q. Okay. Good morning, Dr. Barroll. This is -- for the record, this is Lee Leininger. I'm continuing the questioning this morning. So yesterday, we had discussed the draft AWRMs, and one question I want to go back to, it's the first public draft, Exhibit 11. Do you still have a copy of that in front of you?

A. Yes, I do.

Q. If you'd turn to Page 14.

A. Yes.

Q. And see Paragraph AAA --

A. Yes.

Q. -- called, "Supply administration date." And it reads, "Supply administration date, colon, a date to be determined as necessary by the State Engineer for implementation of supply administration to temporarily curtail junior water rights in years in which the Rio Grande project supply is insufficient to provide an EBID allotment of 3.024 acre-feet per acre." Did I read that correctly?

A. Yes.

Q. Okay. So this is the -- we spoke a little bit about 3 acre-feet per acre in one of the earlier exhibits that was produced by the OSE. This is the only reference to 3.024 in the draft AWRMs and so explain to me why it was important to the OSE at this time to have a supply administration date tied to 3.024 acre-feet per acre to provide an allotment to EBID?

MR. ROMAN: I'm going to object to foundation.

You can answer.

A. Yes. My understanding of the use of the 3.024 in this context was to provide an indicator of whether it was a full supply year for the project or not, and the -- that was related to the fact that I believe that certain kinds of administration -- certain type, and probably the supply administration, was intended to only occur in years -- in -- in non-full supply years.

Q. (BY MR. LEININGER) Okay. So we had had some previous testimony with regard to EBID's allotment

targeted to 4.0 acre-foot per acre. Do you recall that earlier testimony?
A.   I think we were talking about limits on groundwater pumping.
Q.   Okay.
A.   At 4 --
Q.   Well, wasn't it in the context of a farm delivery requirement?
A.   It was in the context of, yeah, the -- the -- a limit of groundwater pumping associated with a farm delivery requirement of 4.
Q.   So, in other words, we had an exhibit in which you talked about a combined rate for EBID. So we had a surface water plus groundwater, which resulted in an amount of water to calculate a farm delivery requirement; is that a fair statement?
A.   Right. A farm delivery requirement that was used to determine the limit of -- for irrigation well pumping for EBID farmers.
Q.   Okay. So the farm delivery requirement of 4.0 exceeded the 3.024 acre-feet per acre allotment under the project; is that correct?
A.   Yes.
Q.   Let's go to the next exhibit. Sorry. I have to untether. I was looking in the wrong pile. Here

A. Well, there was not really an allocation process. It was the Bureau simply allowed people to order water as they see fit. That was -- I mean, I consider the allocation process when the Bureau is telling the districts or the farmers how much they can order, how much they're entitled to order. That's what I call the allocation process. And prior to '51, there were a few years in which the Bureau was saying, looks like we might be short, everybody start conserving water or you can only order two-and-a-half or three, but by the end of the year, they had dropped that limit. That's the extent of the allocation process prior to 1951.

Q. Have you written a report or otherwise provided information, anecdotal or otherwise, with respect to the -- what I will call the allocation process predicated, upon the fact that you've defined that previously, that describes exactly what you just talked about?

A. What I've talked about, I've learned from reading the project histories. So what I'm describing is -- is what I've gleaned from reading the project histories of that time period.

Q. Have you done an analysis of the amount of water apportioned to Texas under the 1930 -- 1938 Rio

Grande Compact?
A. No. The '38 Compact has quantitative delivery obligations to Elephant Butte. That's -- and I have played around with those relationships a little bit. Beyond that, no.
Q. Explain what you mean by you've played around with those relationships a little bit.
A. I -- somewhere I have a spreadsheet in which the numbers from the delivery obligations are tabulated, and I think I probably have the numbers from the original Compact and the numbers after the 1948 change from delivery from San Marcial to Elephant Butte and compared and contrasted those. That's what I mean.
Q. Do you have an opinion -- an expert opinion about the quantity of water that was apportioned to Texas under the 1938 Compact?
A. Well, Texas -- I don't regard myself as an expert on the Compact or what the Compact law is. I think that's what the Supreme Court is going to tell us.
Q. Do you have a -- a -- a opinion as an engineer hydrologist who certainly has rendered opinions with respect to what the allocation -- the Bureau of Reclamation allocation responsibilities are,

do you have a similar view, a non-legal view as to what Texas apportionment under the Rio Grande project was?

A. My understanding is that at the time of the Compact, there was an interdistrict contract in which a division of water under times of shortage was set at 57/43 basically, and that I -- it seems to me that that having been contemporaneous with the Compact that there is a relationship between the 57/43 and what the Compact is apportioning the states below Elephant Butte. But this is, again, my speculation. When I first started working the Lower Rio Grande, my understanding of the law was that a court had decided that the Compact kind of ended at Elephant Butte and nothing that went on below the Elephant Butte was a Compact matter.

Q. I'm sorry. I --

A. That nothing that went on below Elephant Butte was a Compact matter. There was that case, El Paso V. Reynolds in which I think New Mexico was arguing there was Compact issues below Elephant Butte, and the Court said, no, there are not. But, again, this is my own vague understanding of how these things work. It seems to me that what goes -- that any apportionment below Elephant Butte is a difficult subject.

Q. In what context then are you opining with respect to obligations with respect to allocations pursuant to D2?

MR. ROMAN: Object to form.

A. I -- again, I don't know what the Compact obligates New Mexico to deliver to Texas below Elephant Butte. I've -- I've read the complaints and some of the responses in other court documents. I've read some of what the first special master wrote and some of what the second special master said. I find it pretty confusing. There's a strong suggestion that the Compact encompasses the project, and I've always thought that the Compact was designed to kind of protect the project and make sure enough water got into Elephant Butte to supply the project and then the project would then be responsible for delivering the water between the two states below Elephant Butte. So in the sense that the project is protected by the Compact, the Compact is intended to support the project in some ways as its delivery mechanism. I would think that the Compact is not inconsistent with a well-running project in both New Mexico and Texas, which means that in low supply years, supplemental pumping is necessary and is considered to be part of keeping the project running.

Q. (BY MR. SOMACH) Is that only -- is that pumping only in low supply years or is it allowable in every year?

A. We're getting beyond where I'd want to speculate. I -- I think, again, that's all going to be up to the Supreme Court.

Q. Well, you have made a number of -- of -- you've rendered a number of opinions with respect to New Mexico somehow being shorted because of the way the Bureau of Reclamation is operating and allocating; is that correct?

A. Yes. I think current allocation and delivery is -- there's been a large change in allocation and delivery to the detriment of New Mexico, and I think that change has been too great.

Q. That change must be from some thing; is that correct? In other words, there must be a baseline upon which you are evaluating that change; is that correct?

A. Yeah. That baseline would be the operations of the Rio Grande project since its inception until 2005.

Q. So "since its inception" means all the way back to, what, 19 -- some year in the early 1900s?

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE CORRECTION REASON FOR CHANGE

214/13 change "for" to "or" transcription error

223/13+14 omit "from surface water to groundwater" I misspoke

225/9 change "that the" to "what sort of" I misspoke

263/13 change "in" to "and" transcription error

277/3 change "and" to "in" transcription error

281/19 change "I've sorted" to "assorted" transcription error

297/4 should read "effect of changes in accounting between the two" transcription error

306/25 → 307/1 should read "the whole delta is 137,000 AF, and the delta part I'm getting out of accounting is about 75,000" I found the numbers and made the calculation

337/8 should read "We demonstrated that the quality etc" I misspoke

PEGGY BARROLL, VOLUME II

Job No. TX3852890

SIGNATURE OF WITNESS

I, PEGGY BARROLL, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

Peggy Barroll 5/4/2020

PEGGY BARROLL, VOLUME II

Job No. 3995842

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, PEGGY BARROLL, to the interrogatories as indicated were made before me by the said witness after being first duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. LEININGER - 03:03:19
MR. ROMAN - 00:00:00
MR. SOMACH - 01:04:52
MR. WALLACE - 00:00:00
MS. O'BRIEN - 00:00:00
MS. BARNCASTLE - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 24th day of February, 2020.

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Tab 22

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION OF
PEGGY BARROLL
AUGUST 7, 2020
VOLUME 2

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION of PEGGY BARROLL, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on August 7, 2020, from 8:01 a.m. to 3:40 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the offices of HEATHER L. GARZA, CSR, RPR, The Woodlands, Texas, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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VIDEOGRAPHER:
Mr. Christian Barrett

ALSO PRESENT:

Al Blair
Bert Cortez
Ian Ferguson
Shelly Dalrymple
Susan Barela
Estevan Lopez

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WITNESS: PEGGY BARROLL

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THE VIDEOGRAPHER: The time is 8:01 a.m., and we are on the record.

PEGGY BARROLL,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. SOMACH:

Q. Dr. Barroll, we've got to quit meeting like this. This is -- you know what I was thinking is we should do some kind of an agreement, you stop writing reports, and I will stop deposing you.

A. Okay.

Q. I don't think I've ever deposed a witness over such a long period of time before. So that's a deal, right?

A. Yeah. That's a deal.

Q. You'll stop writing reports?

MR. SOMACH: Let's make some appearances. This is Stuart Somach on behalf of the State of Texas. I notice that Robert Hoffman from our office is also on the phone. Jeff, appearances for New Mexico?

MR. WECHSLER: Jeff Wechsler on behalf of the State of New Mexico, and we also have Shelly Dalrymple, Susan Barela, and Estevan Lopez.

MR. SOMACH: Lee, for the United States?

You are muted.
MS. O'BRIEN: You're muted.
MR. LEININGER: Let me try that again. This is Lee Leininger for the United States. Good morning. And it looks like I am the only United States representative at this time. That may change, and I'll -- I'll add the record during the first break if necessary.
MS. O'BRIEN: Lee, I think Ian is actually on.
MR. LEININGER: Okay. Thank you. Ian Ferguson joins us from the Bureau of Reclamation.
MR. SOMACH: Chad, for Colorado?
MR. WALLACE: Good morning. This is Chad Wallace, along with Preston Hartman for Colorado.
MR. SOMACH: And Maria?
MS. O'BRIEN: This is Maria O'Brien for the El Paso County Water Improvement District No. 1, and Dr. Al Blair.
MR. SOMACH: I'm not sure whether or not that's your phone, Maria.
MS. O'BRIEN: That's not me. It looks like -- Peggy, do you have another phone? There's another box that has Peggy Barroll, and that was what was making noise while I was speaking. You have your

picture and then you have a box that also says Peggy Barroll. That was indicating noise earlier.

THE WITNESS: Yeah, I don't know what that is.

MS. O'BRIEN: Anyway, okay. It wasn't me.

MR. SOMACH: Anybody else that we haven't -- I'm looking at the list here. It looks to me like that may -- we may have gotten it, but anybody else?

(No response.)

MR. SOMACH: Okay. Let's get started. What we've got today is we'll go to about a quarter of 9:00. We have a status conference with the Special Master starting at 9:00, so I talked to both Lee and Jeff, and we thought that stopping at that point was probably good. I -- I didn't ask this question, and that is how we determine when we want to come back. My thought is we either do one of two things, we give ourselves a half an hour to kind of regroup after the conference or we go ahead and take an early longer break and then just pick up at -- at a certain given time after a lunch break. So, Jeff or Lee, do you have any thoughts on what you'd like to do there?

MR. WECHSLER: Lee, do you have any

A. Are you asking about the differences in loss in the Rio Grande versus the reduction in canal seepage versus the increase in drain flows.

Q. Yes. What -- what you're talking about in terms of -- of this -- this -- this chapter, this section.

A. I don't provide quantification of those individual terms.

Q. Okay. And I think I -- I may have asked this in terms of the summary, but I'm looking at -- at the next paragraph at the very bottom again where you say, "I provide these results in the form of graphs and tables in which the impact of pumping is calculated as Run 3 minus Run 1 and represents, again, in bold, the change in project allocation and diversions that would result from turning off all New Mexico pumping." Did I read that correct?

A. I think so.

Q. Correctly? Is it your conclusion -- and, again, we may have said this as part of the summary, but I just want to make sure I'm understanding it, that the project benefits from turning off New Mexico wells, that -- that 's -- that's a correct statement, isn't it?

A. As I think I said earlier, if there were no groundwater pumping, the project would have run into serious problems during the periods of low supply and so, therefore, the costs and benefits of pumping, it's not -- not all a one-way street; however, if there were no New Mexico pumping, the -- there would have been more project supply available in certain years.

Q. What -- what you're talking about there is in times of drought when there's low surface water supply that had -- it's a good thing to pump some groundwater; isn't that correct?

A. Yes.

Q. Okay. That's -- I think it's been referred to as far as a conjunctive use program where, when you have less surface water supply, you pump groundwater; is that right?

A. Yes.

Q. Okay. And the assumption is that -- that you keep your pumping of surface water during those drought periods to a level that the groundwater basin will sustain itself; is that correct?

A. Well, historically, in the New Mexico part of the project, groundwater levels have recovered following periods of low supply periods in which a lot of groundwater pumping has occurred. So up until about 2000/2005, that was the situation in the New

Mexico part of the project.

Q. And then I think you also had indicated previously that thereafter, the groundwater basin was mined, which by using that word, I -- I suspect you're saying it hasn't been recovered or it -- it can't recover itself?

A. That's right.

Q. Okay. We -- that -- your focus then is the cause of that is the operating agreement; is that correct?

A. Yes.

Q. Is it 100 percent of the cause or -- or is it a factor?

A. I'd say it's the dominant factor. I mean, a groundwater level decline happens because of drought. The failure to recover happens because of the operating agreement.

Q. If you can take a look at your Figure 1, that's a -- a graphic look at the -- the difference between Run 1 and 3; is that correct?

A. That's correct.

Q. And what -- what is that -- take me through -- through what -- and let's start out with -- you have two graphs there. One is an EBID graph, and the other is an EPCWID graph -- graph. What do we

see -- what are you showing there? What is the intent in that?

A. So I'm showing the difference -- or I'm plotting out model results from the time period 1980 to 2020 -- or 2017 is when the model runs end. The open circles are Run 3 -- the open symbols are Run 3. The closed squares are Run 1. Run 1 is the base run so that is historical practices are occurring. Run 3 is the no New Mexico pumping run, so that is the equivalent historical run that if you just turned off all of New Mexico pumping and return flows associated with that pumping. And so we see that these plots are both current-year allocations so I'm not including consideration of carryover in this. And we see that New Mexico's current-year allocation would have been higher without New Mexico -- with no New Mexico pumping, and the same is true, to a lesser extent, for EP No. 1.

Q. So the real beneficiary based on these charts of no groundwater pumping in New Mexico is New Mexico; is that correct?

A. Yeah. That's especially true once the operating agreement kicks in, because the effect of the diversion ratio amplifies the impact of New Mexico pumping and then, of course, since New Mexico's allocation has been reduced, they pump more, and then that reduces the diversion ratio more.

Q. On the bottom of the second paragraph on Page 4, you're talking about, "In general, turning off pumping during the full supply years reduces the releases from Caballo necessary to meet demands." In that last sentence, you say, "In effect, during full-supply conditions, reductions in groundwater pumping that impact Project efficiency cause accretions to reservoir storage." When you say -- well, explain to me your use of the word accretions there.

A. It means that since the reservoir had to release less water to supply demands, there was additional water left in the reservoir each year that this occurred and so the project supply increased relative to the base case year by year during full supply periods until a spill occurs or a low supply year happened.

Q. And, of course, if a spill occurs, it just -- it gets spilled, it gets lost no matter what you intend to do, but in large supply years, it's minimized; is that correct?

A. That's correct.

Q. Okay. Now, if we take a look at Page 5,

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
176/20	change "charge" to	"charged"
181/2	"the advantage"	"is an advantage"
182/11	"so"	"between"
200/12-13	"things are"	"is"
201/22-23	change "is no longer being charged" to "is being charged as Project Supply now"	
202/2 change	"it" to	"if"
204/11	"tie" to	"tide"
209/19	"accomodation" to	"combination"
218/22	change "in large supply years, it's minimized" to "in low supply years, it's utilized"	
228/22	change "start" to	"short"
231/21	change "effluent in" to	"effluent and"
246/21	"is when it it" to	"that"
246/4	"little"	"poor"
268/2	omit "were"	

PEGGY BARROLL, VOLUME II

SIGNATURE OF WITNESS

I, PEGGY BARROLL, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

Peggy Barroll 9/26/2020

PEGGY BARROLL, VOLUME II

Job No. 65038

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, PEGGY BARROLL, to the interrogatories as indicated were made before me by the said witness after being first remotely duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. SOMACH - 02:27:02
MR. WECHSLER - 00:00:00
MR. LEININGER - 01:39:53
MR. WALLACE - 00:00:00
MS. O'BRIEN - 00:00:00
MS. BARNCASTLE - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 2nd day of September, 2020.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 04-30-22

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Houston, TX 77027
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Tab 23

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION OF
PEGGY BARROLL
OCTOBER 21, 2020

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION of PEGGY BARROLL, produced as a witness at the instance of the United States, and duly sworn, was taken in the above-styled and numbered cause on October 21, 2020, from 1:02 p.m. to 3:29 p.m, before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the offices of HEATHER L. GARZA, CSR, RPR, The Woodlands, Texas, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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VIDEOGRAPHER:

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ALSO PRESENT:
Arianne Singer
Estevan Lopez
Greg Ridgley
John D'Antonio
Erek Fuchs
Michelle Estrada-Lopez
Al Blair
Bert Cortez
Shelly Dalrymple

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WITNESS: PEGGY BARROLL

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THE VIDEOGRAPHER: The time is 1:02 p.m. We're on the record.

(The witness was sworn.)

MR. DUBOIS: Why don't we do appearances. For the United States, I am James Dubois. I am one of the attorneys for the United States, and Jennifer Najjar, Shelly Randel, and I think eventually Mr. Leininger -- yes, Lee Leininger also on for the United States, and I think that is -- oh, and Bert Cortez and Ian Ferguson. That's it. So New Mexico?

MR. WECHSLER: Jeff Wechsler for the State of New Mexico. We also have Lisa Thompson, Susan Barela, Arianne Singer, Greg Ridgley, John D'Antonio, and Shelly Dalrymple.

MR. DUBOIS: For Texas?

MS. KLAHN: Sarah Klahn for the State of Texas, and I'm joined by Stuart Somach.

MR. DUBOIS: Colorado?

MR. HARTMAN: Preston Hartman for Colorado.

MR. DUBOIS: Let's go to the amici. Is anyone on for EB -- EPCWID? Renea?

MR. HICKS: Hold on. I'm here. I didn't know Maria wasn't on.

MR. DUBOIS: I don't see her.

MR. HICKS: Okay. She just skipped out on me then. I'm here.

MR. DUBOIS: Is anybody else on?

MS. COLEMAN: Judy Coleman is on for the United States.

MR. DUBOIS: Thank you, Judy. Renea, also, Al Blair is on.

For EBID?

MS. BARNCASTLE: Yes. This is Samantha Barncastle for the Elephant Butte Irrigation District, and I'm joined by Dr. Erek Fuchs.

MR. DUBOIS: Okay. Let me see who else. I'm just sort of scanning through and seeing who's on. Is NMSU on?

(No response.)

MR. DUBOIS: No. City of El Paso?

MR. CAROOM: Doug Caroom for the City of El Paso.

MR. DUBOIS: And are there any other representatives on for any of the other amici?

(No response.)

MR. DUBOIS: Okay. I don't see any.

PEGGY BARROLL,
having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. DUBOIS:

Q. All right. Can you state your name for the record, please, Dr. Barroll?

A. Margaret Barroll.

Q. All right. Now, you've been deposed in this proceeding before once or twice or three times or possibly more so you know the basic ground rules, but I'll go over them anyway. You're under oath as if you were in a court of law. We will try not to talk over each other. Let me finish my questions, and I will try to let you -- to not interrupt your answers. If you don't understand one of my questions, please let me know, and I will try to rephrase it. Otherwise, I'll assume you understand the question. Your other communication devices such as e-mail and texts should be off, and I think that's about it.

You've been identified as a 30(b)(6) witness on behalf of New Mexico with respect to limited topics; is that right?

A. That's right.

Q. Okay.

MR. DUBOIS: Kayla, will you pull up the

-- the notice of -- of deposition?

(Exhibit No. 1 was marked.)

Q. (BY MR. DUBOIS) And, Dr. Barroll, you should have control of that. Have you seen this document before, Dr. Barroll?

A. Yeah. I've --

Q. Okay.

A. -- at least seen the one from September, which I think is the same.

MR. WECHSLER: Jim, sorry to interrupt. I would suggest making that exhibit sticker PB as in boy instead of G as in go cart.

MR. DUBOIS: Oh. Thank you for catching that.

MR. WECHSLER: Peggy, if you go all the way to the top --

MR. DUBOIS: Yes, please make that a PB, not a PG.

THE VIDEOGRAPHER: Sorry. We're fighting over it right now. Peggy, hang on one second, and I'll change it.

THE WITNESS: Thanks.

Q. (BY MR. DUBOIS) And, Dr. Barroll, if you'll go down to Pages -- I guess it would be on Page 13 for purposes of -- of your topics.

A. That's right.

Q. And my understanding is that you've been identified to -- to testify regarding Topic C?

A. That's correct.

Q. And the first bullet in Topic D; is that correct?

A. Yes.

Q. Okay. Now, are there any other topics that you've been prepared -- that you're prepared or authorized to respond to for purposes of the 30(b)(6)?

A. No, I don't think that I'm authorized to respond on any other topics.

Q. All right. And do you understand that you're testifying as if you are the voice of the State of New Mexico for purposes of this deposition so you're testifying as to the positions of the State and those positions will be binding on the State; do you understand that?

A. Yes, I do.

Q. Okay. And you also testified as an independent consultant in this case, but you're here today -- are you here today as an independent consultant or are you just speaking on behalf of the State of New Mexico?

A. I'm speaking on behalf of the State of New

Mexico.

Q. Okay. And should we understand that the -- well, let me rephrase that.

Does -- does your role as a 30(b)(6) deponent today change any of the responses that you gave at your -- your prior depositions as an expert witness in this case?

A. No, it does not.

Q. Okay. So should we understand the opinions you gave as an independent consultant are also the views of the State of New Mexico?

MR. WECHSLER: Well, I'll just object to form. Yeah, to the extent that they are on the same subject, Jim, I mean, there was a lot of subjects she covered in her deposition, and I don't know that they overlap with her designations.

MR. DUBOIS: Fair enough. Fair enough.

Q. (BY MR. DUBOIS) What did you do to prepare for the deposition today?

A. I reviewed a number of documents and I talked with the District 4 staff and I talked with counsel and some of the state engineer office lawyers.

Q. Did you review any depositions in preparing for today's deposition?

A. Yes, I did. I --

Q. Any deposition transcripts. I'm sorry.
A. Yes. I reviewed Ryan Serrano's deposition, Cheryl Thacker's deposition, and Estevan Lopez's 30(b)(6) deposition.
Q. Okay. And who did you meet with from the state -- from the state engineer's office?
A. Ryan Serrano.
Q. Okay. And what kind of documents -- oh, I'm sorry. Go ahead.
A. And also Dave Hotstef [phonetic] from Hydrographic Survey.
Q. Okay. And which counsel did you meet with?
A. Shelly Dalrymple and Jeff Wechsler.
Q. Okay. And you said you -- you reviewed a lot of -- a number of documents. Can you tell me what kind of documents you reviewed?
A. The AWRM statute and a few related statutes, the AWRM general statewide rules, the water master order -- metering order, and a few other associated administrative documents associated with the Lower Rio Grande like the Mesilla guidelines and domestic well order, 101 Settlement.
Q. Have the AWRM regulations for the Lower Rio Grande been adopted?
A. There have not been district-specific

regulations for the Lower Rio Grande that have been adopted. There is statewide framework rules and regulations which have been adopted and were succeeded in the constitution in the New Mexico Supreme Court.

Q. How are those statewide regulations applied in the Lower Rio Grande?

A. They were applied in that they help frame the role of the water master in the Lower Rio Grande. It was kind of almost simultaneously with these framework rules that we appointed the water master, but the water master of the Lower Rio Grande is in accordance with the framework rules on the metering order for the Lower Rio Grande, again, is in accordance with the framework rules, and I think the framework rules do inform the activities of the water master, which are ongoing.

Q. Under the Rio Grande Compact, what obligation does the state of New Mexico have with respect to administration of water rights downstream from Elephant Butte Reservoir?

A. My understanding from -- especially from listening to Estevan Lopez and rereading his deposition, that New Mexico's Compact responsibilities below Elephant Butte involve one cooperating with Reclamation and the Project in the effectuation of the

MR. WECHSLER: Object to form.

A. Let's -- those water rights that were existence and being exercised prior to 1980 do not have any offset requirements, and the state engineer does enforce against over diversion of those water rights. There may be other areas of enforcement that occur as to drilling new wells, transfers. I mean, there is administration of those water rights. I think the statement that there's no enforcement of -- of those water rights might be a little broad, and then furthermore, if necessary, the state engineer can administer water rights in priority to curtail water rights in priority, if necessary.

Q. (BY MR. DUBOIS) Has that ever been done in the Lower Rio Grande?

A. There certainly has not been any curtailment of groundwater rights in priority in the Lower Rio Grande.

Q. Prior to the adjudication of water rights in the Lower Rio Grande, did the state engineer have authority to administer a priority call?

MR. WECHSLER: Object to form; foundation.

A. This might be getting into a legal issue. I believe that in the tri-state decision, the New Mexico

Supreme Court may have decided that the --

Q. (BY MR. DUBOIS) That was in, what, two thousand -- that was in 2012?

A. 2003.

Q. Okay.

A. Oh, the decision was in 2012. It's -- I mean, the question did -- did the AWRM statute give the state engineer the authority to administrative priority prior to an adjudication being completed or did the state already have that -- state engineer already have that authority under the constitution, and the statute just made it more clear that the state engineer has the authority and the state engineer instructions to get at it to begin the process as necessary to do that. I think the State's position is that the state engineer, under the constitution and statute, has always had the authority to administer in priority.

Q. And how would you determine administer in priority should not have adjudication?

A. Yeah. That is -- to address that issue is part of what the AWRM statute and framework -- framework rules were written to address and in the -- the general framework rules, there's a section on how that determination would be made based on the best available information starting with adjudications and -- and going on down the list. But prior to the AWRM statute and the regs, again, I think it is the position of the State of New Mexico that the constitution gives the State to administer -- the state engineer the authority to administer in priority, and the state engineer would have indeed used the best information available to him to perform that administration.

Q. Does the State of New Mexico have any policies or administrative practices in place to ensure that non-project water rights in the Rio Grande basin below Elephant -- in New Mexico below Elephant Butte do not reduce or diminish the surface water supply available to EBID?

MR. WECHSLER: Object to form.

A. The State of New Mexico has policies and administrative practices in place to manage non-project water rights in the Rio Grande basin below Elephant Butte. The purpose of that administration is to protect senior water rights and the Rio Grande Project.

Q. (BY MR. DUBOIS) Have those policies or administrative practices ever been applied or enforced to prevent reduction or diminishment of the surface

water supply to the project?

MR. WECHSLER: Object to form.

A. There has been no priority administration applied in the Lower Rio Grande to curtail water rights that might impact the Rio Grande Project, but there is, again, no -- New Mexico did not have an obligation to prevent all depletions. New Mexico has a right -- water users in the state of New Mexico have a right to deplete water.

Q. (BY MR. DUBOIS) Did they have a right under state law to take water away from the project?

MR. WECHSLER: Object to form.

A. Water users are -- water users in New Mexico cannot divert water that they're not entitled to and so that water users who do not have legal authority cannot divert surface water away from the Rio Grande project if groundwater use is impacting the Rio Grande project, then it would be necessary to, I believe, New Mexico would have to -- sorry. Groundwater use depleting the project were alleged, it would have to be investigated and demonstrated. Groundwater depletions negatively impacting the project demonstrated the New Mexico remedied the priority administration, but this has not occurred.

Q. (BY MR. DUBOIS) There hasn't been any

investigation that demonstrates that groundwater pumping in New Mexico depletes the flows of the Rio Grande?

MR. WECHSLER: Object to form.

A. Which investigate and quantify, simulate the impact of groundwater pumping on surface water flows.

Q. (BY MR. DUBOIS) I think -- I think you and Jeff spoke at the same time, and I think the response, looking at the transcript, missed the first part of your answer.

A. There have been investigations in New Mexico which quantity, investigate, simulate the impact of groundwater pumping on surface water flows. In fact, some of those investigations have been done as part of this litigation by New Mexico experts.

Q. Okay.

A. And then simulations of the sort was involved in development of the groundwater model used for administration of groundwater rights in the Lower Rio Grande.

Q. And I think that you just said that if those investigations demonstrated groundwater depletions negatively impacting the project, that the -- that New Mexico would be required to apply priority administration; is that my understanding?

MR. WECHSLER: Object to form.
A. I -- I don't think that's what I said. I said if --
Q. (BY MR. DUBOIS) Okay.
A. -- negative impacts were alleged, and by this, I mean through, say, a priority call or other official complaint alleged and then investigation demonstrated, in fact, that this indeed was a problem, that the depletions occurring from groundwater pump -- pumping were impairing the project, then New Mexico's remedy would be priority administration.
Q. And does New Mexico have any obligations under the Compact to assure that its non-project water rights don't deplete the project water supply?
MR. WECHSLER: Object to form.
A. So I -- I guess I base my answer on the opinions that Mr. Lopez prefer -- proffered and that that might be the case and that it's -- so, again, New Mexico is obligated to work in good faith with the Compacting states, with the U.S., with the project resolve issues that are brought to it -- that are brought to New Mexico about the actions -- about the actions of New Mexico water users or the hydrologic conditions within New Mexico.
Q. (BY MR. DUBOIS) I'm trying to avoid

scheme for administering water rights?

MR. WECHSLER: Object to form.

A. Yes. I believe that it would be possible for another group of water users to organize and come up with an alternative administration scheme, which if acceptable to the state engineer, could be approved as alternative administration.

Q. (BY MS. KLAHN) Would that be under the AWRM statute?

A. Yeah. Yes, it would.

Q. And that was an effort that was begun maybe ten years ago or 15 years ago, not long after the AWRM statute was adopted down in the Lower Rio Grande, right?

A. What do you mean, what -- what effort?

Q. That wasn't a very com -- understandable question. I apologize. I'm remembering a PowerPoint that you did for the Lower Rio Grande water users group from 2006 about 15 years ago was when the state was looking at adopting local AWRM regulations; is that correct?

A. That's correct. So you're right. Shortly after the passage of the AWRM statute and -- and the promulgation of the AWRM general framework regs, we did do a push to try and get district-specific rules in place in the Lower Rio Grande but that did not come to fruition.

MS. KLAHN: Kayla, I e-mailed you an -- an exhibit that was marked in the Thacker deposition. Could you pull that up.

THE VIDEOGRAPHER: Okay. It's pulled up. I'm just going to mark it now.

MS. KLAHN: Thank you.

(Exhibit No. 4 was marked.)

MS. KLAHN: So this is going to be Barroll 3 -- 4, right?

THE WITNESS: 4.

Q. (BY MS. KLAHN) Could you turn in this document back to -- the document is Bates numbered, and it -- you're welcome to take a look at it. It's a packet of material we received from New Mexico in discovery. It's Bates numbered, and it starts out with while metering requirements. But if you go back to New Mexico No. 210807, there's objectives -- list of objectives. I don't know if you can hear my dogs. I apologize. They're keeping us safe from the mailman.

A. 807. Okay. Let me see if I can rotate this sucker. I rotated it. Okay. So Objectives for Lower Rio Grande District-Specific Regulations.

Q. So I want to draw your attention to Letter H. We've talked a lot today about administration and how it works with the Compact and -- Letter H on 210807 says that one of the objectives for Lower Rio Grande District-Specific Regulations is to establish a system for administration as required to meet downstream interstate delivery entitlements.

A. Yes.

Q. Do you have an understanding what that objective was aiming for?

A. My recollection is that at this time, I'm uncertain as to whether there was a down -- any Compact constraints or requirements below Elephant Butte due to the language of the Compact being silent or -- or, rather, at least not specifying -- sorry -- not specifying delivery targets below Elephant Butte. So -- but we thought that that was possible to occur and also thought, I think at the time we were trying to be proactive, and we were trying to estimate what a reasonable downstream delivery would be based on the knowledge we had at the time and come up with an administrative scheme that would allow us to try and meet that.

Q. If the -- are you familiar with the draft district-specific regulations, what the concept was

behind them?

A. Yes.

Q. Was it to drill groundwater wells within a certain distance from the river?

A. In those rules, we did have -- we did introduce a new administration scheme or propose a new administration scheme, supply administration, and I believe that was for a short-term temporary curtailment of wells that were close to the river.

Q. And what --

A. In order to support the Rio Grande Project.

Q. And what was the reason for that approximate -- or for that distance from the river for making them based on the distance from the river?

A. Because wells that are a significant distance from the river would not provide any effect on the river within the short periods of time we were thinking about the temporary administration.

Q. But the wells that are distant from the river are still depleting the river, just taking longer for the effect to hit the river, right?

A. Yes. This was a short-term administration and, therefore, we were focused on wells that would give a short-term response to the river.

Q. Was there any talk of curtailing or maybe not

entirely curtailing, but some curtailment of municipal and irrigation wells -- I'm sorry -- municipal and industrial wells?

A. Yes.

Q. For the City of Las Cruces?

A. I believe that some of their wells would have fallen within that zone near the river for supply administration and then, of course, the AWRM framework rules also provide for depletion limit administration and there was no restrictions on distance from the river that were considered for the application depletion limit administration.

Q. There was quite a bit of discussion at the beginning of your deposition about the New Mexico administration policies -- administrative policies to avoid depleting EBID's surface water from what Mr. Dubois was terming as non-project water rights. Do you recall that?

A. Yes.

Q. Would you consider EBID farmers holding groundwater rights to have non-project groundwater rights?

MR. WECHSLER: Object to form.

A. Well, in that discussion, I assumed that Mr. Dubois regarded EBID farmer pumping as not being included in the non-project groundwater rights.

Q. (BY MS. KLAHN) I know. I'm -- that's -- okay. That's fine, but that's not what I was asking. I was just asking the question what do you consider non-project water rights in the Lower Rio Grande?

A. Well --

MR. WECHSLER: Form.

A. Yeah. It's -- I mean, the project itself doesn't have groundwater rights, but I regard the EBID farmers that are pumping wells as part of a combined right with an EBID surface water right, I would consider that as in the -- in the broader sense within the universe of -- of project-related water rights. I wouldn't consider them in the category of non-project water rights.

Q. (BY MS. KLAHN) So in terms of New Mexico's views on administering the Lower Rio Grande, you don't consider curtailment of the EBID farmers as a means to avoid depletions to the Rio Grande?

MR. WECHSLER: Object to form.

A. Well, I do not think that EBID farm pumpers would be exempt from priority administration.

Q. (BY MS. KLAHN) Is conjunctive use one of the policies that the State of New Mexico relies on in the Lower Rio Grande?

S I G N A T U R E O F W I T N E S S

I, PEGGY BARROLL, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

____

PEGGY BARROLL

Job No. 65834

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, PEGGY BARROLL, to the interrogatories as indicated were made before me by the said witness after being first duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. DUBOIS - 01:16:41
MR. WECHSLER - 00:00:00
MS. KLAHN - 00:45:07
MR. HARTMAN - 00:00:00
MR. HICKS - 00:11:48
MS. BARNCASTLE - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, this, the 31st day of October, 2020.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 04-30-22

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Tab 24

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS,	§	
	§	
Plaintiff,	§	
	§	
vs.	§	ORIGINAL ACTION
	§	CASE NO.: 220141
STATE OF NEW MEXICO,	§	(ORIGINAL 141)
and STATE OF COLORADO,	§	
	§	
Defendants.	§	

****
REMOTE VIDEOCONFERENCED DEPOSITION OF
GARY ESSLINGER
AUGUST 18, 2020
****

Job No. 63595

REMOTE VIDEOCONFERENCED DEPOSITION OF GARY ESSLINGER, produced as a witness at the instance of Defendant State of New Mexico, and remotely duly sworn by agreement of all counsel, was taken in the above-styled and numbered cause on August 18, 2020, from 9:02 a.m. to 3:16 p.m. before Karen L. D. Schoeve, RDR, CRR, reported remotely by computerized machine shorthand, pursuant to Section 5.4 of Appendix C of the September 6, 2018 Case Management Plan, as amended (CMP) and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

This deposition is being conducted remotely regarding the COVID-19 State of Disaster status of the world.

REPORTER'S NOTE: All exhibits presented to the court reporter prior to the deposition were not used; only the referenced exhibit numbers were used during the deposition.

Please note that due to the quality of a Zoom videoconference and transmission of data and overspeaking causes audio distortion which disrupts the process of preparing a videoconference transcript.

Quotation marks are used for clarity and do not necessarily reflect a direct quote.

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Susan Barela
Jordan Brown, Videographer

THE COURT REPORTER:
Karen L. D. Schoeve
Certified Realtime Reporter
Registered Diplomate Reporter
Realtime Systems Administrator

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Elephant Butte Irrigation District Policy 2012-GW1
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Fax from Law Office of Steven Hernandez, dated 04/05/11 to Governor Martinez from Samantha Barncastle
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Email thread dated 08/11/11 to Filberto Cortez, et al. from Al Blair
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News Article titled State Sues To Block Water Release, dated 08/09/11
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Exhibit GE-54 170
Email thread dated 04/24/12 to Mike Hamman, et al. from Gary Esslinger
Subject: River pumpers
Bates stamped US0588975 - 588976
Highly Confidential

Exhibit GE-55 172
Elephant Butte Irrigation District Letter dated 05/24/13 to Mike Hamman from Gary Esslinger
Subject: O&M Budget for the Rio Grande Project 2014
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United States Department of the Interior Letter dated 05/01/14 to Gary Esslinger from Linda Weiss
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P R O C E E D I N G S

THE VIDEOGRAPHER: The time is 9:02 a.m. We're on the record.

MR. WECHSLER: Good morning, Mr. Esslinger.

THE WITNESS: Good morning.

MR. WECHSLER: I'll just remind you that you're still under oath and that the rules we talked about yesterday still apply.

Do you understand that?

THE WITNESS: Yes, sir, I do.

MR. WECHSLER: Let's go ahead and take appearances.

MR. WECHSLER: This is Jeff Wechsler on behalf of the State of New Mexico.

We also have Aryian Singer, Shelly Dalrymple, Susan Barela, and that looks like it for now.

How about for the State of Texas?

MS. KLAHN: The State of Texas, this is Sarah Klahn. It looks like I'm riding solo today. I don't see anybody else.

MR. WECHSLER: And the United States?

MR. TUSTIN: John Tustin for the United States.

And I believe we have Filberto Cortez with us from Reclamation as well.

MR. WECHSLER: Good morning.

For the State of Colorado?

MR. WALLACE: Good morning.

This is Chad Wallace for Colorado.

MR. WECHSLER: Good morning.

EBID?

MS. BARNCASTLE: Good morning.

This is Samantha Barncastle for EBID and I believe we have Dr. King with us and Dr. Fuchs will join us soon.

MR. WECHSLER: For EP#1?

MS. O'BRIEN: Good morning.

Maria O'Brien for El Paso County Water Improvement District Number 1, and I am the only one on at this point. Jesus Reyes may join us in a little bit.

And for the court reporter, that will show up as a 915 number. It's a conference room in El Paso at the District.

MR. WECHSLER: Thank you.

For the Pecan Growers?

MS. DAVIDSON: Good morning.

Tessa Davidson on behalf of New Mexico

Pecan Growers.

MR. WECHSLER: For ABCWUA?

MR. BROCKMANN: Good morning.

It's Jim Brockmann on behalf of the Water Authority and also City of Las Cruces.

MR. WECHSLER: For New Mexico State University?

MR. UTTON: Good morning.

This is John Utton for NMSU.

MR. WECHSLER: Do we have anyone for Hudspeth or the City of El Paso?

(No response.)

MR. WECHSLER: All right. Let's go ahead and get started.

MR. TUSTIN: Before we begin, I'm sorry, this is John Tustin.

Chris Rich from the Solicitor's office at the Department of Interior also is on with us today.

MR. WECHSLER: Great. Thank you.

GARY ESSLINGER,

having been previously sworn to tell the truth, the whole truth, and nothing but the truth, so help him God, testified further:

EXAMINATION

BY MR. WECHSLER:

Q. All right, Mr. Esslinger. Let's get started. I have a whole number of documents that I'm hoping to look at with you today. And I'll try and move fairly quickly through those.

The first thing I want to talk to you about a little bit is the water rights that the District uses or that individuals within the District are using. Yesterday we discussed the adjudication orders from the New Mexico adjudication.

Do you recall that discussion?

A. Yes, sir, I do.

(Deposition Exhibit GE-06 marked for identification.)

Q. (BY MR. WECHSLER) And I want to understand something, again, from your Elephant Butte motion, which is Exhibit 6. So if you will go to GE-06, and at this time, I'm looking at .pdf page 36.

A. (Examined exhibit.)

Q. Do you have that before you?

A. It's Number 23, page 23?

Q. Page 36 of 52. And oh, yes, you're

correct. The page of the motion is 23 at the top.
So just below the indented language there, that's where I'm looking. And here we see that EBID wrote that "Therefore the surface water users in New Mexico who received Project water deliveries for irrigation of their lands possess the beneficial interest in the project's water rights and EBID represents those New Mexico water users."
Do you see that?
A. I'm trying to find it. This is quotes from the State of Nevada versus United States.
Q. It's just below the indented quote.
A. (Examined exhibit.) I see it now. I'm sorry. I was looking at the indented quote.
Q. My question is: Is it your understanding that the beneficial interest to the water rights is actually held by the farmers themselves?
A. Yes.
Q. And many of those farmers also hold water rights from the State of New Mexico; is that right?
A. In the form of groundwater rights.
Q. That's what I'm referring to. You're aware of that?
A. Yes.
Q. Does the EBID track the number of EBID

members that have groundwater permits?

A. No. We don't have any system of tracking. We try to work with the District office in Las Cruces to understand. And when land is sold and transferred, we work closely with them to make sure that new owners have access to those wells and groundwater and surface water.

Q. Turning to the water rights for the District itself, have the -- any rights been adjudicated to the District in the New Mexico adjudication?

A. I believe there were some groundwater rights adjudicated to the District.

Q. And we'll look at those in a moment.

Have any surface water rights, right to divert water, been adjudicated to the District yet?

A. I don't believe so.

Q. Do you recall there being an offer of judgment from the New Mexico State Engineer?

A. I recall the offer but not the specifics of it.

Q. And there also are some documents that the District itself has submitted to the State Engineer as part of the adjudication process. Are you aware

of that?

A. Yes, I'm aware of those documents.

Q. Let's look at some of the documents related to, first, the District's groundwater right.

And I'm gonna mark Deposition Exhibit 17.

(Deposition Exhibit GE-17 marked for identification.)

Q. (BY MR. WECHSLER) Do you recognize this document?

A. (Examined exhibit.) I've seen it before but not fluently recognizing all of what's in it.

Q. We can see the title is the New Mexico -- it's an Emergency Application For Permit to Use Supplemental Wells to Supplement Ground Or Surface Waters and it's being filed by the Elephant Butte Irrigation District; is that right?

A. Yes.

Q. And the contact lists you as one of the contacts?

A. Yes.

Q. The other person is Mr. Salopek who was the president. Is he still the president of EBID?

A. No, sir. He's not.

Q. Is he still on the board?

A. Yes, sir, he is.
Q. If you can turn to page 6, .pdf page 6 of this document, and you should see at the top an affidavit of Jim Salopek, president of Elephant Butte Irrigation District.
Do you see that?
A. Yes.
Q. So I just showed you that page for reference. A couple paragraphs I want to ask you about. The first is page 7, .pdf page 7, paragraph 7, and we don't need to read that paragraph into the record. This document will be part of the record. But this is consistent with your testimony of yesterday about groundwater pumping in EBID during the drought in the '40s and '50s; is that right?
A. Yes.
Q. We can see in the second sentence there Mr. Salopek is saying that during that drought, the United States Bureau of Reclamation encouraged EBID's constituent farmers to supplement their project surface water supply by drilling irrigation wells.
Do you see that?
A. Yes, sir, I do.
Q. Is that your understanding?

the solar battery's low or whatever. But that's the meter that we're describing we would like to see on all wells in the Lower Rio Grande.

Q. Page 29.

A. Let me rephrase. I said all wells, all agricultural wells. I don't know what the city or the mutual domestics use.

Go to which page, sir?

Q. Page 29. This says -- the heading is Well Meter Applications - Coordinated Well Metering and we can see you're identifying five different groups. What is this slide illustrating?

A. When we went out to do our ground truthing to develop how we were going to adhere to the metering order. We did a study with the hydrology department of finding out which wells were being metered at the time and which wells didn't have meters at all but had a direct discharge into our facility.

We found wells that were metered and they had an indirect charge into EBID, maybe through a private ditch that would come back in our system and then there were groups of wells that had no meters and no indirect discharges into facilities. And then it was obviously Group 5, which they don't even come close to getting into our canal system.

Q. And then what's meant in this slide? And we talked about a similar slide before, but what's meant here about coordinated well metering?

A. That meant that if there was a coordination between the EBID facility and the well, then that's what it was described here, like Group 1, whereas Group 4 was not coordinated because it didn't have anything to do with our canal system.

Q. Let's look at another exhibit. This one I'll mark as Deposition Exhibit 32.

(Deposition Exhibit GE-32 marked for identification.)

Q. (BY MR. WECHSLER) You should have a new exhibit.

Do you recognize Deposition Exhibit 32?

A. Yes, I do.

Q. What is it?

A. It's a report from Kirby Engineering to me regarding return flow from the Rio Grande Project.

Q. Do you recall why you were receiving this report?

A. A little -- just a brief history. When I became manager in 1988, the board recommended that

Jim Kirby, who was project superintendent of the Lower Rio Grande -- the project superintendent of the Rio Grande Project for 35 years, he was then at that time a consultant brought on by our board.

And so for one year, I traveled around in a pickup learning everything there was I could learn from him about the Rio Grande Project. And probably sometime five years later there was a question about return flows and that's where he gave me this report.

Q. Is that your signature in the upper right-hand corner?

A. No.

Q. In that first page, he says "Other waters entering the bed of the Rio Grande below Caballo Dam and above Riverside Heading also constitute Project water under the jurisdictions and belonging to the Rio Grande Project. These waters include return flows from the project's drainage system, storm waters from natural or engineered sources, sewage effluent, industrial effluent and any other water not mentioned above which reaches the Rio Grande below Caballo Dam and above Riverside Dam."

Do you agree that all of these waters form a part of Project supply?

A. Yes. If it hits the bed of the river.

Q. And he emphasizes that, which you just did, that says waters -- and he underlines entering the bed of the Rio Grande. And why is it important that those flows enter the bed of the river?

A. Because that's the only way that that water can leave this Valley and go into the next Valley. It's the system, the natural system of any river.

So you need a way to discharge it and return water to the river so that the water in the river could go further down to either serve another demand or be wasted if it's so much of flow, like a flood flow, that you can't use it anyway. So the river is the means of getting flood flows, return flows, storm water, sewage effluent, industrial effluent all back to the river to go on downstream.

Q. Does that mean that those flows that do not enter the bed of the Rio Grande are not a part of project supply?

A. I don't have the transcript. Can you repeat the question?

MS. BARNCASTLE: I'll object to foundation, too.

Q. (BY MR. WECHSLER) My question,

Mr. Esslinger, was those flows that do not enter the bed of the Rio Grande, does that mean that those flows are not part of Project supply?

MS. BARNCASTLE: And objection; form.

A. I would say that those flows that don't hit the bed of the Rio Grande eventually get there. It could be a flood flow that floods a parcel of land that is a mile away from the river. Well, that floodwater's gonna have to go someplace, so it may just go into the groundwater, which is recharged; and that recharge then eventually gets to the river at some point, and then it becomes Project water.

That's the example I can give you there. That's the only one that comes to mind.

Q. (BY MR. WECHSLER) So it becomes Project water once it hits the river, in your example?

A. Yes.

Q. In that example, the way that water could get there is that it sits in that field and it's -- some of that water's evaporated, some of it goes to the plant. The rest goes into the ground. When it goes in the ground, there's probably a drain system nearby. The drain picks it up and takes it to the river.

The timing of all that, I could not

tell you when it happens. But eventually all the water that comes off of any tributary flow somehow, some way will get to the river eventually, in some form or fashion. I'm not a hydrologist.

Q. Understood.

Somewhere within the documents, we may have a chance to look at it if we have time today. The Bureau was answering a question from the EBID about flood flows and EBID was asking: Are we allowed to capture these flood flows or are they Project supply? And the answer was -- I think similar to yours -- and that was that EBID was allowed to capture flood flows, arroyo flows, because they didn't become project flows until they hit the bed of the river.

Do you recall that?

A. Yeah. I think that's something mentioned in the Operating Agreement as well because this Valley is still very susceptible to flooding and it's vulnerable to flash floods that are devastating and could cause loss of life, to that respect.

And so trying to manage flood flows through a system that has irrigation water in it, it becomes -- it becomes a hot potato, let me tell you. And so I had to know what I could do with this flood

CHANGES AND SIGNATURE

WITNESS NAME: GARY ESSLINGER

DATE: AUGUST 18, 2020

PAGE/LINE		CHANGE	REASON
19	11	New Mexico	Not Nevada
30	24	Management	Not Manager
42	7	The river	Not the aquifer
42	13	earthen lined	Not lime
42	19	earthen lined	Not lime
46	21	Hubert	Not Coubert
63	15	prefer	Not refer
66	24	early	Not area
73	19	dams	Not depths
74	7	button	Not area
97	13	Fuel	Not Field
98	21	discharge	Not charge
102	18-25	part of my answer	not part of my question
103	1-4	part of my answer	not part of my question
116	18-19	"offset withdraws with purchase"	his question not mine
139	13	plan	Not Plant
140	18	Service	Not surface
140	19	PSB	Not PSV
142	15	Board	Not Award
149	2	Union	Not Inyon
155	2	Plan	Not Plant

CHANGES AND SIGNATURE

WITNESS NAME: GARY ESSLINGER

DATE: AUGUST 18, 2020

PAGE/LINE		CHANGE	REASON
160	10-23	This is a question not an answer	
164	18	add study	replace zoom cut-out
169	14	everything answer yes then starts question	Dr. King... is not my answer

I, GARY ESSLINGER, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction pages(s).

GARY ESSLINGER

Subscribed and sworn to before me this 5th day of October 2020 by Gary L. Esslinger

State of New Mexico
Dona Ana County

Notary Public

My commission expires 12/20/2022

Job No. 63595

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS, §
§
Plaintiff, §
§
vs. § ORIGINAL ACTION
§ CASE NO.: 220141
STATE OF NEW MEXICO, § (ORIGINAL 141)
and STATE OF COLORADO, §
§
Defendants. §

****

REPORTER'S CERTIFICATE
REMOTE VIDEOCONFERENCED DEPOSITION OF
GARY ESSLINGER
AUGUST 18, 2020

****

I, Karen L. D. Schoeve, Registered Diplomate Reporter, Certified Realtime Reporter, and Realtime Systems Administrator, residing in the State of Texas, do hereby certify that the foregoing proceedings were reported by me and that the foregoing transcript constitutes a full, true, and correct transcription of my stenographic notes, to the best of my ability and hereby certify to the following:

That the witness, GARY ESSLINGER, was duly remotely sworn by the officer and that the transcript of the oral deposition is a true record of the testimony given by the witness;

I further certify that I am neither counsel for, related to, nor employed by any of the parties in the action in which this proceeding was taken, and further that I am not financially or otherwise interested in the outcome of the action.

That the amount of time used by each party at the deposition is as follows:

JEFFREY WECHSLER - 04:21
SAMANTHA BARNCASTLE - 00:00
SARAH A. KLAHN - 00:02
CHAD WALLACE - 00:00
R. LEE LEININGER - 00:00
MARIA O'BRIEN - 00:00
SAMANTHA BARNCASTLE - 00:00
JAMES C. BROCKMANN - 00:00
TESSA T. DAVIDSON 00:00
JOHN W. UTTON 00:00

Subscribed and sworn to on this the 18th day of August, 2020.

Karen L.D. Schoeve

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Job No. 63595

Tab 25

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Tab 26

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****

ORAL DEPOSITION OF
JORGE GARCIA
FEBRUARY 6, 2019

****

ORAL DEPOSITION of JORGE GARCIA, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on February 6, 2019, from 9:34 a.m. to 11:59 a.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the offices of LAS CRUCES UTILITIES, 680 North Motel Boulevard, Las Cruces, New Mexico, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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ALSO PRESENT:

Mr. Phil King
Mr. Ryan Serrano
Ms. Cheryl Thacker
Ms. Rhonda Diaz

EXAMINATION INDEX

WITNESS: JORGE GARCIA

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SIGNATURE REQUESTED 79

REPORTER'S CERTIFICATION 80

JORGE GARCIA,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MS. KLAHN:

Q. Good morning, Dr. Garcia.

A. Good morning.

Q. My name is Sarah Klahn. I represent the State of Texas. Could you state your name for the record and spell it, please?

A. Jorge Garcia, J-O-R-G-E, G-A-R-C-I-A.

Q. And your work address?

A. Utility Center, 680 Motel Boulevard, Las Cruces, New Mexico.

Q. What's your position with the City of Las Cruces?

A. Director of utilities.

Q. Have you had your deposition taken before?

A. Yes.

Q. In what matters?

A. Litigation with another water company.

Q. How long ago was that?

A. Maybe four or five years. I don't know.

Q. Okay. Before that, had you had your deposition taken?

A. Not before those cases.

Q. Okay. So you know you need to speak clearly and not nod your head?
A. Yes. Yes and no, yeah.
Q. And if you have a question that you don't understand -- if I ask a question you don't understand, please ask me to clarify.
A. Yes.
Q. If there's a question pending on the table, you cannot consult with your lawyer, but as soon as you answer the question, we can certainly take a break. Okay? And if you need a break at any time, let me know.
A. Okay. Thank you.
Q. How long have you been the director of utilities here?
A. Since the spring of 2001.
Q. Where did you work before that?
A. In the city. Here in the city utility.
Q. Also in the utility?
A. Yes.
Q. So how long have you been with the City of Las Cruces Utilities Department in any capacity?
A. Approximately 29 years.
Q. Where did you go to college?
A. Utah State University.

Q. And did you get your -- which degree did you get at Utah State?
A. All of them.
Q. What's your area of specialty?
A. I have graduate degrees in civil engineering, undergraduate degree in agriculture and irrigation engineering.
Q. Have you ever managed an irrigation system?
A. No.
Q. Other than your work with the City of Las Cruces, what other work have you done either professionally or academically that was water rights related?
A. I worked about almost five years in academia, but it was not water rights related. Also research engineer at Utah State University while working on my doctorate.
Q. What was your thesis on for your PhD?
A. It was dealt with the calibration -- search techniques and parameter estimators in the calibration of computer models.
Q. Computer modelling of what?
A. Rainfall runoff models.
Q. Was there a particular area of the country or the world that you were studying rainfall models?

A. No. We were evaluating search techniques for calibration with data and prior calibrations of the Stanford Watershed Model.

Q. Okay. What was your role in the 40-year plan that we were talking about with Ms. Widmer yesterday?

A. I was certainly involved in the scoping of the plan with a consultant and then review -- review of the document of the various drafts of the document. I was also involved in submitting the drafts to the utility board and get their comment and input, et cetera.

Q. What is the effect -- the policy effect of this 40-year plan on the utility department?

MR. STEIN: Could people speak up just a little?

MS. KLAHN: Oh, I'm sorry.

MR. STEIN: That's all right.

Q. (BY MS. KLAHN) What is the policy effect of the 40-year plan in the utility department?

A. One of the -- one policy change -- obviously the -- the 40-year water plan is a planning document for our water resources, our water supply. One of the policy changes was the shift from -- from a potential surface water source to some other alternative source.

MS. KLAHN: Before I follow up on that

question, for people on the phone, the microphone is incredibly sensitive, and we can literally hear if you move in your chair, so I'd recommend you putting it on mute because it's -- it sounds kind of funny in here. We're not sure what you're doing.

Q. (BY MS. KLAHN) So one of the policy changes you said was the shift from potential surface water source to some other alternative source?

A. Yes.

Q. And that shift that you're talking about was -- does that relate to the city's -- to a decision by the city not to pursue surface water as an alternate source?

A. Yes.

Q. In any form?

A. Yes.

Q. So currently, the city owns -- so -- and I'm going to ask a few questions now about the surface water sources that I believe you do own or operate. What -- what is the status of the city's efforts to acquire new leases or new purchases of water righted lands in EBID?

A. I don't believe we have acquired any lands in the last few years.

Q. Okay.

A. Or water -- or surface water rights.
Q. Okay. And then of the lands that you have acquired, what are you planning to do with those?
A. For now --
Q. Do you have a plan?
A. -- we're holding up to them and we pay the tax to the district. We're not getting rid of those rights, but we certainly have not acquired any more.
Q. And the reason for -- can you talk a little bit about the reasons why you've decided to abandon surface water as an alternate source?
A. There's no water in the river.
Q. Hard to capitalize water plan on 3 inches a year?
A. That's correct.
Q. Okay. So as far as the city's current groundwater supplies, as the utility director, how do you envision the city growing into the current groundwater supplies that it has? As I understand it, there's an expectation the city will have 150,000 people by, what, in 30 or 40 years?
A. Yes. The -- the 40-year water plan, I believe, has high, medium, and low projections. We've had very high growth in the 2006, '7, '8, and then it slowed down so, you know, that's why we have a range

of scenarios of growth. But -- but, yes, the intent is to continue to plan and use those resources as water rights that we currently have for -- for the growth of the city and the growth of the customer base.

Q. Now, yesterday when we were talking with Ms. Widmer, she testified that there were some wells in which you've seen water level declines to the extent the existing -- let's talk about LRG-430 for a moment. To the -- if I use the term LRG-430, do you know what I mean?

A. Yes.

Q. Okay. So the wells that are permitted for use and allowed -- legally allowed to be used under LRG-430, to the extent that you experience water level declines in those wells, what source would you envision going to next to replace the supply that isn't available from LRG-430 in the future?

MR. STEIN: Objection as to lack of foundation. He hasn't testified that they would be necessary to go to a different source because of the declines.

Q. (BY MS. KLAHN) Well, let's start there. Given that there are concerns apparently valley wide and that the city has seen declines in water levels, do you have a concern about the sufficiency of the supply under the LRG-430 wells?

A. Not in the short term.

Q. And how long is the short term?

A. We're -- we're looking at -- I haven't read the 2017 report, which is the last one that -- that we did on the groundwater monitoring report. We're talking about drops of between -- and I -- and I'm -- I'm just giving you a range of numbers. I'm not -- 1.2 feet to 2-and-a-half feet per year on a 900-foot well. So --

Q. So that doesn't cause you concern professionally?

A. Well, I'm concerned of the trend is a concern, not the order of magnitude at this time. I think we all need to have a better understanding as to what the long-term order of magnitude will be. I'm talking about 40, 50, 60, a hundred years.

Q. Sure. Okay. So the -- yesterday, we talked about the -- I think there are other sources of groundwater that the city has available to it. Have you explored the use yet of any of the brackish groundwater supplies that may be available?

A. No, not yet.

Q. Is that something the city is considering?

consumptively use that amount of water." And my question was: Even if that pumping depletes the Rio Grande?

A. Again, my answer is yes, because I don't believe it depletes the Rio Grande. It is connected -- it's a river-connected aquifer, but I don't believe our pumping has depleting effects.

Q. Well, then why --

A. On the river that are sizable.

Q. Then why does the priority date matter? This sentence says, "The city's priority date of 1905, quote, provides it with the right to affect surface flows of the Rio Grande." We're talking about groundwater rights. So why does the priority date matter?

A. The priority date matters because if you had a priority call under state law, then having an early priority would give you some more flexibility, let's say, and be able to continue to pump.

Q. If the -- if the two sources aren't connected, the priority date shouldn't make any darn difference. There would never be a basis, a factual basis for any administration against the wells if they're not connected. Wouldn't you agree?

MR. STEIN: Objection as to vague and

ambiguous. Are you talking about -- are you saying that there's no connection here in this circumstance? Is that your hypothetical now? Are you --

MS. KLAHN: Mr. -- Dr. Garcia's answer was the priority date matters because if you had a priority call under state law, then having an early priority would give you more flexibility, let's say, and be able to continue to pump. My question was if the two sources aren't connected, the priority date shouldn't make any darn difference, because there would never be a basis -- factual basis to administer against the wells.

Q. (BY MS. KLAHN) The state isn't going to go administer wells up on the East Mesa that aren't connected to the river, so is that your testimony that the wells that the city pumps under LRG-430 are not connected to the Rio Grande?

A. No, that's not -- that's not my testimony.

MR. STEIN: Counsel, you're raising questions that are very complicated --

MS. KLAHN: Please don't interrupt.

MR. STEIN: -- that have different -- wells that have different depths, different levels of connection, that affect the river or may not affect the river under different flow conditions.

MS. KLAHN: This gentleman has a PhD in civil engineering. He's perfectly capable of conditioning his answer in any way he believes is necessary. Mr. Stein, stop it.

MR. STEIN: Please ask questions that are specific and precise that he can answer.

MS. KLAHN: I'll ask any question I want, and if I don't get a good answer, that's my problem, not yours.

MR. STEIN: The questions are frequently confusing, Counsel.

MS. KLAHN: For you.

MR. STEIN: Yes, they are. Absolutely.

Q. (BY MS. KLAHN) Dr. Garcia, I assume your counsel would like you to not answer this question, but I would really like you to answer this question. Is it your testimony that the wells that the city pumps under LRG-430 are not connected to the Rio Grande?

A. No. They are connected to the Rio Grande. They are in the same aquifer. They are deeper wells, so if there's any effects on the actual stream flow, you could argue that the -- the effects would be either delayed effects or -- or, you know, it depends how deep the wells are, too.

Q. I understand. But they are connected so pumping --
A. It's the same aquifer, yes.
Q. It's the same aquifer?
A. Yes. It's the same aquifer.
Q. So pumping an LRG-430 well causes depletions to the Rio Grande in some way, shape, or form?
MR. STEIN: Objection; assumes facts that are not in evidence and does not characterize his testimony, conclusion of Counsel's.
MS. KLAHN: The testimony was --
MR. STEIN: Talking about a connection. He did not talk about depletion.
MS. KLAHN: -- it's the same aquifer -- if it's the same aquifer --
MR. STEIN: You haven't accounted for returns.
MS. KLAHN: If it's the same aquifer --
MR. STEIN: You haven't accounted for returns.
MS. KLAHN: When you take his deposition, you can ask the questions any way you want to. Until then, let me ask the questions. Stop it. This is extremely unprofessional.
MR. STEIN: I don't think so.

MS. KLAHN: It's not necessary.
MR. STEIN: I think your questions are vague and ambiguous. They -- they assume facts that are not in evidence.
MS. KLAHN: I know what you think.
MR. STEIN: They mischaracterize testimony on occasion.
MS. KLAHN: I'm reading from the testimony, and I'll go back and ask the question again.
Q. (BY MS. KLAHN) Your testimony, Dr. Garcia, was that the wells in LRG-430 in the Rio Grande are part of the same aquifer -- connected to the same aquifer, correct?
A. Yes.
Q. And your testimony was that pumping from the LRG-430 wells will cause an impact on the river. You said that earlier?
A. Uh-huh.
Q. And your counsel's concern, and let's talk about this right now, is that the impacts that come from LRG-430 pumping could be, possibly, might hypothetically be offset by the returns of water that the city does not consume; is that accurate?
A. That's correct.

Q. Have you quantified the returns associated with the LRG-430 pumping?
A. We -- we do quantify their return from the plan to the river.
Q. The Jacob hands plan?
A. Yes.
Q. Okay. And when you say you quantify, you have a meter on that discharge?
A. Correct.
Q. Okay. And the majority, if not all of the water from LRG-430 is treated at the hands plant, correct?
A. That's correct.
Q. Okay. In addition, other -- the city treats wastewater from other providers, doesn't it?
A. That's correct.
Q. At the hands plant?
A. Yes.
Q. Okay. So some of the water coming out of the hands plant is attributable to LRG-430, but not all of it?
A. The majority is, but there's other small water systems that add to it.
Q. Okay. And I read that in the 40-year plan, that you are a wastewater provider for other entities.

Based on your quantification of the discharges from the hand plant, do you have an understanding of how much of the LRG-430 pumping is returned to the Rio Grande on any time frame that you can speak to?
A. I would have to look at the data, but it's -- the majority -- and I think yesterday there was the discussion on two of the wells on the East Mesa, but the -- I think potentially some of that water could go to the reclamation facility well. But I would say the majority of the water may be about 10,000 acre feet a year, go back into the river. We reclaim about 300 acre feet a year, so -- so the order of magnitude of molecules of water from LRG-430 going through reclamation and avoid -- and replacing some freshwater pumping is still small.
Q. Right. So the reclamation plant is very small?
A. Well, it has a capacity of a million gallons a day, but when you look at the -- the demand, it's only in the summer so overall, I think the numbers that come to mind are in the 300 acre feet a year or so.
Q. Okay.
A. Of reclamation. It has capacity to -- to treat more, but there's no demand in the winter

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
31/22	MINED	INCORRECT
36/19	PLANT	INCORRECT
46/5	HANDS	"Hands" plant
46/5	PLANT	"
68/22	MODFLOW	MODEL NAME
68/23	MODFLOW	MODEL NAME
74/1	DELETE "YEAR"	SHOULD BE 365-DAY...
52/19	WECHSLER	INCORRECT
61/17	ACEQUIA MADRE	(CORRECT WORD)

Jorge Garcia

JORGE GARCIA

Page 78

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STATES ASTER Page 8 ers tories ness d tion; th t id se ot y at L OF OFFICE, on R, CRR S 600 Pag 1 (Pages 78 -

S I G N A T U R E   O F   W I T N E S S

I, JORGE GARCIA, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

JORGE GARCIA

Job No. 3169882

OFFICIAL SEAL
LINDA DAWSON
NOTARY PUBLIC - STATE OF NEW MEXICO
My commission expires: 2020

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS)
)
Plaintiff,)
) Original Action Case
VS.) No. 220141
) (Original 141)
STATE OF NEW MEXICO,)
and STATE OF COLORADO,)
)
Defendants.)

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, JORGE GARCIA, to the interrogatories as indicated were made before me by the said witness after being first duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MS. KLAHN - 01:52:59
MR. STEIN - 00:00:00
MR. ROMAN - 00:00:00
MR. DUBOIS - 00:00:00
MS. BARNCASTLE - 00:00:00
MR. BROCKMANN - 00:00:00
MR. WALLACE - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 25th day of February, 2019.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 12-31-19
VERITEXT LEGAL SOLUTIONS
Firm Registration No. 571
300 Throckmorton Street, Suite 1600
Fort Worth, TX 76102
1-800-336-4000

Tab 27

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****
REMOTE ORAL AND VIDEOTAPED DEPOSITION OF
ESTEVAN LOPEZ
JULY 6, 2020
VOLUME 1
****

REMOTE ORAL AND VIDEOTAPED DEPOSITION of ESTEVAN LOPEZ, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on July 6, 2020, from 9:06 a.m. to 4:50 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the offices of HEATHER L. GARZA, CSR, RPR, The Woodlands, Texas, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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Ms. Kayla Brown

ALSO PRESENT:

Peggy Barroll
Ken Knox
Lela Hunt
Ian Ferguson
Michelle Estrada-Lopez
Gary Esslinger
Erek Fuchs
Susan Barela

EXAMINATION INDEX

WITNESS: ESTEVAN LOPEZ

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THE VIDEOGRAPHER: The time is 9:06 a.m. We're on the record.

ESTEVAN LOPEZ,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. SOMACH:

Q. Mr. Lopez, I'm Stuart Somach, and I'm counsel of record for the State of Texas in this litigation. Let me -- before I ask you any questions and kind of give you an idea of what -- what we'll do over today and perhaps tomorrow, let's do some -- some appearances for the record.

MR. SOMACH: Again, I'm Stuart Somach for the State of Texas. With me are Theresa Barfield and Robert Hoffman. I think that's all we've got.

For New Mexico?

MR. WECHSLER: Good morning. Jeff Wechsler for the State of New Mexico. We also have John Draper, Peggy Barroll, Ken Knox, and Lela Hunt.

MR. SOMACH: For the United States?

MR. GEHLERT: David Gehlert on behalf of the United States, and I believe also on are Ian Ferguson and Michelle Estrada-Lopez.

MR. SOMACH: For the State of Colorado.

MR. WALLACE: Good morning. This is

Chad Wallace along with Preston Hartman for Colorado.

MR. SOMACH: And Albuquerque?

MR. BROCKMANN: Jim Brockmann for the Water Authority.

MR. SOMACH: City of El Paso? City of Las Cruces?

MR. BROCKMANN: Stuart, this is Jim again. I'll be sitting in. I think Jay might join a little bit later.

MR. SOMACH: Okay. El Paso -- EP No. 1?

MS. O'BRIEN: Yeah. This is Maria O'Brien for El Paso County Water Improvement District No. 1.

MR. SOMACH: EBID?

MR. ESSLINGER: Good morning. This is Gary Esslinger.

MR. SOMACH: Hudspeth County? New Mexico pecan growers?

MS. DAVIDSON: Good morning. Tessa Davidson on behalf of New Mexico pecan growers.

MR. SOMACH: New Mexico State?

MR. UTTON: Good morning. This is John Utton.

MR. SOMACH: Anybody else that we missed?

(No response.)

Q. (BY MR. SOMACH) Mr. Lopez, let me kind of talk a little bit about what we're going to do. We've got two days of outline or -- or carved out for your deposition. We have already -- you've already been deposed twice. I'm aware of that. The first time was back in May of 2019, before you were disclosed as an expert witness, and it was -- you were being deposed then as a -- essentially a percipient witness. That's a fact witness. Then you were deposed again on February 26th, 2020 on your first report. We have not finished that deposition and decided at that point in time to continue it with the knowledge that you were going to do a rebuttal report and that we would finish up with respect to the first report and -- and then ask you some questions about the second report. So that's the purpose of today and tomorrow's deposition. To date, for the most part, only Texas has asked you questions, and the United States certainly has questions to pose to you, and there may be others. I'm not sure what the rule is, but -- but I think there will be others, including EP No. 1, that may want to ask you some questions related to the operating agreement, but let me start -- I will try, to the best of my ability, not to repeat a bunch of

stuff. I have read both the depositions that were taken, and as you know, Ms. Klahn took those depositions on behalf of Texas. She's preparing for another deposition and just finished one up last week, so I'm -- I'm around a little bit here so you'll have to bear with me. But I'm going to ask you a couple of questions that may go back to those first two depositions, but I want to do that as a matter of foundation, as much as anything else. I noted that in your first deposition, you were retired as of May 7th, 2019, or at least that's what you said in that deposition so -- and let -- let me -- before I do that, this is -- I'm aware of the fact that you've had your deposition taken a number of times. This deposition is a little bit different than the last ones because we're doing it remotely, and so the rules are all the same, but you're kind of on your honor here not to be looking at a lot of communications from other people during the deposition, during the time you're being questioned. Do you understand that?

A. I do.

Q. Okay. And because we're not in all of the same room, sometimes it's difficult to -- to hear. We're -- we're aided by the realtime transcript so you have that in front of you, and it's working just fine?

A. It seems to be working great.

Q. Okay. And just like in a normal deposition, if you have any questions, you should -- should ask me to rephrase them, and if you need a break after I'm done -- after you're done answering the question, please don't hesitate to tell me you need a break, and we'll take it. Do you understand that?

A. I do.

Q. Okay. I suspect I'm -- and -- and just because it's a remote deposition, you're aware of the fact that it -- it -- we treat this like a regular deposition, and anything you say, you said under oath, and that your testimony here can be used at -- at trial. Do you understand that?

A. I do.

Q. Okay.

MR. SOMACH: Let's put up, and we'll -- we'll start here just simply because it's convenient to make sure everything is working. If we could put up what I'll mark as Exhibit 1. And I -- I'm going to start over in terms of deposition numbering simply because doing anything else would be beyond my capability. Let's put up the notice of deposition and subpoena of Estevan Lopez, please.

(Exhibit No. 1 was marked.)

Q. (BY MR. SOMACH) And I think, Mr. Lopez, I think you can control that as soon as it gets marked.

MR. SOMACH: Okay. Have you turned over the control to -- to Mr. Lopez?

THE VIDEOGRAPHER: He just needs to click the screen. He's got it.

Q. (BY MR. SOMACH) Okay. Do you have that?

A. Yeah. Getting used to -- trying to figure out how to maneuver.

Q. That's fine. This is a good one to practice on.

A. Okay.

Q. Have you ever seen what has been marked as Exhibit 1 before?

A. I have.

Q. Okay. And what is Exhibit 1?

A. Subpoena from my deposition.

Q. Okay. And if you look on Page 2, there's a request for documents, and did you -- are there any documents that you provided to your legal counsel that are responsive to the document request?

A. I don't think there's any additional documents, other than what I've disclosed in my reports. I think that legal counsel has copies of my billing records, and I think we were going to get some copies of additional photos that I have reviewed and that sort of thing.

Q. Okay.

MR. SOMACH: Jeff, just for the record, I may have received those or someone here received those, but are those going to be forthcoming? What -- what is your intent there?

MR. WECHSLER: They are, Stuart. My apologies for not getting them to you previously, but you'll have the billing records today along with the additional photos that Mr. Lopez is talking about.

MR. SOMACH: Okay. That shouldn't be any problem at all. I got things to talk about, and when I get done, I'm sure others will have questions. So why don't we take that exhibit down, so I can see Mr. Lopez's full face here.

A. I have to see myself, too.

Q. (BY MR. SOMACH) Yeah. Well, you know, it's -- it's -- it comes with the territory.

So where I was going was -- before I interrupted myself with Exhibit No. 1, as of May 7th, 2019, you were retired, and at that point, at least based upon my reading of that first deposition, you didn't indicate that you had been retained, so I assume that your retention for New Mexico to write

your expert reports occurred some time after May 7th, 2019; is that correct?

A. Yes. I don't remember the exact date, but it was some time after my first deposition, my fact deposition.

Q. And when you were asked to write an expert report, what was -- what were you asked to do?

A. I've got a copy -- clean copy of my report here that I'd like to refer to if that's all right.

Q. Yeah. Well, let's actually put it up. I -- I went to the -- to the --

MR. SOMACH: Let's put up the 10/31/2019 expert report. Let's mark this Exhibit 2.

(Exhibit No. 2 was marked.)

Q. (BY MR. SOMACH) We'll -- we'll refer to this periodically in the -- in the deposition. What -- so I asked you what your -- what your assignment was, and you said you wanted to look at your report, so if you could do so with reference to what you've got up here, that would be most helpful. And before we -- before you do that, what is what has been marked as Exhibit 2?

A. This is my expert report of October 31st, 2019.

Q. Okay. Why don't you go ahead and look then

where you want to look.

A. I'm going to have to get used to navigating this thing.

Q. That's fine. That's fine.

A. So I'm looking here at the "Purpose" section of my report. That describes pretty much the answer to your question. I was asked, based on my prior experience, to address some of the following, to provide background and context for the Compact, to explain the Compact, Compact accounting and the relationship of the project to the Compact, to describe the function and the history of the Compact Commission, discuss the measure of Compact compliance below Elephant Butte, explain the impact of the 2008 operating agreement on Compact accounting and compliance, explain operational changes that resulted from the 2008 operating agreement and the resulting impacts on Compact accounting, provide context for the 2011 Compact credit water release and explain its impacts from the perspective of the Compact, and discuss action needed to ensure future Compact administration in the section of the river below -- below Elephant Butte -- or between Elephant Butte Dam and Fort Quitman, Texas.

Q. Is what you've described Items No. 1 through

8 of -- of your -- your October report, are those -- is that exactly how you were employed as a consultant, they gave you these eight questions, and that's what you understood your job to be or -- or was it a broader scope and then through discussions, it was narrowed down to these eight points?

A. As -- as I recall these I've taken from kind of the con -- contract that I was asked to sign by the State of New Mexico and so these were the points that they asked me to discuss in -- in the contract. And as to whether the -- I, frankly, don't recall the -- the sequence of events to get to this point. I know we had some general conversations first about my interest in -- or willingness to -- to serve as an expert, and we went from there.

Q. Okay. Now, your last job with the State of -- of New Mexico was -- was as director of the Interstate Stream Commission; is that correct?

A. That is correct.

Q. And you were first appointed by -- by Governor Richardson; is that -- is that also correct?

A. That is correct.

Q. Okay. Did you have a lot of contact with Governor Richardson during the time he was governor and you were the director of the Interstate Stream

Commission?

A. What do you mean by "a lot of contact"?

Q. What was your relationship? Was it you never saw him and reported through other people to the governor's office or did you have periodic meetings with the governor to discuss water issues?

A. It was a bit of both. I did not see him on a daily and sometimes not even a weekly basis, but I certainly had instances where I reported directly to him and had meetings with him to discuss the issues.

Q. What -- would you say in your opinion that Governor Richardson was -- was involved in water issues and knowledgeable about them?

A. He was fairly involved, from my experience. You know, I've got limited experience as to the number of governors that I've served under. I've served under two governors. But of those two, I would say that he was -- he was involved. He was -- he was -- he made it a point of being knowledgeable about a broad range of issues, and he -- he read a great deal.

Q. When you say "a broad range of issues," I assume that includes issues with respect to water?

A. Yeah. And -- and so with regard to water, and you probably listened to John D'Antonio's deposition a few days ago, he -- he mentioned -- and

I -- I will do the same, that Governor Richardson brought on a policy advisor for water issues, Mr. Bill Hume, and Mr. Hume kept him apprised on almost a daily basis.

Q. Now, you were director of the Interstate Stream Commissioner under two governors. Who was the other governor?

A. Governor Martinez.

Q. And was Governor Martinez involved at the same level that Governor Richardson was in water issues?

A. I would say, at least in my experience, no.

Q. What -- what is the role of the Interstate Stream Commission with respect to the operation of the Rio Grande project?

A. I think it's probably best to answer that question by talking broadly about the role of the Interstate Stream Commission.

Q. That's fine.

A. And, again, I think I'll refer to my -- my report. So a good indication of kind of the breadth of the responsibilities of the -- of the Interstate Stream Commission is in this indented paragraph. I'll just go ahead and read it. "The Interstate Stream Commission is a nine-member commission that is

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE CORRECTION REASON FOR CHANGE

18/13 Strike "a" and replace with "or"; wrong word
19/6 Strike "then" and replace with "and"; wrong word
21/3 strike "projects" and replace with "project segments"; clarity
23/22 Insert "in a" before "facilitation"; clarity
26/4 Strike "with"; clarity
31/9 Strike "she" and replace with "he"; wrong pronoun.
31/12 Insert "It" before "Moved"; clarity.
35/20 Strike "effects" and replace with "affects"; wrong word
38/16 Strike "groundwater" and replace with "ground"; clarity
38/25 Strike "ground"; clarity
44/7 Strike "safe" and replace with "saved"; clarity
50/15 Strike "was" and replace with "were"; wrong word
65/6 Strike "not" and replace with "and"; clarity
65/7 Insert "to" before "Hudspeth"; clarity
66/11 Insert "separately" before "from"; clarity
74/6 Strike "Compact square. The Compact" and replace with "compacts where the compact"; clarity
74/15 Strike "lands" and replace with "man's"; wrong word

ESTEVAN LOPEZ, VOLUME I

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
82/14	Strike both uses of "project" and replace each with "Compact"	clarity
82/16	Strike "article" and replace with "project"	clarity
99/16	Change "schedule" to "schedules"	correcting quote
110/9	Strike "have and replace with "had"	wrong word.
125/5	Strike "but it's" and replace with "when there's"	clarity
126/21	Strike the first instance of "the"	clarity
129/19	Strike "for"	clarity
147/3	Strike "eyes" and replace with "us"	clarity
149/6	Strike "repetition" and replace with "refutation"	wrong word
155/17	Strike "draws" and replace with "drawn"	wrong word
162/25	Strike "does" and replace with "has been done"	clarity
170/3	Strike "in"	clarity
176/14	Strike "may" and replace with "might"	clarity
176/16	Strike "I'm seeing" and replace with "I've seen"	clarity
177/3	strike "in"	clarity
177/19	strike "post supply"	clarity
180/23	strike ". I mentioned" and replace with "or mention"	clarity
182/22	strike "Compact" and replace with "contract"	wrong word

[signature]

ESTEVAN LOPEZ, VOLUME I

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
188/2	strike "the" and replace with "below"	; clarity
188/3	strike "real estate" and replace with "the state"	; clarity
190/23	strike "30"	; clarity
191/12	strike "the"	; clarity
192/25	strike "tightening" and replace with "tightly"	; clarity
194/9	strike "system" and replace with "doctrine"	; clarity
197/1	strike "delay" and replace with "define"	; clarity

Est R. Lopez

ESTEVAN LOPEZ, VOLUME I

S I G N A T U R E O F W I T N E S S

I, ESTEVAN LOPEZ, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

ESTEVAN LOPEZ, VOLUME I

Job No. 63570

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, ESTEVAN LOPEZ, to the interrogatories as indicated were made before me by the said witness after being first remotely duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. SOMACH - 05:01:50
MR. WECHSLER - 00:00:00
MR. GEHLERT - 00:59:19
MR. WALLACE - 00:00:00
MS. O'BRIEN - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, this, the 22nd day of July, 2020.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 04-30-22

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Tab 28

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS)	
)	
Plaintiff,)	
)	Original Action Case
VS.)	No. 220141
)	(Original 141)
STATE OF NEW MEXICO,)	
and STATE OF COLORADO,)	
)	
Defendants.)	

****
REMOTE ORAL AND VIDEOTAPED DEPOSITION OF
ESTEVAN LOPEZ
JULY 7, 2020
VOLUME 2
****

REMOTE ORAL AND VIDEOTAPED DEPOSITION of ESTEVAN LOPEZ, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on July 7, 2020, from 9:00 a.m. to 4:17 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the offices of HEATHER L. GARZA, CSR, RPR, The Woodlands, Texas, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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VIDEOGRAPHER:

Ms. Kayla Brown

ALSO PRESENT:

Ian Ferguson
Michelle Estrada-Lopez
Arianne Singer
Peggy Barroll
Shelly Dalrymple
Susan Barela
Lela Hunt
Rolf Schmidt-Petersen
Erek Fuchs
Gary Esslinger

EXAMINATION INDEX

WITNESS: ESTEVAN LOPEZ

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THE VIDEOGRAPHER: The time is 9:00 a.m. We're on the record.

ESTEVAN LOPEZ,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. GEHLERT:

Q. Thank you. Just one quick preliminary question before we start. Is there any reason today that you're not capable of giving truthful and complete answers?

A. No.

Q. Thank you. I want to start by revisiting the hypothetical we discussed yesterday about the water traveling through the EBID canal. We talked about what would happen if the water seeped out of the canal into the ground, and I believe your testimony was that that water would not be considered project water or usable water at that point; is that correct?

A. Well, that hypothetical -- hypothetical kind of morphed as we went along, and I think toward the end, you had asked me about if it comes back as return flow, is it usable water, and yes, it is. If it's -- if it -- return flow is part of project supply. What I -- where I thought you had begun with that hypothetical was that it was just simply lost, it seeped into the ground and was not coming back.

Q. Yeah. So during the interval between the time when the water seeps out of the canal and reenters a different canal or the river or some other project feature, you consider it to be not project water and not usable water; is that correct?

A. Well, until -- until it returns to the system, yes, it's not usable. It's not project supply. I mean, that's why I drew that distinction. Initially I was thinking you were talking about water that has simply seeped into the ground and is not returning.

Q. Okay. Thank you. Appreciate the clarification. I want to change the hypothetical in just one way. Instead of the water seeping out of the canal, does it change your opinion that the water is pulled out of the canal by a pump?

A. Are you asking -- what's the question you're asking?

Q. The hypothetical, water is traveling down a canal within EBID. We're agreement that water in the canal is project water and it is usable water, but my question to you is: What happens if that water is pulled out of the canal by a pump?

A. So I think I understand what you're asking.

Yeah. So if the -- if the pump is pumping groundwater and then that is applied on project -- on project lands, yeah, I would say that that -- that portion of -- of project water is usable water -- excuse me. That portion of groundwater that was pulled from -- from the canal and then applied to the project, that -- that's project water.

Q. Okay. And I want to look at it from the -- the other end, as well. You talked about how if water had seeped out of the canal and it moved to a point where it reentered another canal or project feature, it would then become project water. What happens if the water is intercepted by pumping before it is able to reach a project feature and become return flow under your definition?

A. I'm not sure how that's significantly different than what we just talked about.

Q. So the pumping would be taking project water and usable water?

A. Say that again, please.

Q. I just wanted to confirm that your testimony is that the pumping that was preventing water from reaching the system and becoming return flow under your definition would be taking project water and usable water?

MR. WECHSLER: Object to form.

A. Taking project water --

Q. (BY MR. GEHLERT) Let me clarify. Taking water that is both project water and usable water.

A. Well, I probably need to -- to go back to the definition of usable water. It's in the Compact, and in the Compact, the definition of usable water is -- excuse me. So -- so -- and I realize that we talked about this yesterday about usable water being part of the release water, but under the Compact, the definition of usable water -- and just to be clear and not confuse matters, we probably ought to stick with that definition. That's water in project storage that is available for release. So once it's released, at least under that definition, it's not usable water. At that point, it becomes part of project supply, and I'd like to just keep that distinction point.

Q. I appreciate that. Let me rephrase my question, and we'll just refer to it as project water or project supply. Do you understand project water and project supply to be essentially synonymous?

A. That's the way I've been using it, yeah.

Q. Okay. So, again, we have water that would be otherwise reaching a project feature but for pumping, and my question is whether the water that's captured

by the pump is project water or not?

A. Yeah. I -- I think it's -- so, you know, we're kind of going around in circles about this whole thing, but I've already talked about the fact that, yeah, groundwater pumping impacts surface supply, and -- and this is -- this is kind of what we're describing.

Q. Okay. Do you have an opinion on to what extent pumps within EBID are drawing water that's derived from surface features? And by "surface features," I mean the river drains or canals.

A. What do you mean do I have an opinion? Are you asking me if I can quantify it?

Q. Yeah. Do -- have you seen studies or have you done any quantification yourself?

A. I have not done any quantification myself but, yes, I've seen some studies.

Q. And what were the conclusions of those studies?

A. I don't recall in detail, but the -- yeah, there's -- there's impacts of on-the-ground water pumping -- excuse me. There's impacts from the groundwater pumping on that project supply.

Q. And can you identify for me the studies that you're thinking of?

A. Well, I'm thinking of some of the work that's been done by our -- our modeling team through the integrated models.

Q. Anything else?

A. I think that -- I think that Peggy has done some -- some other -- excuse me -- Dr. Barroll has done some quantification of those impacts, as well. It's not necessarily coming through the modeling, but I -- I can't recall specifically.

Q. Okay. You were just looking at the definition of usable water. In your opinion, does the Compact require usable water to be divided up along the 57/43 percent split that we talked about yesterday?

A. No.

Q. It's just the whole project supply?

A. Yes.

Q. Thank you. You talked about conjunctive use of groundwater. Can you -- what can you tell me about how conjunctive use is managed in New Mexico?

MR. WECHSLER: Object to form.

A. Well, the state engineer has adjudicated an overall farm delivery that's allowed, and that can -- that is made up of the combination of surface supply and -- and groundwater supply. So once that limit is

Grande underground water basin. When was that created?

A. I think it was declared, I think is the -- is the word that we use and -- and I think that was some time in the '80s, in the early '80s.

Q. Okay. Do you have a sense of how much of the pumping that's presently within the New Mexico portion of the Rio Grande project had been established by 1980?

A. Not exactly. I do know that there had been pretty extensive pumping that had gone on in the '51 through '78 period, but I -- offhand sitting here, I -- I can't remember what those proportions are relative to what's going on today.

Q. Is there someone who would be better equipped to answer that question?

A. Well, I think -- I think there's probably a few people that can answer that question better that have the information as part of the reports and stuff. I think Dr. Barroll does. I think probably Greg Sullivan and Heidi -- Heidi Welsh. Their report had some information along those lines. There may be others.

Q. Thank you. And if I understood you correctly, after the creation or declaration of the

groundwater districts, new wells are required to be offset?

A. Not groundwater districts. We don't create -- declare groundwater districts. We declare a basin that is the state engineer ascertains reasonably defined boundaries of it and defines those, and after that point, the -- the -- there's -- any new uses are required to be permitted, and any new uses are required to be offset, that sort of thing.

Q. Great. I appreciate your correcting my terminology. So we're talking about the basin. What is -- what does offset mean?

A. Offset means that to the extent that the -- that the impacts of that new use are impacting the surface water supply, that -- those impacts need -- need to be offset by -- by some method or another.

Q. And what are some of those methods?

A. Well, it could be in -- in the case of, say, a municipal user or something like that, it could be by the return flows. If the return flow is -- is sufficient to offset the surface water impacts, that could be the offset for a time. Over time, that'll change, and then maybe additional offsets will be required. It could be acquiring a water right and -- and using that water right to offset those impacts.

It could be -- although I don't know that this has happened down there, it could be the importation of water from some other source.

Q. Okay. So you're not certain whether there are any permits that require imported water or water to be imported as an offset?

A. You know, I don't -- I'm not aware of them. I do believe that there's some importation of non-basin water that's going on, but it may be that it's -- that this is pre -- pre-declaration, so I don't know that that's required for an offset, but in the case of Las Cruces, I believe some of their supply comes from the -- the Jornada that's not hydrologically linked to the -- to the surface water system. So any water that comes in from that system, the return flows that are coming in for that are essentially imported supplies that augment to the surface water supply.

Q. I believe you mentioned that there -- that a possible offset would be acquisition of another water right?

A. I think that's correct, yeah.

Q. Do you know if that has actually been done?

A. I don't.

Q. Is there somebody who's better equipped to

talk about the -- what's been done as far as offsets within the district?

A. I would expect that the water master and the -- the district state engineer personnel down there would -- would know that quite well.

Q. And who is the water master?

A. I believe it's Ryan Serrano. I think that's correct.

Q. I'll ask you one last question about offset. How is the quantity that needs to be offset determined?

A. Well, it kind of depends on -- on how complex it is. It might be -- if it's a -- it's a groundwater source that's very close to the river and shallow, it might be a simple calculation using the Theis equation or it may -- if it's more complex and further away, it might require a groundwater model to assess what those impacts are.

Q. And those processes for potentially assessing the impacts, those occurred during the permitting process?

A. Yeah. And -- and as I mentioned before, I think there's at least a potential that some of these could change over time so they'd probably have to be revisited from time to time. I, frankly, don't know exactly how often they revisited or -- or if they do or if all of it is kind of done ahead of time.

Q. Okay. Do you know when New Mexico started work on -- on the AWRMS, Active Water Resources Management System, I believe?

A. I think we refer to it as just AWRM, and I don't know exactly. I think -- I think there was -- there was at least the -- the -- the concept that was being fleshed out by the time I came to work for the ISC and -- and John D'Antonio came to work as state engineer the first time, that is at the start of 2003, I think there had been some very preliminary work done before that, but really, I think most of the -- most of the effort arises after 2003. In 2003, there was some kind of key state legislation that mandated that the state engineer should put in -- put in effect the administrative tools necessary to administer water rights if necessary, even in -- in -- without a completed adjudication. And -- and so much of the work for AWRM -- or AWRM as we affectionately call it -- was done after that point.

Q. And AWRM is a statewide process, correct?

A. It is.

Q. And then there are -- there are what I'll call local regulations. Is it stated that there would

be a separate set of regulations for the Lower Rio Grande?

A. I should back up on that question and perhaps be a bit more precise. I don't think it's a statewide process. There is a -- kind of an overarching set of regulations that I think has been put -- put in place and affirmed and -- and then, yeah, you're correct, for the more specific areas, there's district-specific regulations that would be required and -- and -- to actually make it functional.

Q. And when you say "district specific," what's the applicable district for the Lower Rio Grande?

A. It may be called the Lower Rio Grande district. I'm not sure exactly what it's called, but it -- my understanding of that is that it's generally the -- the correspondence to the -- the boundaries of -- of the project boundaries within New Mexico.

Q. And have those district-specific regulations been promulgated?

A. I don't believe that they have.

Q. There's -- there's been some reference to groundwater pumpers within E BID supplementing their -- their water supply. Do groundwater pumpers have separate water rights for pumping?

A. I believe that -- so we're talking here about conjunctive -- conjunctive use of groundwater, and I believe that, yes, they have separate groundwater rights.

Q. Are those considered supplemental rights as a matter of New Mexico law?

A. I -- I'm not sure. I -- I don't know.

Q. Okay. Would the water master be a better person to ask about that?

A. I think that they would have that -- would understand it very well.

Q. Okay. Do you have any familiarity with the priority of pumping water rights within EBID?

A. Do -- do I know the priority of what?

Q. Of the groundwater pumping rights within EBID.

A. Well, it depends on when they were developed, and as -- as we know from this case, quite a lot of that -- those groundwater pumping -- the groundwater pumping was begun in the -- in the early '50s, so probably a fair amount of it is from that time frame. Some of it may be later.

Q. So it's -- it's -- there are -- is a little junior to the project water rights?

A. Correct.

Q. When you spoke with Ms. Klahn in February,

you talked about some time around --

A. Could I back up -- could I back up just a second?

Q. Yeah. Certainly.

A. I'm -- you asked me -- the last question you asked me has a rule that they're junior to -- to the project. If -- if that implies that all groundwater pump -- groundwater pumping is -- is junior to the project, I'm not sure that that's exactly been decided, that we have a final answer on that. I know that at least the City of Las Cruces began developing some groundwater rights close to the time of the -- of the Compact, and I think that that -- that still may be an open question or at least open to appeal.

Q. Okay. Thank you. I appreciate the clarification. When you spoke with Ms. Klahn in February, you talked about some time around 2013, the State had curtailed a -- a pumper within EBID. Did -- do you recall that conversation?

A. I think we talked about some river pumping -- river pumping -- excuse me -- river pumpers that we had some concerns raised about by perhaps it was IBWC or -- or -- or maybe Texas. I think that there has been some instances where the State has curtailed some of them, and some of them, the State has verified that

WITNESS CORRECTIONS AND SIGNATURE.

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE CORRECTION REASON FOR CHANGE

14/8 Strike "before" and replace with "for"; clarity
20/16 Strike "the correspondence" and replace with "it corresponds"; clarity
22/6 Strike "has" and replace with "if as"; wrong words
23/23 Strike "that"; extraneous word.
24/15 Strike "analysis" and replace with "canals"; wrong word
26/16 Strike "alfalfa" and replace with "wastewater"; wrong word
28/3 Insert "inflow" after "tributary"; missing word
28/21 Strike "of the year" and replace with "years"; clarity
46/22 Strike "pre" and replace with "pretty"; clarity
50/20 Strike "it" and replace with "I"; clarity
58/23 Strike "there's" and replace with "they're"; wrong words
62/17 Strike "I'd call" and replace with "I've called"; wrong words
66/13 Strike "and" and replace with "in"; wrong word
76/12 Strike "carryover" and replace with "accrued"; wrong word
77/7 Strike "a" and replace with "or"; wrong word
77/7 Strike "or apportionment" and replace with "of a portion"; clarity
77/18 Strike "that" and replace with "and there"; clarity
84/5 Strike "through" and replace with "to"; wrong word.

ESTEVAN LOPEZ, VOLUME II

WITNESS CORRECTIONS AND SIGNATURE.

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE CORRECTION REASON FOR CHANGE

94/4 Strike "options" and replace with "experts"; clarity
106/16 Strike "independence" and replace with "independent"; wrong word
106/24 strike "gain" and replace with "game"; wrong word
110/20 Strike "it" and replace with "them"; clarity
114/3 Strike "that does"; Clarity
115/3 strike "is" and replace with "was"; wrong word
117/25 strike "that" and replace with "to the"; clarity
118/11 strike "on" and replace with "an"; clarity
125/16 Strike "they're" and replace with "you're"; clarity
141/4 strike "with the" and replace with "that"; clarity
142/17 Strike "didn't"; Clarity
142/18 Strike "didn't" and replace with "did"; Clarity
148/4, 6, 9, 15, 16-17, Strike "warrant act" and replace with "Warren Act" (5 times) wrong name
151/11 strike "an images" and replace with "a damages"; wrong words
155/14 Strike "transacts" and replace with "transects"; wrong word.
158/23 strike "the" and replace with "as"; clarity
166/4 Strike "for" and replace with "from"; wrong word
176/20 Strike "it was"; clarity

[signature]

ESTEVAN LOPEZ, VOLUME II

WITNESS CORRECTIONS AND SIGNATURE.

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE CORRECTION REASON FOR CHANGE

180/11 strike "report seem" and replace with "court seemed"; wrong word

183/16 strike "for" and replace with "that"; clarity

ESTEVAN LOPEZ, VOLUME II

S I G N A T U R E   O F   W I T N E S S

I, ESTEVAN LOPEZ, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

ESTEVAN LOPEZ, VOLUME II

Job No. 63571

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, ESTEVAN LOPEZ, to the interrogatories as indicated were made before me by the said witness after being first remotely duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. SOMACH - 00:17:58
MR. WECHSLER - 00:00:00
MR. GEHLERT - 03:14:41
MR. WALLACE - 00:00:00
MS. O'BRIEN - 00:55:00
MS. BARNCASTLE - 00:55:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 25th day of July, 2020.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 04-30-22

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Tab 29

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION OF
ESTEVAN LOPEZ
SEPTEMBER 18, 2020

****

REMOTE ORAL AND VIDEOTAPED DEPOSITION of ESTEVAN LOPEZ, produced as a witness at the instance of the United States, and duly sworn, was taken in the above-styled and numbered cause on September 18, 2020, from 9:02 a.m. to 12:38 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, remotely at the offices of HEATHER L. GARZA, CSR, RPR, The Woodlands, Texas, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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Kari Olson
Al Blair
Greg Ridgley
John D'Antonio
Robin Cypher
Gary Esslinger
Erek Fuchs
Phil King
Cheryl Thacker
Daniel Ortiz

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THE VIDEOGRAPHER: The time is 9:02 a.m. We're on the record.

MR. DUBOIS: First, let's do appearances. Mr. Lopez, my name is Jim Dubois. We've met once before, pre COVID, I think your first deposition when you were not an expert witness, and I am representing the United States. Also on the line, I believe, is Lee Leininger, who appears that -- oh, and Judy Coleman, and that appears to be it for the United States this morning. Jeff?

MR. WECHSLER: Jeff Wechsler for New Mexico, and it looks like we have the state engineer, John D'Antonio, Gregg Ridgley, Cheryl Thacker, Shelly Dalrymple, Kari Olson, and Susan Barela, and Arianne Singer.

MR. DUBOIS: And for the State of Texas?

MR. SOMACH: Yes, this is Stuart Somach. I'll be asking Mr. Lopez questions to the extent Mr. Dubois doesn't cover the universe. Sarah Klahn is also on, and she'll be covering the other depositions today. Theresa Barfield is on, Mac Goldsberry is on for Texas, and I believe there are a couple of other people, but to be honest with you, I'm not certain who they are. But if anybody else, either at my firm or representing Texas wants to make an appearance, that would be good for the record.

MR. DUBOIS: Okay. For Colorado?

MR. WALLACE: Yes, this is Chad Wallace for Colorado. Also with us today is Preston Hartman.

MR. DUBOIS: And we'll try and cover the amici. I don't remember who everybody is. Let's start with El Paso County Water Improvement District No. 1.

MS. O'BRIEN: Good morning. This is Maria O'Brien for El Paso County Water Improvement District No. 1. Also on is Renea Hicks and Dr. Al Blair.

MR. DUBOIS: Is there anybody on for EBID?

MS. BARNCASTLE: Yes. Good morning. This is Samantha Barncastle for EBID, and with me today will be Gary Esslinger, the manager of the district, Dr. Erek Fuchs, and Dr. Phil King.

MR. DUBOIS: Okay. City of El Paso?

MR. CAROOM: Doug Caroom for the City of El Paso, and with me is Daniel Ortiz, general counsel for El Paso Water.

MR. DUBOIS: Las Cruces and/or Albuquerque Bernalillo?

MR. BROCKMANN: Yeah. This is Jim

Brockmann on behalf of both amici.

MR. DUBOIS: Mr. Utton, I'm blanking on who you're representing. Is it NMSU?

MR. UTTON: Yes. Good morning. This is John Utton representing New Mexico State University.

MR. DUBOIS: And for the water users group?

MS. DAVIDSON: This is Tessa Davidson, good morning, for New Mexico pecan growers.

MR. DUBOIS: And are there any other amici who are on that I have missed?

(No response.)

MR. DUBOIS: Okay. Hearing none, apparently that's everybody.

ESTEVAN LOPEZ,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. DUBOIS:

Q. All right. Mr. Lopez, you've been deposed before in this proceeding several times. You've -- you've done video depositions in this case. I'm just going to cover the very basic ground rules. You're under oath this -- as if you're testifying in a court of law. We need to try not to talk over each other. Let me finish my questions, and I will try not to

interrupt your answers, and we'll have a cleaner record. If you don't understand a question, please ask me to clarify it, and I will try and rephrase it; otherwise, I'll assume you're -- if you're answering, you're understanding the question. And because this is a remote deposition, your other communication devices, e-mails, texts, things like that need to be turned off. Is that all clear

A. It is.

Q. Let's pull up the -- the notice as a starting point.

MR. DUBOIS: Kayla, if you can load up the 30(b)(6) U.S. notice.

THE VIDEOGRAPHER: And how did you want to mark this one?

MR. DUBOIS: That's a good question because Mr. Lopez was up to 9 or 10, but this is -- this is a 30(b)(6) deposition, so it is slightly different.

MR. SOMACH: Yes. Mark it 1, Jim, because it is a 30(b)(6).

MR. DUBOIS: Yeah. Let's go with -- let's mark it Lopez 30(b)(6) No. 1.

(Exhibit No. 1 was marked.)

Q. (BY MR. DUBOIS) All right. Mr. Lopez, you

should have on your screen what's been marked as Lopez 30(b)(6) No. 1. Do you see that? Do you have that up?

A. I do.

Q. Okay. And have you seen this before?

A. You know, I think that I have not.

Q. Okay. All righty. So this was not provided to you by counsel?

A. You know, they may have. I -- I don't know. I've seen so many documents that it's just not registering with me.

Q. Okay. So you've been identified as -- as a 30(b)(6) witness on behalf of the State of New Mexico. Do you understand that?

A. I do.

Q. Okay. And do you -- do you understand what a 30(b)(6) deposition is?

A. Well, I -- I understand it as it was explained to me by my attorneys, yes.

Q. And how was that explained?

A. So it was -- I was told that I would be answering as to the State's position on the questions that I was being asked.

Q. Okay. So you understand you're testifying as -- as if you were the State of New Mexico and -- and

the positions that you state are going to be binding on the State?

A. Yes.

Q. As the State's positions? Okay. And looking at the -- if you would go to Page -- the attachment to the notice, which has a listing of topics. And my PDF is -- I'm trying to get to that page of it, as well, but my -- there we go. Keep scrolling down. I'm going to try to find the appropriate PDF page number here. All right. Go to PDF Page 11. You got it? Okay. Now, you've been designated. Do -- do you understand what portions of this notice that you've been designated to testify about?

A. Yes.

Q. Okay. So my understanding is you've been designated to testify about all of Topic A; is that correct?

A. I believe that's correct.

Q. Okay. And Topic B, except for Counterclaim Nos. 5 and 8; is that correct?

A. I believe that's correct. That's --

Q. Okay.

A. -- that's what I understood, as well, yes.

Q. All right. And then Topic C as to the Interstate -- interstate Stream Commission's policies

and -- and regulations; is that correct?

A. I don't -- I don't know if I was told that, but I think that I can.

MR. WECHSLER: Hey, Jim, that -- sorry to interrupt. I think that designation was as to the Compact issues, whereas to state administration issues, that will be Ms. Thacker.

MR. DUBOIS: All right. And I think Mr. Lopez as the star of the ISC rules regarding that topic that he can answer, that he does know the subject so if we've got coverage, we can -- can and will ask?

Q. (BY MR. DUBOIS) What did you do to prepare for this deposition, Mr. Lopez?

A. I reviewed my report -- my reports, my original report from October, '19, and a rebuttal report from June of this year, my supplemental report from July. The report -- I reviewed other reports from New Mexico witnesses. I reviewed transcripts of my depositions, and I met with my attorneys.

Q. How long did you spend in -- in preparation for this deposition?

A. Are you asking about how many hours or --

Q. Yeah. How much time?

A. I'm not certain, but I would -- I would estimate 20 to 25 hours.

Q. Did you spend any time with representatives of the state other than your attorneys?

A. I did have a meeting that included other states.

Q. Which others?

A. I believe --

Q. Within the state?

A. I believe there was State Engineer John D'Antonio, Rolf Schmidt-Petersen, Gregg Ridgley, and Arianne Singer, and this was on a phone call. Yeah. I think -- I think that was it.

Q. Okay. And nobody else from the State?

A. I spoke to -- to Peggy -- Dr. Peggy Barroll at least one or two times.

Q. Were you involved in drafting New Mexico's counterclaims in this case?

A. I was not.

Q. Okay. Now, you previously testified as an outside independent consultant; is that correct?

A. Yes.

Q. And, now, you're testifying as essentially the voice of the New Mexico government in this deposition today, right?

A. I believe that's correct, but I'm still an outside independent consultant.

Q. Okay. You're not an employee of the State?

A. I am not.

Q. Okay. And does your role as a 30(b)(6) deponent change any of the responses you gave in your prior depositions as an expert witness?

A. That's a very broad question, but I don't think that it really changes any of the -- the responses that I had before.

Q. Okay. So should we understand that the opinions that you gave as an independent consultant are the views of the State of New Mexico?

A. I believe that's correct. You know, there -- there may be some where some portions of the depositions were done. It's been a lot of questions asked. There may be certain questions if I were asked today that I would answer in a more way. It's just as I mentioned, it's a very, very broad question here you're asking me. I don't -- unless I were asked a specific question, I'm not sure that I could give you a more specific answer than that.

Q. Okay. How about the -- the questions that you were asked about what New Mexico's apportionment is under the Compact, will those change?

A. No.

Q. Okay. Is it New Mexico's position that the Rio Grande Compact is a complete apportionment of the flows of the Rio Grande between the head waters and Fort Quitman?

A. Yes. Excuse me. Can I ask a question, kind of a process question?

Q. Sure.

A. In -- in prior depositions, I've had access to realtime -- the realtime transcript. I don't have that up right now. I'm not sure if that's --

Q. I think that's a good idea to get that up.

MR. DUBOIS: I assume, Heather, that it is the usual transcript realtime.

THE REPORTER: Yes.

THE VIDEOGRAPHER: Do you want to go off the record to set this up?

MR. DUBOIS: Yeah. Why don't we go off the record and get that up.

THE VIDEOGRAPHER: The time is 9:18 a.m. We're off the record.

(Break.)

THE VIDEOGRAPHER: The time is 9:23 a.m. We're on the record.

Q. (BY MR. DUBOIS) Okay. I think that we -- you -- we were just talking about whether or not the Rio

Grande Compact is complete apportionment of the flows of the Rio Grande, and you said that it was. What -- what does New Mexico think that a -- a complete apportionment of the flows of the Rio Grande means? What does that mean?

A. I think that it means that all of the flows that arise in the Rio Grande between the head waters and Fort Quitman are divide -- are divided as between the three states.

Q. So was there any flow of the Rio Grande between the head waters and Fort Quitman that was not apportioned by the Compact?

A. I cannot think of any, no.

Q. Okay. Now, you've also -- you previously stated in earlier deposition that the Rio Grande below Elephant Butte was fully appropriated by 1938. Do you remember discussing that in depositions?

A. Yes.

Q. Okay.

A. Yes, I do.

Q. And -- okay. Do you still stand by the -- the conclusion that the Rio Grande below Elephant Butte was fully appropriated in 1938?

A. I do.

Q. Okay. And so that -- I just want to be clear

that that's also the position of the State of New Mexico then?

A. That's correct.

Q. Okay. Okay. What does it mean that the river was fully appropriated?

A. That means that all of the waters -- all of the surface waters of the river are -- have been spoken for.

Q. Okay. So all of the surface water had already been allocated to existing water rights? Is that another way of saying it?

A. Yes. Let me -- let me review that. Yes, that's correct.

Q. Okay. And does that mean that any additional diversions after 1938 that deplete the river would take water away from existing water rights?

MR. WECHSLER: Object to form.

A. It would impact those water rights, yes.

Q. (BY MR. DUBOIS) All right. If you're taking water away from them, that would be a -- add adverse impact of those water rights?

MR. WECHSLER: Object to form. And I also think we're getting a little beyond the scope.

MR. DUBOIS: No, we aren't, but he can answer if he knows anyway.

A. Generally speaking, I think that's correct.

Q. (BY MR. DUBOIS) Okay. Does the Rio Grande Compact apportion water to New Mexico below San Marcial?

A. Yes.

Q. Does New Mexico assert that it receives an apportionment of water -- does New Mexico assert that it receives an apportionment of water from the Rio Grande below San Marcial?

A. I'm not sure I understand what distinction you're making between that and your prior question.

Q. Okay. When did -- when did New Mexico determine that it had an apportionment of water below San Marcial?

A. I think when we agreed to the Compact.

Q. What is New Mexico's apportionment of water under the Rio Grande Compact?

A. Under the Rio Grande Compact?

Q. Yes.

A. This is what we receive from Colorado under Article 3 of the Compact at the state line, plus all of the inflows that arise between the state line and Elephant Butte, less our obligation to deliver water into Elephant Butte under Article 4, plus 57 percent of project supply below Elephant Butte, project supply being comprised of releases of usable water, inflows below Elephant Butte, and return flows, returning drain flows.

Q. So let's -- let's -- and my question was overly broad for my purposes, I guess. So let's just focus on the apportionment of water below San Marcial, the apportionment of water to New Mexico below San Marcial. That's -- just focus on that and call that out from the answer. So what's the apportionment of water to New Mexico below San Marcial?

A. So I think this is probably the same thing, but I'm going to -- I'm going to just clarify that I'm referring to below Elephant Butte given that the delivery point under Article 4 was changed in 1948. So I'll -- I'll be responding --

Q. And that's fine. That's fine. I understand.

A. So as I -- as I answered above, and as I've laid out in my reports and in questions -- in responses to questions before, it is 57 percent of the project supply, and that project supply being comprised of releases of usable water inflows below Elephant Butte and returning drain flows.

Q. So do the downstream contract -- do you -- are you familiar with what the term downstream contracts refers to?

A. I am. Certainly as I've defined them in my reports, there may -- and I think it's consistent with how it's been used otherwise by others.

Q. And so when you're referring to the downstream contracts, what are you referring to?

A. I'm referring -- in my report, I referred specifically to three contracts, 19 -- I may get the dates from memory, get them off, but --

Q. Would it be helpful to have them in front of you?

A. I can look at my reports. I have the copy of my reports in front of me. If it's all right, I can refer to that if you'd like.

Q. You can. I can also -- I can also provide you the contracts.

A. That's fine. So let me tell you generally, it's a 1938 contract between Elephant Butte and -- Elephant Butte Irrigation District and Reclamation. It's either 1937 to 1938, that -- that contract is, and similar time frames for a contract between Reclamation and El Paso County Water Improvement District No. 1, and the third contract that I referred to as one of the -- the downstream contracts is a 1938 contract between the two districts that was later approved by the Department of Interior. I believe it was in April of 1938. Is that -- is that sufficient specificity?

Q. Yes. As I said, I can provide them. I just wanted to make sure that we're talking about the same things. So do the -- do the -- do the downstream contracts between the United States and EBID and between EBID and EPCWID define the apportionment to New Mexico?

A. I think they inform the -- the apportionment to New Mexico. They don't define it as explicitly as -- as -- as I've defined here in my responses to you. They inform it by -- in several ways. First of all, the -- the contract between EBID and -- and EP No. 1 that is EPCWID has a shortage provision that is specific and explicit about in times of shortage, water is to be shared 57/43. In essence, in proportion to the acreage in each of the districts as a total of -- a total project authorized acreages. And then the -- the two contracts between Reclamation and the districts specify the acreages of each of the districts, the authorized acreages of each of the districts. That's consistent with that. Those two contracts also have essentially identical terms except for the -- the proportion of payment that is also proportionate to the acreage and so those things inform that apportionment, and in my report and in responses to my prior depositions, I've explained how the 57/43 that I assert is the apportionment below Elephant Butte we get from a reading of the Compact together with those downstream contracts and the historical practice of how the project has been operated up until essentially 2006.

Q. So is the contract with EBID the sole means for New Mexico obtaining its apportionment under the Compact?

MR. WECHSLER: Object to form.

A. Are you referring only to that -- the apportionment below Elephant Butte?

Q. (BY MR. DUBOIS) Yes. I'm sorry. I should have been clear on that. I apologize.

A. I believe that it is, yes.

Q. Okay. Is it New Mexico's position that the contracts between the United States and the two districts and the contract between the two districts are integrated into the Compact?

A. I think what I testified is that they -- that the Compact and the project are inextricably linked, and the -- and the contracts are also kind of inextricably linked to -- or inextricably intertwined, I think is what I -- what I said in my report. I was using some of the language that the -- that the Supreme Court has used and relied on that -- on that -- their findings, as well.

Q. What do you mean by inextricably intertwined?

A. They work together. They work together, and you can't -- you can't -- you can't read them independent of one another.

Q. So anything -- I'm just trying to understand this. So anything that impacts the project water supply impacts the apportionment; is that correct?

MR. WECHSLER: Object to form.

A. Could you rephrase that? I'm not understanding what you're asking.

Q. (BY MR. DUBOIS) Well, I'm trying to understand when you say that they're inextricably intertwined and that they have to be read as part and parcel of each other; is that correct? Is that what you're saying?

A. Yes. And I'm specifically speaking as to how you -- how you make a determination as to the apportionment. Certainly, there is probably elements that could be looked at independently, but -- but for -- for getting to an apportionment below Elephant Butte, I think you have to look at all three of these -- all, I guess, four of these documents together.

Q. Okay. And so my question was then if they're inter -- interdependent and intertwined, anything that affects -- is anything that affects the project water supply affecting the Compact?

A. So first of all, if -- I think you may have just been reading what I answered earlier. I don't think that I said they were inextricably interdependent. I did they they were inextricably intertwined. And that's -- if you're asking me the difference, I don't know that I -- that I can say what the difference is. But nevertheless, you asked if -- is anything that affects project supply also affecting the Compact. I'm not sure. I don't know that. I don't know the answer to that. Unless you give more specificity to what you're talking about in -- in anything.

Q. Is there any other apportionment in the Compact to New Mexico below Elephant Butte, other than the water under the contract with EBID?

MR. WECHSLER: Object to form.

A. I think I already answered that, and I said no.

Q. (BY MR. DUBOIS) Okay. Is there any apportionment of water to New Mexico below Elephant Butte, other than project water that EBID is entitled

to under what we've been referring to as the downstream contracts?

A. Again, I'm not seeing how this is different than your prior question.

Q. It's slightly different so please answer it. Or should I just -- can I take it that the answer to that is no?

A. I'm rereading it.

Q. Uh-huh.

A. I think the answer is no.

Q. Okay. So are the -- the EBID project allocation and New Mexico's apportionment under the Rio Grande Compact below Elephant Butte the same?

A. They are not certainly -- they are certainly not since the 2008 operating agreement.

Q. That's not what I asked. Are the EBID project allotment and New Mexico's apportionment under the Compact below Elephant Butte reservoir the same?

MR. WECHSLER: Object to form.

A. Not since two thousand -- not since 2006.

Q. (BY MR. DUBOIS) You're refusing to answer the question.

A. I have answered the question.

Q. Let me try again.

A. You don't like my answer.

Q. All right. Let's rephrase the question then. Is it the Compact's intent that the EBID project allotment and New Mexico's apportionment under the Rio Grande Compact below Elephant Butte reservoir the same? Are they to be the same?

A. Would you please -- please define project allotment for me, please?

Q. What EBID is entitled to receive under the downstream contracts?

A. In that instance, I would say yes.

Q. Okay. Are the contracts for the Rio Grande project the only means provided for in the Compact for distribution of New Mexico's apportionment?

MR. WECHSLER: Object to form.

A. Well, to the extent that you're asking that -- I guess the way I would say it and I have said it is that the operation of the project is the -- is the -- the mechanism for effectuating the Compact apportionment.

Q. (BY MR. DUBOIS) And the operation of the project is pursuant to the downstream contracts; is that correct?

A. Generally, yes.

Q. Okay.

A. Or at least --

Q. So the downstream -- I'm sorry. What? I didn't mean to cut you off.
A. Or at least it was.
THE REPORTER: I'm sorry. Please repeat that again.
THE WITNESS: I said, "Or at least it was."
Q. (BY MR. DUBOIS) Okay. Does Texas have an apportionment of water under Elephant Butte -- below Elephant Butte reservoir?
A. As I've testified in my reports and in my depositions, my prior depositions, yes, it has an apportionment below Elephant Butte.
Q. And I know some of this is repetitive, Mr. Lopez, but you're now -- you're now speaking for the State of New Mexico as opposed to as an independent contractor so they seem redundant, but I'm still needing to ask you these things. So it's fine that you clarify and -- and reiterate your prior testimony, but, you know, there's -- there is a reason that we're covering some same ground?
A. I understand.
Q. So just --
A. I'm simply --
Q. Okay. All right.

A. -- simply trying to -- you asked me earlier if -- if my responses had changed. They hadn't, and hasn't really changed --

Q. Okay.

A. -- from my reports either.

Q. No, and that's -- and that's fine. Basically, that's what we're trying to -- to make sure that we're consistent going along here, so that's -- that's fine. Understand that I do appreciate some of this is plowing old ground, but because of sort of your -- your position in this deposition, we're going to -- we're going to recover some of that. So I'm, you know, just explaining that I'm not merely doing this to be obnoxious, not the only reason.

A. And I'm not -- I'm not trying to be obnoxious by responding by referring to --

Q. No.

A. -- my prior depositions or my reports. I simply want to say that it hasn't changed.

Q. Okay. And that's -- and that's fine. So just so we know that we're -- we're both on the same track, so that's good.

So what's Texas' apportionment of the Rio Grande Compact?

A. 47 -- excuse me. 43 percent or roughly 43 percent of the project supply that arises below Elephant Butte, and that is comprised of releases of usable water of Caballo reservoir, inflows between there and Fort Quitman, and returning drain flows.

Q. So do the downstream contracts define the apportionment to Texas?

A. My response here would be the same as my response was to -- to their relationship to -- they inform the apportionment to Texas in the same way that they inform the apportionment to New Mexico that I described above.

Q. So under the Compact, is the EPCWID project allotment intended to be identical to Texas' apportionment?

MR. WECHSLER: Object to form.

A. With the same caveats as my responses earlier, that is that at least originally, yes.

Q. (BY MR. DUBOIS) Okay. And are -- are the contracts for the Rio Grande project to EPCWID the only means provided for in the Compact for distribution of Texas' apportionment?

MR. WECHSLER: Object to form.

A. I will respond again mirroring my response to your similar question on EBID, and that is that it's my opinion that the -- that the operation of the project is the means, the mechanism by which the Compact apportionment is effectuated.

Q. (BY MR. DUBOIS) Is there any apportionment to Texas under the Rio Grande Compact other than project water that EPCWID is entitled to under its contracts?

MR. WECHSLER: Object to form.

A. I would say no.

Q. (BY MR. DUBOIS) Okay. Does New Mexico agree that groundwater pumping in New Mexico below Elephant Butte dam in the Mesilla and Rincon basins for irrigation and municipal and industrial uses in New Mexico deplete the flows of the Rio Grande that are available for diversion by the Rio Grande Project?

MR. WECHSLER: Object to form; scope.

A. The groundwater pumping in New Mexico does impact surface supply.

Q. (BY MR. DUBOIS) Does it deplete the surface supply?

MR. WECHSLER: Same objection.

A. I think that it does, yes.

Q. (BY MR. DUBOIS) Okay. What obligation does New Mexico have under the Compact to be sure that the project water supply is not depleted or reduced by non-project water users?

A. I'm not sure that we have any specific obligation not to deplete or reduce project supply unless -- unless there is some notice that -- that there is -- that Texas is not getting its apportionment. Having said that, New Mexico does and has permitted such uses to -- to require that any impacts -- any such impacts would be offset since it's closed the basin -- or since it's -- since it's declared the basin. Excuse me.

Q. All right. So all the development before it closed the basin is ignored for purposes of administration; is that correct?

MR. WECHSLER: Object to form.

A. No, it's not ignored, but I think that unless -- unless we are put on notice that Texas is not getting its apportionment, we don't necessarily have to do anything about it.

Q. (BY MR. DUBOIS) So there's no obligation under the -- let me rephrase that. If pumping of groundwater in New Mexico depletes the flow of the Rio Grande, either directly by pulling water from the river drains or by preventing water from returning to the river and -- and they reduce the project water supply, do those depletions to the river count against New Mexico's apportionment?

MR. WECHSLER: Object to form.

A. I think that it is non -- for non-project uses. If it is for non-project uses, those might have to be offset, but not if it's for project uses.

Q. (BY MR. DUBOIS) Why not if it's for project uses?

A. Because -- well, one of the -- one of the purposes of the Compact is to -- is to make the -- the project viable over the long haul, and that viability includes getting -- or having access to groundwater for conjunctive use, and that's consistent in both states.

Q. Is there any limitation on New Mexico as to how much surface water can be depleted by pumping in New Mexico?

MR. WECHSLER: Object to form.

A. Are you asking about for a specific purpose or just generally?

Q. (BY MR. DUBOIS) Generally.

A. Well, yes, I think there is a limitation. If -- if Texas is not getting 43 percent of its project supply of the project supply then I think that would -- that would set the limitation.

Q. But you've told me that depletions to the water supply from pumping, at least for pumping for project beneficiaries, does not count against the

these relatively quickly, because I know we have others and other depositions that we want to get into today. You indicated at the beginning of Mr. Dubois' questions that you understood that you were testifying as if you were New Mexico; is that correct?

A. Yes.

Q. That's the difference between your depositions that were taken as an independent expert versus your 30(b)(6) deposition that's being taken here today, you understand that distinction; is that correct?

A. Yes, that's correct.

Q. Okay. And so when I refer to you in this deposition, I'll try to distinguish between your prior depositions and your reports versus your speaking for New Mexico and so do you understand that when I use the word "you" in this deposition, I'm referring to the State of New Mexico?

A. I will try and keep that in mind.

Q. Okay. And I'll remind you if there appears to be any confusion. Is it your opinion that actions by New Mexico are having -- with respect to -- to actions below Elephant Butte reservoir are having no injury, they're not injuring Texas in any respect?

A. I guess to the extent that you're asking in any given year, I don't know the answer in any given year. I think if you look at things cumulatively through, let's say, I think from '85 through 2017, I would say that, yes, there's -- there's been no injury to Texas.

Q. And under the same qualification you just made, are you saying that the converse or the contrary is true with respect to Texas' injury to New Mexico, that, in fact, over that period of time, Texas' actions have injured New Mexico's rights under the Compact?

A. So I -- let me just answer the question fully just so that -- I believe that during that same time period, Texas' actions have injured New Mexico.

Q. Okay. Does groundwater have any -- anything to do at all with the 1938 Compact apportionment?

A. No. Other than I would say that the Compact allows the conjunctive use of that groundwater.

Q. And -- and what do you refer to with respect to the Compact that gives rise to that answer?

A. Well, again, I'm -- I'm referring to documents that were contemporaneous with the Compact and -- and -- and the practice that has happened since -- since then up until now. The specific document that I -- that I would refer to there is the rules and regs of the -- of the -- of the Compact commission.

Q. Are you referring, when you say this, to the rules and regulations or other historic documents that relate to the fact that except as provided for in the Compact, each state is allowed to fully develop their water resources, is that -- is that what you're talking about?

A. Yes. That's paraphrased, but yes.

Q. Okay. And --

A. And then the other -- the other aspect of it that I was referring to has been the historic practice that has -- that has come about since the Compact was signed.

Q. Okay. Let's -- let me look upstream a little bit here above Elephant Butte just to understand and provide some context for that. Are there any limits on Colorado's ability to develop its upstream resources within the Compact, is there any Compact limit on what they can do in terms of -- of developing water upstream.

MR. WALLACE: Object to form?

A. I think there are, and specifically, I think that they are able to develop their -- their upstream resources as long as they continue to meet their obligations under Article 3 and -- and then there's other limitations in terms of the storage of water in post-Compact reservoirs, I think, in their instance, it's post '37 reservoirs, but other than that, you can develop their resources.

Q. And I think we -- we may have talked about this in one of your prior depositions, but those limitations are to ensure that depletions in Colorado would be -- it seems what existed in 1938; is that correct?

MR. WALLACE: Object to form.

A. I think that's largely -- largely correct. Mr. Somach, can I ask you to speak up just a little bit? I'm having a little bit of trouble hearing you as you ask your questions.

Q. (BY MR. SOMACH) I will -- I will try to speak up and get closer to my microphone here.

A. Thank you.

Q. Now, with respect to development above Elephant Butte reservoir, to the extent that there are limits on what New Mexico can do in terms of developing full water resources above Elephant Butte, is that also similarly limited to -- to depletions that would have existed at -- in 1938?

A. I think that's correct. I think there's reference in New Mexico -- in New Mexico's case to depletions as of 1929. I think there's a couple of references to that, one with regard to reservoirs built after '29, and then a second for the -- in the resolution -- the 1948 resolution that changed the -- our delivery point from San Marcial to Elephant Butte, I think there's also -- depletions above Otowi have to be constrained to 1929, and if they're not, then you have to make an adjustment as between above Otowi and below Otowi.

Q. 1929 was the date of the temporary -- so-called temporary contract among Colorado, New Mexico, and Texas; is that -- is that correct?

A. The temporary Compact, correct? Is that --

Q. I said contract. I meant Compact.

A. Yeah. Yes. That's correct.

Q. Were New Mexico's ability to develop -- fully develop its water resources below Elephant Butte Reservoir also constrained by ensuring that depletions below Elephant Butte reservoir did not exceed that which existed in 1938?

A. I don't think those are similarly constrained, no.

Q. Okay. So -- and here, I'll -- I'll separate out New Mexico from Texas below Elephant Butte. So New Mexico -- Colorado was constrained by the

depletions that existed as of 1938 in its delivery to New Mexico, and New Mexico was constrained in terms of its deliveries into Elephant Butte reservoir based upon depletions that existed in 1938, but New Mexico below Elephant Butte reservoir is not constrained by depletions that might have existed in 1938; is that -- is that what you're saying, that there's a distinction between the obligations above Elephant Butte and those that exist below Elephant Butte?

MR. WALLACE: Object to form.

A. I think that's correct. There is a distinction.

Q. (BY MR. SOMACH) And explain to me that distinction.

A. There is no constraint below Elephant Butte. There is no 1938 -- in my report and in response to previous depositions, I -- I've responded about the '38 condition -- depletion condition. That's -- that's what I was talking about. There is -- there is no -- there is no such condition placed in the Compact for the section below Elephant Butte.

Q. Let -- let me clarify something here, and that is -- and this is the distinction between you as the State of New Mexico and you as Estevan Lopez, independent expert. You've written a number of expert

reports that have been disclosed and submitted in this case; is that correct?

A. I have.

Q. How many reports have you -- have you written in this case?

A. I guess three, and then the third one has a second edition.

Q. Okay. And that -- the last report was what we got earlier this week, I think; is that correct?

A. That's correct. That's the second edition of the supplemental.

Q. Okay. Those reports all have opinions within them; is that correct?

A. They do.

Q. Do you, as New Mexico, have a -- a different view with respect to the opinions that you rendered in -- that -- that Estevan Lopez rendered in his reports that Estevan Lopez did with respect to those opinions? In other words -- let me try to say that better.

I'm just trying to figure out if -- if you, as New Mexico, concur with all of the opinions that were rendered in the Estevan Lopez expert reports. I'm hoping that that will shorten things up because we've asked you about all of those things, and I'm just trying to figure out if that's the case?

A. I, as New Mexico, concur with the opinions expressed by I, as Estevan Lopez.

Q. Okay. And presumably, to the extent that questions were asked of you in depositions, you, as the State of New Mexico, concur with the answers you gave to those questions when you were acting as Estevan Lopez, expert witness; is that correct?

A. Yes. That's generally correct. As I mentioned earlier with Mr. Dubois, I think there was a lot of questions, and I might answer some of those questions with a bit of different nuance, answering on behalf of the State of New Mexico.

Q. And why -- why is that? Why would it -- why would your answers be more nuanced for the State of New Mexico than when you responded to those same questions on behalf of the -- of the -- on your own behalf?

A. Well, I think -- I think even -- even from my very first deposition, I've -- just speaking as -- as Estevan Lopez, I think my understanding has evolved somewhat over time of various aspects of things, and -- and that continues into today as -- as I speak for the State of New Mexico.

Q. Okay. So -- so it's just the evolution over time of the more you've thought about these things,

the little variation, it's nothing more systemic, more -- more substantive than just that evolution; is that correct?

A. I think that's correct. I think as a result of your questions and those of other lawyers, I certainly have thought about things much in more detail than I have as I wrote these things initially.

Q. Now, you referred to, I think, three contracts as defining the apportionments of the relative apportionments below Elephant Butte and to -- to Texas and to New Mexico, and those were the two 1937 contracts between the districts and the United States, plus the 1938 contract among the United States, EP No. 1, and EBID; is that correct -- is that correct?

A. That's generally correct. I did not say that they define the apportionments. I said they inform the apportionments along with the Compact and with historic practice.

Q. That's -- actually, you've -- you've -- you've hit on the exact question, whether you knew it or not, that I wanted to ask. I don't understand what the word inform means in the context of that response. I simply don't know how you're using it there so perhaps you can explain the difference between

something informing and -- and something being the apportionment?

A. I'll do my best. What I mean is, you know, I've said in -- in my reports, my Estevan Lopez reports, that -- that the Compact is not explicit as to how it apportions water. Well, nor -- the -- those downstream contracts are not explicit that way either. They don't say New Mexico gets 43 percent of the water from the project, and Texas gets -- or New Mexico gets 57 percent, and Texas gets 43 percent. Rather, there's other elements that -- that we read together with the Compact with other historical documents from the time and the practice that evolved from that to come to the conclusion that the apportionment is 57/43. That's what I meant by saying that it informs that.

Q. So do you start with those contracts? Is that the place you start and then there is -- I mean, the contracts provide certain specific things, don't they?

A. They do provide certain specific things. I start with the Compact first, and -- and then the -- then I look to the -- to the contracts, which were essentially contemporaneous with the Compact. I think they were probably at the fore of everybody's thinking

what the something is. So let's -- let's begin back in 1938 when the Compact was executed. I understand we won't call it a 1938 condition in the way you've -- you've disagreed with it, but certainly there was a physical setting in 1938 upon which you could make the 57/43 allocation, and it included as you said usable water that's released from the reservoir. It included return flows. It include -- included other accretions, and it presumably, it subtracted depletions. Is that more or less what would have occurred in 1938?

MR. WECHSLER: Object to form.

A. I don't believe that it subtracted the depletions. I think there was a defined what was referring to as a normal release, 790 up to, you know, 790 usable water that potentially could be used and -- and that the -- that based on the historical hydro-- hydro-graphical information that they had, they felt would get them a full supply. In fact, the full supply that they've used and delivered has been based on releases less than 790, and so as far as I know, I don't think that there was ever any subtraction of depletions. There was, though, an expectation that 790 would yield a full supply, and to my understanding, it always has, and less than that has yielded a full supply, as has been defined by the project.

Q. (BY MR. SOMACH) Well, I think you -- you also said, though, that groundwater pumping, which is --

A. I'm sorry. I'm having trouble hearing you again.

Q. I think you've also said that groundwater pumping, which is a -- a condition of depletions has increased over time and that that increase in depletion has affected flow in -- in -- in the river. I think you said that?

A. Well, you know, I think -- I think I probably did say that, but let me put some fine point -- finer points on that. It certainly increased pretty dramatically in the '50s from essentially no groundwater pumping, for project purposes, to pretty substantial project -- groundwater pumping. Then we have a period of full project supply where groundwater pumping was greatly reduced in the early 2000s, 2003/2004, again, groundwater pumping went up pretty dramatically, but not -- not appreciably more than what we had that we experienced in the '50s. It did go up appreciably after the 2006 and the 2008 operating agreement where New Mexico's surface water allotments were dramatically reduced as a result of the operating agreement.

Q. To the extent that -- that losses exist in the system, do they -- do they reduce the amount of surface water that -- that is available for application of consumptive use in the project? And here, I'm not -- I'm not distinguishing between -- between New Mexico project lands and Texas project lands. I'm just asking the general question of whether losses affect the amount of water that can be applied and consumed by crops?

MR. WECHSLER: Object to form.

A. So certainly, losses reduce the amount of water. If there were no loses, there would be more water available. We could build up -- keep a lot more water in the reservoir, wouldn't have to call -- call for as much water. But the project -- you know, the project anticipated that. Every project has losses, and this one is no different.

Q. (BY MR. SOMACH) If losses are greater in one year than they were in a prior year, with everything else being equal, that is the amount of -- of usable water released from the reservoir, if -- if losses are greater in one year than another year, will that result in less water available for actual application to -- to irrigated lands?

MR. WECHSLER: Form and foundation.

A. It depends. It depends. I mean, certainly losses probably vary every year. I doubt that they're ever exactly the same from one year to the other. But, you know, if you have a full supply period, you might have very -- very high losses and still there's absolutely no reduction to -- to the project users. So that's a -- you're going to need a lot more information before you can answer that question.

Q. (BY MR. SOMACH) I think you said, and actually, I wrote this down from the realtime. I think you said, "I'm not sure that New Mexico has any specific obligation not to deplete or reduce project supply." Do you recall saying that?

A. You're talking about earlier today?

Q. Yeah.

A. Yeah. I think -- I think that I did say that.

Q. I think you said that you -- you qualified that by saying unless you have notice, and I think at the very end of Mr. Dubois' questioning, you suggested that the complaint itself in this case was -- was notice; is that correct?

A. I did.

Q. Do you, State of New Mexico, think that you

have a obligation not to deplete or reduce project supply if you -- if you know that your actions are depleting project supply?

MR. WECHSLER: Object to form.

A. Again, I -- I don't -- I don't think that we -- if -- if our actions are such that were depleting the project supply and Texas is not getting their apportionment and they let us know and, yes, in fact, we verify it, yes, I think we have to do something about it.

Q. (BY MR. SOMACH) Yes. But you added something to that in that if they let us know.

A. Right.

Q. What happens if you know but Texas hasn't provided you whatever you are talking about in terms of notice?

A. I'm sorry? I -- let me -- let me read this. I'm having trouble hearing you.

Q. I'm sorry. You -- you qualified your answer to the last question with "if Texas lets us know." What happens if Texas doesn't provide you notice, but nonetheless, you are aware that you are depleting supplies that otherwise would be going to Texas? Do you have an obligation if you know that that's what's happening?

A. I would say no, not if we're depleting supplies, but rather if Texas is not getting its apportionment, then we have an obligation.

Q. Even if Texas hasn't provided you notice?

A. If we know about it, I would say yes.

Q. Does the Compact treat lands apportioned water in New Mexico the same way as it treats lands apportioned water in Texas?

A. I'm -- I'm puzzled by -- by your -- your question asking about how the Compact treats lands. What -- what are you getting at? Perhaps you can expand on that.

Q. What I'm looking for or what I'm asking is whether or not the -- the Compact apportionment treats New Mexico below Elephant Butte the same as it treats the apportionment to Texas below Elephant Butte reservoir. Is there any distinction made in the Compact?

A. In my estimation, no. I believe that both should be treated -- that the Compact should -- treats both equally.

Q. Okay. Let me look -- I want to be -- I want to be done, actually. I want to in the worst possible way be done, but hold on a second. I think you indicated earlier that the historic operations of the

project, since 1938, are an element of understanding New Mexico's apportionment; is that -- is that correct?

A. I -- I think they're an element of understanding both states' apportionment, yes.

Q. Are there any specific years after 1938 that one looks to or is it the entire universe of years from 1938 to price of time that one -- or at least in 2006 that one looks to?

A. I would look at the entire period between '38 and 2006, but recognizing that in the very first few years, through the '40s, there was kind of a unique situation, one was an abundance of supply. I think that everybody was still getting used to -- used to operating under a Compact and what that meant, and finally, not until the late '40s and into early -- the 1950s, did they -- did Reclamation specifically start really focusing in on tightening up its operation to make sure that in less than full supply years, they were allocating or apportioning water consistently.

Q. Well, can you point to any specific years after 1938 where they got it right versus other years where they got it wrong?

A. You know, no, that -- that -- I prefer not to do that. I'd rather look at kind of the entire time frame and, you know, this is a lot of what Dr. Barroll did for us. She -- she tracked how much was delivered to each district year by year, and under different operations regimes and -- and largely, as I said, if we just kind of remove the '40s from the '50s through '78 is pretty consistent. Largely 57/43, then after '78, D1/D2, that was meant to -- that was a mechanism, frankly, to try and repeat what had happened before under the control of three different entities as opposed to a single entity, and largely, it accomplished that, and the districts, by and large, got 57/43. Not until 2006 did that really start changing.

MR. SOMACH: Okay. I don't -- I don't have anymore questions.

THE WITNESS: Am I done?

MR. SOMACH: I don't know.

MR. DUBOIS: Not quite. Not quite. I've got literally one follow-up question, and I don't know if anybody else is going to have any questions or not so I'll just ask my one follow-up question, and we'll work from there and see if anybody else has any questions.

S I G N A T U R E   O F   W I T N E S S

I, ESTEVAN LOPEZ, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

____

ESTEVAN LOPEZ

Job No. 65405

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, ESTEVAN LOPEZ, to the interrogatories as indicated were made before me by the said witness after being first remotely duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. SOMACH - 00:48:35
MR. WECHSLER - 00:00:00
MR. DUBOIS - 02:02:47
MR. WALLACE - 00:00:00
MS. O'BRIEN - 00:13:01
MS. BARNCASTLE - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 7th day of October, 2020.

NDTCA . Signed Electronic Transcript .

____
HEATHER L. GARZA, CSR, RPR, CRR
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Tab 30

IN THE SUPREME COURT OF THE UNITED STATES
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STATE OF TEXAS	)	
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	)	Original Action Case
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	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

****

ORAL AND VIDEOTAPED DEPOSITION OF
RYAN SERRANO
FEBRUARY 26, 2019

****

ORAL AND VIDEOTAPED DEPOSITION of RYAN SERRANO, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on February 26, 2019, from 9:23 a.m. to 3:29 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the RAMADA HOTEL & CONFERENCE CENTER BY WYNDHAM LAS CRUCES, 201 East University Boulevard, Las Cruces, New Mexico, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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Ms. Brandi Pate

ALSO PRESENT:

Mr. Erek Fuchs

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WITNESS: RYAN SERRANO

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EXHIBIT NO.73 103
Memorandum dated January 29, 2019

THE VIDEOGRAPHER: My name is Brandi Pate representing Veritext. The date today is February 26th, 2019, and the time is approximately 9:23 a.m. The deposition is being held at Ramada Hotel located at 201 East University Avenue, Las Cruces, New Mexico 88005. The caption of this case is State of Texas versus State of New Mexico and State of Colorado. This case is being held in the Supreme Court of the United States, Case No. 220141. The name of the witness is Ryan Serrano.

At this time, the attorneys present in the room and everyone attending remotely will identify themselves and the parties they represent.

MR. GOLDSBERRY: Francis Goldsberry. I'm with the law firm of Somach Simmons & Dunn, and I represent the State of Texas.

MR. DUBOIS: James Dubois, U.S. Department of Justice representing the United States.

MS. RANDEL: Shelly Randel, Solicitor's Office Department of Interior with the United States.

MS. O'BRIEN: Maria O'Brien representing El Paso County Water Improvement District No. 1.

MS. BARNCASTLE: Samantha Barncastle representing Elephant Butte Irrigation District, and with me is Erek Fuchs. He's our groundwater manager.

MR. WALLACE: Chad Wallace from the Colorado Attorney General's Office.

MR. ROMAN: David Roman and Chris Lindeen on behalf of the State of New Mexico, and with us is Shelly Dalrymple from the Interstate Stream Commission.

THE VIDEOGRAPHER: Our court reporter, Heather Garza, representing Veritext, will swear in the witness, and we can proceed.

(The witness was sworn.)

MR. GOLDSBERRY: I think we also need to have appearances on the record from the folks that are on the telephone.

MR. UTTON: Good morning, this is John Utton representing NMSU. We just ask that the speakerphone -- the speaker microphone be close to the witness. Some of you, it's hard to hear, but if it's close to the witness speaking, that would be very helpful. Thank you.

MS. DAVIDSON: This is Tessa Davidson on behalf of Amici New Mexico Pecan Growers.

MS. THOMPSON: And Lisa Thompson and Michael Kopp on behalf of the State of New Mexico.

RYAN SERRANO,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. GOLDSBERRY:

Q. Mr. Serrano, would you state your full name, please, and spell it?

A. Full name is Ryan John Serrano. First name Ryan, R-Y-A-N, middle name is John, J-O-H-N, last name Serrano, S-E-R-R-A-N-O.

Q. Have you had your deposition taken before?

A. No, sir.

Q. Were you -- have you been present during the taking of the depositions of the EBID board of directors and the depositions taken of the folks from Las Cruces?

A. Yes, I was.

Q. So -- so you've observed, what, nine -- nine depositions in this case so far?

A. I believe that's correct, yes, sir.

Q. Okay. Let's -- let's talk about some of the ground rules. I assume you've -- well, let me not assume anything. Have you had a chance, also, to talk to your counsel about the procedures that we're going to be following here today?

A. Yes, I have.

Q. Okay. Just a couple of reminders. If I ask you a question that you don't understand, will you

tell me that you don't understand it, so that I can rephrase it in a form that you can understand?
A. Okay.
Q. You will?
A. I will, yes, sir.
Q. All right. I guess the -- the other thing that I want to remind you about, and this applies to both of us. I -- we -- we need to talk one at a time, so you let me ask my full question, and then I will try to reciprocate by not interrupting you when you're answering my question. That way, we'll keep the court reporter happy and -- and neither one of us will be injured.
Are you -- is there any reason why you feel that you can't proceed today?
A. No, sir.
Q. Are you currently on any medications?
A. No, sir.
Q. Do you have any questions about the procedures that we're going to follow?
A. No, sir.
Q. What -- what is your date of birth?
A. 7/20/1987.
Q. Place of birth?
A. Place of birth is Las Vegas, New Mexico.

process for enforcement, which is -- is laid out in what's called the Supplemental Metering Order, and that's State Engineer Order No. 180. So for us as assistants, that would have been to identify the illegal use, document it appropriately in a field inspection, and attach a red tag notice of noncompliance to that particular point of diversion.

Q. And what was the next step in the process?

A. After that, we would generate -- from our field notes, we would generate a electronic copy of the field report. That would be turned over to the water master, and the water master would have to then generate an official notice, a certified letter that would go out to the owner, and that had to happen within five days of the red tag. And from there, the water master would take over following through with that enforcement action.

Q. Okay. How many such enforcement actions were you involved with during the three years that you were an assistant water master?

A. Several hundred, I'd say.

Q. And all of those investigations were documented in writing?

A. Yes, sir.

Q. Were the written reports that you made out with regard to those investigations maintained here in Las Cruces? Let me withdraw that question, see if I can make it a little clearer.

The written reports that you've referred to, you said that they were transmitted to the water master electronically. Were they also maintained in written form?

A. From our field notes, we would generate a digital copy of the report. A copy would be printed and placed in the meter file, and we could also house an electronic copy on our server here at the Las Cruces office, but the field notes themselves would have been disposed of.

Q. Okay. During the time that you were an assistant water master, did you -- were you involved in any way in permitting?

A. No, sir.

Q. During the three years that you were an assistant water master, did you receive any in-house training from the Office of the State Engineer?

A. All that I can recall is what -- what I would consider on-the-job training, job shadowing other individuals, learning different systems. We never received any formal training.

Q. Did you serve in the military by any chance?

A. No, sir.
Q. Do you hold -- let me withdraw that and start over.
Is the job of assistant water master specifically classified as such by the State of New Mexico personnel people?
A. At -- at that time, there was two different state personnel office classifications that would have been water resource specialist basic and water resource specialist operational.
Q. Okay. So when you started, were you classified as basic?
A. Yes, sir.
Q. Okay. And at some point, did you move up to the operational classification?
A. I did not move up to the operational classification until 2012, when I assumed the role of Lower Rio Grande Water Master.
Q. And what was the specific date of you taking on that position?
A. The specific date, I do not recall, sir.
Q. Approximately, what time of year?
A. I believe it was November, 2012.
Q. So you replaced Craig Cathey?
A. Yes, sir.

Q. And at that time, did the State of New Mexico personnel office have a job classification for the position of water master?
A. That was water resource specialist operational.
Q. So there were -- there was no particular classification directed specifically at being a water master?
A. No.
Q. That you're aware of?
A. Not that I'm aware of.
Q. At the time you were employed as -- as an assistant water master in 2009, did you ever see a job description for that position?
A. Yes, sir.
Q. And -- and what form was that in?
A. That form would have been in what we call a -- as referred to at the time as an MEP, and that's management -- managing employee performance. It was annual evaluation.
Q. Okay. So this -- this performance report actually listed what your duties were?
A. Yes, sir.
Q. Okay. And who -- during the period that you were a assistant water master, who did your

performance reports?
A. That would have been Craig Cathey.
Q. Was anyone else involved in evaluating your performance?
A. Those performance evaluations are done by the immediate supervisor, which would have been Craig Cathey, and they are reviewed by the district manager and then submitted to human resources department.
Q. At some point, were you given a written copy of your performance review?
A. Yes.
Q. What is the current relationship between the district supervisor and the lower Rio Grande water master?
MR. ROMAN: Object to form.
Just not clear what you mean which type of relationship.
MR. GOLDSBERRY: Well, all right, that's fair enough. Let me -- let me try it a little differently.
Q. (BY MR. GOLDSBERRY) As the water master today, do you report to the district supervisor on any subjects?
A. Just -- just to clarify, when you refer to "district supervisor," I believe you're speaking

We sent copied of the new standards to all the well drillers, and we notified them at that point if we continue to see these violations, we'll start to take action. Approximately 15 businesses were notified.

Q. So there is a -- I believe you testified that there is a statewide group that is responsible for overseeing well drillers. Did I get that right?

A. That is correct.

Q. Okay. And where's that statewide group located?

A. They are in Santa Fe, New Mexico.

Q. And who was the head of that group?

A. Currently, that is a woman by the name of Jerri Pohl. That's J-E-R-R-I, last name is P-O-H-L, Pohl.

Q. Are there wells within your district that you know about that aren't metered that should be metered?

A. There are wells within my district that I am aware that are not metered that should be metered; however, we have -- they're in some sort of step in the compliance process to achieve that metering.

Q. Are they all in the compliance process?

A. All of the ones that I'm aware of, yes, sir.

Q. When a permit is issued to replace a well, are the wells necessarily the same size and depth of

the well that's being replaced?
A. No, sir, not always.
Q. How frequently does that occur that the replacement well is going to have a larger capacity or be at a greater depth?
A. I think for the most part, what we see is greater depth, not necessarily larger capacity in terms of casing size or -- or pump size. Greater depth, individuals trying to achieve better quality water, from -- from what I've been told, from those well owners. But we also see where a well -- replacement well will be drilled, you know, sometimes would be smaller, smaller diameter, more depth.
Q. How frequent is that?
A. Probably more on the order of a third of the time.
Q. What is meant by measuring water usage?
MR. ROMAN: Object to form.
You can answer, if you can.
MR. GOLDSBERRY: Let me withdraw the question and rephrase it.
Q. (BY MR. GOLDSBERRY) I believe you testified that one of your duties was measuring and reporting water usage within the district. What's involved in reporting water usage?

A. Well, of course, through our -- through our metering program, we track the -- we quantify -- track and quantify the amount of water diverted in each of -- a number of different use categories, different uses such as irrigation, municipal, commercial, industrial, dairy, domestic.

Q. And -- and are all of those uses reported to the waters database?

A. Yes, sir, they are.

Q. Are municipal and industrial water uses recorded on the water -- waters database accessible to the public?

A. Yes, sir, it is.

Q. Is one of your duties the curtailing of how to priority diversions?

A. The -- the duties, as they're described in -- of a -- in statute, the duties of a water master, yes, sir. Have I ever conducted that activity in my time as the water master, no.

Q. Okay. Why not?

A. I've never had a priority call called in my district.

Q. Is one of your duties the -- some sort of coordination with the United States Bureau of Reclamation?

A. Some -- some coordination with regard to the two districts and their use of surface waters within the district. Not too frequently do we coordinate with the Bureau of Reclamation directly. I do receive some e-mails from the Bureau of Reclamation with regard to annual project operations from the area of field office in Albuquerque, and -- and I use those generally just to get a sense of where Rio Grande project surface waters are within the district, and that -- that gives me a good sense of where I can allocate my staff's time and resources.

Q. And that's the only interaction you've had with the Bureau of Reclamation?

A. That's the only regular interaction I have. I have -- in the past, I have had the Bureau report what -- what they determine -- what they categorized as illegal activity to me. They reported that -- that particular incident, I think it went to the state engineer and, again, that was forwarded to the water rights director. The water rights director forwarded it to the manager, and the manager had me investigate. That's happened a couple of times during my tenure.

Q. Okay. When was the last time?

A. I want to say that was 2013 approximately. 2012/2013.

Q. Okay. And this was an allegation or indication by the Bureau of Reclamation that there was illegal pumping going on?

A. Illegal diversions off of the main stem of the Rio Grande.

Q. Okay. And did you investigate that?

A. I did, yes, sir.

Q. And what was the result of that investigation?

A. We -- we found that many of the sites that the Bureau had identified as illegal were not, in fact, illegal, but were valid under New Mexico statutes. Some of the sites were points -- project points of diversions for individuals who receive water through the Elephant Butte Irrigation District, and there were, in fact, a couple that were illegal, yes, sir.

Q. Okay. And what was done about the illegal ones?

A. The illegal ones, they were, again, in accordance with our -- with our process, we conducted that field investigation. We documented it thoroughly, and I sent them a notice of noncompliance and asked them to remove all of that equipment from the banks of the river immediately.

Q. Okay. And did you get compliance?
A. Of -- of the ones that were found to be in noncompliance, all but one have we achieved compliance on, and that one, it went through the district court process. We had a -- a decision in district court -- excuse me. My enforcement action was tracking in district court, and at the same time for this particular incident, there was a parallel track in the lower Rio Grande adjudication that was occurring. My compliance process was held in district court in lieu of a decision in the adjudication. The adjudication received favorable decision stating that that individual did not have water rights or a right to divert water from the Rio Grande. That was appealed, and I believe that process is still underway.
Q. This investigation that you conducted in 2012 or 2013, was there a report written in connection with the -- what you found?
A. There was. So we -- it was a bulk investigation. We looked at each and every potential infraction that was brought to our attention by the Bureau of Reclamation, and we documented all of that in a field investigation memo that I generated.
Q. And who was the field investigation memo sent to?

A. From what I recall, that would have been the water rights director. That is John Romero, and whoever was the state engineer at the time.

MR. GOLDSBERRY: Please mark that as the next exhibit in order.

(Exhibit No. 66 was marked.)

THE REPORTER: 66.

MR. GOLDSBERRY: 66. Here is another one.

MR. ROMAN: Thanks.

MR. GOLDSBERRY: Pass those around until we run out.

Q. (BY MR. GOLDSBERRY) Okay. I've had a document marked as Exhibit 66. This document bears the alpha numeric notation of NM 82822 through NM 82827. Have you had an opportunity to look at Exhibit 66?

A. I have, yes, sir.

Q. Do you recognize it?

A. I do, yes, sir.

Q. What is it?

A. As it's titled, this is OSC summary regarding the IBWC Rio Grande Project River Diversion Investigation.

Q. Okay. And do you know who created this document?

A. I did not create this document. It's my under -- it's my recollection that this was done by my predecessor, Mr. Craig Cathey, but I did participate in the investigations of these individual sites.

Q. And does this document reference the investigation that you just told me about that was initiated in response to information provided by the Bureau of Reclamation?

A. It does, yes, sir.

Q. Okay. Okay. And am I correct in my understanding of your prior testimony that since the investigation referred to in Exhibit 66, you're not aware of any additional investigations that have been conducted into illegal pumping?

A. There -- there are additional investigations that have been conducted in addition to what's shown here as Exhibit 66.

Q. Okay. Tell me about those, please.

A. Those additional investigations would have been a follow-up to this particular information, and those additional investigations would have been coordinated and conducted by myself and my staff.

Q. Okay. And how were those follow-up investigations documented if at all?

A. They were -- they were documented in -- in a form similar to this one, but it was -- it's a report that I generated in a form similar to this one, but it had associated pictures and maps of all the valid and illegal points of diversions.

Q. When was the last time you conducted such an investigation?

A. The last time would have been late in 2013, and we make it regular practice to go by all these sites on a regular basis and make sure that they're maintaining compliance.

Q. And are those inspections documented somewhere?

A. They are, yes, sir.

Q. And how are they documented?

A. They're documented in paper form, along with associated pictures, maps, and correspondence in the, what we refer to as the meter file.

Q. Okay. So if I wanted to look at these inspections, I'd have to ask for a particular meter file?

A. Yes, sir.

Q. And how are the meter files organized or how are they -- how are they titled or captioned?

A. They're -- they're titled or captioned by the point of diversion number as identified in the waters database.

Q. Okay.

A. And some of these that are -- that are what the OSC considers illegal would not have an associated file number or well number, point of diversion number, but rather just a -- a reference name. For example, the first one on this report that's in front of me, Exhibit 66, you see it's called Greenwood Tract. We would have followed suit and called that meter file Greenwood Tract.

Q. Okay. Take a look at the last page, NM 82827, and the last bullet point on that page. Were you involved with this incident that's described here regarding Dona Ana County pumping water directly from the river for road maintenance?

A. As -- in the capacity as an assistant water master in documenting that particular infraction, yes.

Q. Okay. And how would -- how was that particular infraction documented, other than the notation that we see here on Exhibit 66?

A. From what I recall about that incident, again, we -- we went out to the site, we investigated, we found county staff on site with their pumping equipment. They were instructed to stop immediately, return the water that was in the pumper truck back to the river, and then we followed suit with the notice of noncompliance to the county manager.

Q. Are your enforcement activities coordinated in any way with EBID?

A. Most enforcement actions are not coordinated with EBID; however, in the past, we have had a couple of incidents where we have coordinated with management staff at EBID.

Q. Tell me about the incidents that you have coordinated.

A. The one that comes to mind, we refer to as the Duran River pump. The Duran River pump is a point of diversion on the Rio Grande or that particular individual, that water right owner, Mr. Duran, turns that pump onto receive his allotment of EBID surface water. We found Mr. Duran to be utilizing that pump to pump surface water out of the river outside of an active delivery or an order in place with the Elephant Butte Irrigation District. Their water operations individual was immediately notified, as well as the EBID's manager. I got ahold of that individual the day that we found that particular infraction, and I waited on site for well over an hour for him to come out and shut that pump down. I followed suit with a notice of noncompliance, carbon copied the Elephant Butte district manager, and he, in turn, also sent correspondence to that particular owner notifying him of his violations as it relates to EBID's policies and carbon copied me, and that activity has not occurred again since that time.

Q. How did you know that it was outside an active delivery order?

A. That -- that would have been what the -- the phone call to the water operations manager at the time. I let him know the particular site that I was at over the phone. He checked his system, and he was able to tell me at that point in time that there was not an active order.

Q. Why -- what -- aroused your suspicion to make that call?

A. I physically saw the pump pumping water out of the river.

Q. Had you had prior experiences with this particular pump?

A. I knew it existed. I knew it -- what its purpose was. As part of our -- our regular rotation and our field work and our presence in the field, we generally go by the site pretty frequently, because we have a surface water monitoring location within a mile of the Duran pump. So in driving by, that's when we caught that activity.

Q. Okay. How much of your time, on average, is spent -- your personal time is spent in the field currently?

A. Two to three days a week.

Q. And how much time did your -- do your four assistants spend in the field per week on average?

A. On average, four to five.

Q. Do you attend EBID board meetings?

A. I do, yes, sir.

Q. Why?

A. In my role as the water master, it's important for me to -- to know and understand the activities of the irrigation district, their allotments of surface water and any issues that they might be having, like I stated previously, because it gives me a really good idea of how to coordinate my staff's time around the movement of surface water within the district.

Q. Is -- is there a particular time of year that you attend those meetings?

A. I attend those every month as I'm able to.

Q. What other out-of-the-office meetings do you attend on a regular basis?

A. None on a regular basis that I can think of.
Q. And what was your reason for attending the EBID depositions?
A. To -- to get a -- a better understanding of -- of how the depositions would be conducted and to participate in a -- in a support role with the legal team.
Q. Have there been other activities that you've been involved in -- let me withdraw that and start over.
Did you participate in gathering information in response to the request for production of documents that the State of Texas made to the State of New Mexico?
A. I did, yes, sir.
Q. What did you do in that regard?
A. I produced any documents, whether that be electronic or paper that were responsive to the individual request for production.
Q. Okay. So you were provided with a written copy or an electronic copy of the -- of the entire set of requests for production?
A. No, sir, not the entire set.
Q. Okay.
A. Just the ones that pertain to my -- my

jurisdiction.

Q. So how did you go about looking for electronic documents that were responsive?

A. Based on the question that was raised in the RFP, I searched through my personal folders, through our network folders for anything even vaguely related to the particular topic. General word search, and then just using my own personal knowledge where some of those individual electronic files might be within our server.

Q. Are your e-mails maintained on the server?

A. Our e-mails are most definitely maintained. I do not believe they are maintained on our District 4 server. I think it's a larger -- it's my understanding that it's a larger based platform operated by the State of New Mexico's Department of Information Technology.

Q. And was that search for documents related to your activities?

A. I'm not aware of that.

Q. At least you didn't do the search?

A. I didn't do that, no, sir.

Q. You didn't have access to that system?

A. To the e-mail system, yes.

Q. Okay.

A. Through my own personal e-mail, and I did -- some e-mails were provided as part of that RFP process.

Q. Do you know how long your e-mails are maintained?

A. No, sir, I don't know.

Q. What stimulates a field check of the well? Let me rephrase that question. I don't like it.

What causes you to go out and do an inspection of a well?

A. There's -- there's a couple of different things. One -- the first would be when a meter is installed on a well or a meter is replaced or repaired, the owners will notify us of that activity, and that would trigger an inspection on the part of me and my staff. We would go out and make sure that the meter and the meter installation adheres to our standards and specifications. The second would be, I think we talked a little bit about this earlier, with regard to the buckslip and the standard process for the water rights division. When those approved applications are forwarded through me, we'll set up an appropriate meter file for that particular point of diversion, and when the well log is received for that particular application, we'll go out and inspect that well to make sure that all the well driller's rules and regulations with regard to construction are followed, the permit conditions are followed, and as well as the metering conditions and all the related meter requirements as stated in the lower Rio Grande metering order. So that's a second trigger. And then the third would be in the course of our day-to-day activities out in the field, if we come across a well that's pumping, that's diverting groundwater, my staff would make a point to stop and test those meters on a regular basis to ensure that they're -- they fall within our acceptable accuracy range.

Q. And what is that range?

A. As stated in the lower Rio Grande metering order, that range is plus or minus 10 percent installed accuracy. The manufacture accuracy out of the box has to be plus or minus 2 percent.

Q. So the -- the folks that have the meters on their wells, they have an obligation to, I think you told me, to report either on a quarterly or monthly basis the amount of their diversions, correct?

A. Correct.

Q. And is that done electronically?

A. It takes on several different forms. Electronic is one, via e-mail. They also send in paper copies of their meter forms to the office or they fax it in.

Q. Okay. How does -- how did the faxed and paper copies, how did those get entered in the database?

A. When they're received, our front office staff date stamps those. They hand them off to any one of my four assistant water masters, and they enter that data on a daily basis.

Q. Okay. So your -- your assistants are doing the entry. How many -- how many wells -- I may have asked you this, but I'll ask it again anyway. How many wells are you getting metering reports on currently?

A. Currently, we're receiving approximately 90 percent of our metered wells are sending in their readings, and that's as of -- as of our last quarterly on that particular issue, which was run some time last month.

Q. So 90 percent of what sort of a total?

A. Right in the range of 2,600 wells. So 90 percent of the 2,600 is -- has a reading entered for the last quarter of 2018.

Q. I take it that will be referred to in your 2018 annual report, correct?

A. Yes, sir.

Q. Has that been completed, your 2018 annual report?

A. As of today, no, sir. I've kind of been busy with RFPs.

Q. Haven't we all? So as of the last quarter of 2018, you've got about 260 wells that aren't sending in their reports, correct?

A. Approximately, yes, sir.

Q. Walk me through the process of what you're going to do about those folks.

A. Well, the -- the process would have began prior to the last quarter, so we have a standard process for achieving -- or receiving those last quarter meter readings. What we do every year is we send out a postcard, a reminder postcard to every single owner of an actively-metered well, reminding them of their obligations to submit their readings at the end of the year or for every quarter for that matter, and that's sent out prior to the January 10th reporting deadline. After the January 10th reporting deadline, roughly two weeks after that has past, I will run a query to see which readings are still outstanding, and I will send a notice -- an initial notice noncompliance to those owners who had not sent in the readings, and we usually -- we generally get a really good response to that, and it'll bump up our percentages up to 70 or 80 percent. And from there, if we still have some outstanding, what we do is we'll conduct what's called a meter blitz, and the purpose of the meter blitz is to acquire those meters that are outstanding for the purpose of completing our water master report and ensuring that we have a representative sample of all the wells reporting. So from there, after that point, it would be where we're at today. If those readings are outstanding, we'll send a second notice of noncompliance to those owners and begin a process where -- with our administrative litigation unit where we can try to seek penalties for them not complying with their requirements to report.

Q. When you took over the job as the water master, what was the compliance rate with regard to meter reporting?

A. It -- it was variable at times, more in the range of -- of 80 to 85 percent submittal rate.

Q. Okay. And that -- and that submittal rate is documented every year in your annual report?

A. Since -- since my time as the water master, yes, sir.

Q. Okay. Now, what type of wells have a monthly

reporting requirement?
A. That would be municipal, commercial, industrial.
Q. How many of those wells do you have currently in the district?
A. I can't say that I've ever broken out that particular category. What I would consider non-irrigation, which is inclusive of some of those types of uses is on the order of 400 to 450.
Q. So you get 400 to 450 wells that are non-irrigation, and that includes municipal, commercial, and industrial?
A. A portion, yes, sir.
Q. Okay. What else does it include?
A. It includes some metered domestic, some metered multiple domestic, some ag use -- what are considered ag use, which is non -- it's ag use that's non-irrigation. There would be some fish and game propagation, some utilities, some subdivision, some school use. There -- there's a long list of categories in the non-irrigation field.
Q. And where would I find that if I wanted to look for it?
A. You can find that -- we try to detail that in our annual water master report, but a more complete

list would be available in the water rights abstracting bureau, because we follow suit with their codes as they're entered into the water database.

Q. Okay.

MR. GOLDSBERRY: Let's break for lunch.

THE VIDEOGRAPHER: Off the record, 12:03.

(Break.)

THE VIDEOGRAPHER: On the record, 1:36, File 4.

Q. (BY MR. GOLDSBERRY) Just before lunch or shortly before lunch, you mentioned something about the administrative litigation unit collecting penalties for non -- noncompliance. Are you involved in the actual -- well, tell me the process. How -- how do they get to the -- to the penalty stage?

A. The penalties themselves are not collected by the administrative litigation unit. We -- through our compliance order and action process, we will -- we'll send an initial notice like we've talked about from the water master, then there's a certain period of time between a second notice will be sent from the administrative litigation unit if the issue hasn't been resolved, and if the issue continues to be unresolved then we will petition district court for enforcement of an administrative compliance order. Once we're in district court, we will request fines of up to a hundred dollars a day per day that that person has been in violation, and we will also request, you know, that that specific issue be remedied, whether it be the installation of a meter, the removal of equipment, if it's an illegal pump, things of that nature, then the Court will order that a certain amount of the requested fines be paid.

Q. Who actually handles that litigation?

A. The Administrative Litigation Unit.

Q. How much was collected in penalties in 2018?

A. Oh, gosh.

MR. ROMAN: Objection; foundation.

A. I'm not sure.

Q. (BY MR. GOLDSBERRY) Okay. Where would I go to find out?

A. The Administrative Litigation Unit would have -- I believe they would have a record of how much was collected in either of the districts in the state.

Q. Who is -- who is in charge of the Administrative Litigation Unit?

A. We've had some turnover recently, and I'm -- to be completely honest, I'm not sure who currently is the head of that department.

Q. Okay. And they're in Santa Fe?
A. They're in Santa Fe. And that's -- that's under the -- the purview of our general counsel.
Q. Does the general counsel do an annual report?
A. I am not aware.
Q. Okay. How do you figure out who's delinquent in their meter reporting?
A. So I have to use -- we run queries, and those queries are developed in the Microsoft access platform. We use that as a user interface to talk to the waters database to -- to extract data from the waters database. With regard to delinquent meter readings, I can run queries based on a certain date. So if readings hadn't been received as of today, for example, I could run a report, and it would generate a list of -- of all those delinquent owners and readings.
Q. Were any of those reports produced in your recent efforts to respond to requests for production from Texas?
A. Yes, sir.
Q. Let's talk about your annual report for a little bit. When you started as the water master, had annual reports been prepared by your predecessors on an annual basis?

A. I would not call them reports. Matter of fact, I think they're referred to as summaries. The previous -- my predecessors developed annual summaries with some general information regarding the submittal rates, the amount of water in the specific use categories, how much water was diverted in each of the use categories.

Q. And are those annual summaries available on the district's Website?

A. The -- the district does not have a Website. The -- the engineer's office does. I am not aware if those reports of my predecessors, those summaries, are on there, but they can be -- you can get those from the district office or by request.

Q. Were those summaries produced in the -- in response to the recent requests for production?

A. I do believe they were, yes, sir.

Q. What brought about the switch to an annual report?

A. You know, as I -- as I assumed the role of the water master, I kind of reviewed my duties as laid out in my job description and reviewed statute, and it seemed to me that that was a critical component of what my duties were, and I felt it was appropriate to expand upon those summaries that were generated by my predecessors and put forth a more comprehensive and detailed report that -- that would be useful not only to the district, but also upper management and maybe water users within the lower Rio Grande.

Q. So you're the one that generated the idea to go to an annual report?

A. Yes, sir.

Q. Okay. And where are you on the report for 2018?

A. For 2018, we're still -- we're still compiling the data. Like I mentioned earlier, we have approximately 90 percent submittal rate at this point, and I've yet to run the queries for the final end-of-year data just because of my time. I haven't had a chance to do that.

Q. So who actually writes the report?

A. I do.

Q. Does any -- are any parts of the report drafted by any of your assistants?

A. They do not draft any portion of the report, but they will review the content at certain times.

Q. And do you submit a draft to anyone for review prior to its becoming available to the public?

A. I will usually submit a draft to the district manager, and she reviews that. She does final review for content, completeness, and grammatical structure, things like that.

Q. And how is the report distributed?

A. The report is distributed electronically via e-mail.

Q. To whom?

A. To the water rights director, to the state engineer, to the director of the interstate stream commission, general counsel and deputy general counsel, the Water Use and Conservation Bureau director, what -- what I would consider to be upper management.

Q. Who is the water use and conservation bureau director currently?

A. Currently, that is Molly Magnauson.

Q. Have you ever received any guidance from the state engineer with regard to the format of the annual report?

A. No, sir.

Q. How are the -- how is the -- how is the annual water usage tabulated?

A. Again, through those queries, we're able to see each individual water right and that the diversions from each of -- each of those water rights points of diversion is extracted from the water database and to that access program that I discussed, and we export that in the form of an Excel spreadsheet. And those -- from there, we go through a process of cleaning the data to sort by categories, removing duplicates, things of that nature, and once everything is cleaned up, we sort -- we go through, and we tabulate and run some dynamic equation queries -- dynamic equations, excuse me, in Excel to try to quantify the amount of water in each of those use categories.

Q.   In your experience, what is the accuracy of the water -- waters database?

A.   In my experience, in my tenure, I know there's been at least one-third-party audit of our data for three accounting periods, and that audit had always reflected less than 10 percent.

Q.   Who performed those audits?

A.   That particular audit was performed by Ballew Groundwater.

Q.   Is the water use -- is the annual water usage tabulated by water right or by well or both?

A.   By water right.

Q.   If you wanted to determine how much water was diverted by an OWMAN, owner management program file, in a given year, how would you do that?

A. It's the same process. It gets reported when I run the end-of-the-year query. Those all have unique file numbers, the ownership management files do, and their total water usage is extracted out of the database when we run those queries.

Q. Are the -- any of the -- any of the totals in the waters database ever manually adjusted?

A. As part of our quality assurance process and quality check after the data has been extracted, we go through, and sometimes there are some anomalies that appear in those data sets where it would show excessive water use for particular files or not enough water use based on the averages. So we'll go in and investigate that, and sometimes it's a matter of data entry error or maybe the meter readings may have been submitted wrong or even some issues with the abstracting process and some bugs that exist in the database where maybe a file was modified or corrected as part of the -- the abstracting process, and it's still holding onto a point of diversion that it shouldn't be holding onto or something of that nature. So we try to correct all those problems.

Q. And how are those corrections documented if -- if at all?

A. If myself and my staff was involved in correcting those, we will -- there will be either a memo in the meter file or a note of the -- or the adjustment.

Q. Okay.

MR. GOLDSBERRY: Let's mark that next in order, which is --

MR. ROMAN: 67.

MR. GOLDSBERRY: -- 67.

(Exhibit No. 67 was marked.)

MR. GOLDSBERRY: Pass those around, please.

Q. (BY MR. GOLDSBERRY) Have you had a chance to look at Exhibit 67?

A. I have, yes, sir.

Q. And I should indicate for the record that Exhibit 67 is marked NM 18261 through 18289. And what is this document?

A. This document is the Lower Rio Grande Water Master Annual Report for the 2017 accounting year.

Q. And that's -- that's a document that you authored, correct?

A. Yes, sir.

Q. How many of the over diverters referred to in that report are still remaining as of today?

A. For the -- the 2017 accounting year, it's my recollection that we achieved full compliance, and we had repayment plans in place for all of the over diverters that we identified.

Q. Were any of them prosecuted?

A. No, sir.

Q. Are there over diverters that are still out there from previous years?

A. No, sir.

Q. On Page 5 of this exhibit, "this exhibit" being No. 67, at the bottom of the page, you talk about an open house that was held in September of 2017 with EBID. Was -- tell me about that open house. What all went on there?

A. In that particular accounting year, 2017, there were -- there was a late adjustment to the surface water allotment within EBID, and when that was announced, there was concern amongst myself and my staff and the OSE in conjunction with the Elephant Butte Irrigation District that that late allotment -- late increase to the surface water allotment would cause potential widespread over diversions, because irrigators had irrigated early in the season with an understanding of a certain amount of surface water being available. So in an effort to be proactive, we had a few meetings with Elephant Butte Irrigation

District. We decided to -- we did a -- a press release. We had some notices that we developed that were posted in both our office and, I believe, in -- in the offices of the Elephant Butte Irrigation District. We coordinated this open house where we would have EBID officials present, OSE officials present to answer any questions related to the dynamics that we were experiencing in that year.

Q. Was that open house recorded in any way?

A. Recorded?

Q. By video or court reporter?

A. I'm -- I'm unaware if there was a video recording or audio recording.

Q. Were there minutes taken of the proceeding?

A. I do not believe there were, no, sir.

MR. GOLDSBERRY: Let's mark this next in order.

(Exhibit No. 68 was marked.)

Q. (BY MR. GOLDSBERRY) Okay. Exhibit 68 is a two-page document annotated as NM 94847 and 94848. Have you had an opportunity to review the document?

A. Yes, sir.

Q. And are you familiar with the document?

A. I am, yes, sir.

Q. And were you the author of the document?

A. I was, yes, sir.
Q. And does this describe the situation you previously testified to about the problem in 2017?
A. It does. If I -- if I could, there's -- there appears to be an error here with regards to the date.
Q. That was going to be my next question.
A. I did not do this memorandum on July 29th of 2019. I imagine when it was opened, it automatically had the date repopulated. This was done in July of 2017. And to answer your question, yes, it was done in response to a situation that I previously described.
Q. Do you attend meetings of the Pecan Growers Association?
A. I do not.
Q. Let's talk about the owner management program. Would you describe that program for me, please?
A. The owner management program was derived from the Stream System Issue 101 settlement agreement. There's a specific provision within the agreement that allows for joint ownership in management of water amongst lands that are jointly owner managed. We -- we were -- once we received that order -- settlement

agreement and final order from the adjudication court, and in turn, tried to take that to administer it, we had to look at each of those provisions and develop administrative strategies for handling those things, and the owner management program, as it exists today, is a result of that particular provision. What it does is it allows for the -- for the grouping of lands that are either owned or managed by an individual, and it allows for the averaging of the use of groundwater and surface water across all of those lines.

Q. Okay. What are the -- what are the qualifications for participation in the program?

A. There's a prescribed form that any particular individual has to use, and in order to participate, they have to list the water right file number, the hydrographic survey sub-file number, the amount of acres, whether or not there was a notice of intent on file for that particular water right, and there also has to be a owner signature for each individual water right allowing for those rights to be put in to this grouping. Other criteria before, when we're entertaining all that, we're looking at those groupings, we have to make sure that the water rights listed are recognized water rights within -- by the Office of the State Engineer, so we'll cross reference all that in our database, make sure that they're in good standing with our office and that they're recognized, the water rights that are listed. And then we'll go through with our WRAB bureau, and they'll proceed to group all those water rights together in our waters database under a unique identification number.

Q. Is the requirement of the program that all of the properties that are brought in to a given agreement be managed by a single individual?

A. That's not a specific requirement, but that is usually the case.

Q. So it's not a requirement?

A. No, sir.

Q. Is there a requirement that the owners on any one file have a written agreement with each other?

A. That's not a specific requirement, but, again, that is usually the case.

Q. So what gets filed -- let's take a hypothetical situation. We've got five owners that come together on -- and want to participate in this program. They fill out this form, provide the information, and file it with you?

A. They file it with the office with -- with me, yes, sir. Usually there's a lot of supporting documentation including lease agreements. We require maps of the lands that will be involved in the ownership management agreement, and any sort of other contractual things that they might have between the manager and the owner, they can provide that stuff, but it's not a requirement.

Q. Okay. If they do provide it, does it get included in the new file that's created?

A. Yes, sir.

Q. And does that information all get imaged on the waters database?

A. That information, with regard to ownership management, is not imaged. It's housed in paper files in the District 4 office.

Q. Why is it not imaged?

A. I do not have the answer to that question.

Q. So how does a member -- does the public have access to review those plans?

A. Absolutely. They can come in and see them at any point in time.

Q. So the only way you can see the plan is to come to your office and look at the paper file?

A. That's not necessarily true. There's -- you can look at the -- the particulars of the plan via the waters database. Like I said, it'll have a unique file number assigned to it. All of the lands that are included in that file, you can look at that in waters, the waters database, and it'll show the grouping, it'll show the total number of acres, total allowable diversion, how much groundwater they pumped for the year, how much surface water they've been allotted, the -- the total combined between surface diversions and groundwater diversions, percent diverted and how much is remaining, whether that -- there's a positive balance or negative balance there. That's all available in waters, available to the public.

Q. Do these plans get revised on an annual basis? Let me withdraw that question. That's not really what I want to ask you.

Are they required to resubmit the plans on an annual basis?

A. At this point in time, they are not. The plans will carry through in perpetuity until there's a change. So if there's an addition or subtraction, then they're required to notify us.

Q. And when that happens, does the owner management ship file -- owner management ship fill get -- does a new file get created?

A. No, sir. That -- it retains its number.

Q. Okay.

A. But a new transaction will be reflected in the database where there -- you'll see there was an amendment, either an addition or subtraction.

Q. What happens to the files that get combined in the waters database?

A. Those files remain intact. They're still there. For all intents and purposes, they're still active files, only -- only the diversions and acreages get removed from the removed from files into the into, which is the ownership management account, for accounting purposes. None of the essential elements of the water right are affected by -- by the ownership management plan.

Q. So the ownership management plan doesn't create a new right of any sort?

A. Absolutely not, no, sir.

Q. Is there an approval of -- of a plan required by your office?

A. When the plans are submitted, I review all of the plans for completeness, and on occasion, I'll assign some of them to my senior staff to review to make sure, as I stated earlier, that all the water rights that are being proposed to be included are recognized by the Office of State Engineer, and they're in good standing before we'll give final approval and allow for the entry of that plan in the database.

Q. What do you mean they're in good standing?

A. There may be, you know, an issue with a particular file, if there's outstanding issues in hearing or mediation or things of that nature. We don't want to affect those ongoing processes, so we won't allow them at that point in time to be included.

Q. Do you know if there is a similar program in any of the other New Mexico districts? And I'm talking about the OWMAN program.

A. From what I understand, I believe the OWMAN -- the OWMAN program, as it exists in the lower Rio Grande, is unique, and it does not exist anywhere else.

Q. Prior to that program being created as a result of this settlement agreement and decree was it possible to accomplish the same thing?

A. There was a similar process, administrative process, referred to as a combined and commingle.

Q. Tell me about that process.

A. Prior to 2011, the 101 settlement, an owner who wanted to move water in and amongst farms that he either owned or managed had to submit an application for a combined and commingle, and it would follow the more traditional application process with notice and application review and either permit approval or denial.

Q. So that process actually had to get approved by the district?

A. By the -- the water rights specialist, yes, sir.

Q. All right.

A. Water right division.

Q. Is that process used in other districts?

A. Yes, sir.

Q. Prior to this settlement agreement, was the -- how frequently was the combined and commingle program utilized in -- in District 4?

A. I don't -- I don't have a good sense for -- a good answer for that question, sir.

Q. Fair enough. You know who would?

A. You -- you could run queries on the database to find that exact number out.

Q. Is there a fee charged to file these plans?

A. No, sir. There's no fee assessment.

Q. Why not?

MR. ROMAN: Object to foundation.

MR. GOLDSBERRY: What's that?

MR. ROMAN: Foundation.

MR. GOLDSBERRY: Foundation.
Q. (BY MR. GOLDSBERRY) Do you know why the -- there's no assessment levied for this filing?
A. I do not.
Q. Okay. Do you know who would know?
A. I -- I do not.
Q. Okay. Is there a particular process for canceling one of these plans?
A. We have a -- a withdraw form, so either an individual water right owner who does not -- no longer wants to participate in an owner management plan can submit, come in and file a withdraw form, and we'll promptly remove that particular water right from the ownership management plan, or the manager himself can file that same withdraw form to completely disband the ownership management agreement.
Q. Are these plans mentioned anywhere in the OSE rules and regulations that you're aware of?
A. Not that I'm aware of, no, sir.
MR. GOLDSBERRY: Let's take a break.
THE VIDEOGRAPHER: Off the record, 2:21.
(Break.)
THE VIDEOGRAPHER: On the record, 2:36, File 5.
MR. GOLDSBERRY: Mark that, please.

That is?
THE REPORTER: 69.
(Exhibit No. 69 was marked.)
Q. (BY MR. GOLDSBERRY) Have you had a chance to look at --
A. Yes, sir.
Q. -- the document that we marked as Exhibit 69? This is a copy of a document entitled, "Mesilla Valley Administrative Area Guidelines for Review of the Water Right Applications dated January 5th, 1999." Are you familiar with this document?
A. I've seen it, yes, sir.
Q. Is it still being used?
A. From my understanding, it is, yes, sir.
Q. Have there been any efforts to update this document?
MR. ROMAN: Foundation.
Q. (BY MR. GOLDSBERRY) Are you aware of any efforts to update this document?
A. I -- I am aware that there have been some efforts to update this document, yes, sir.
Q. And what -- what do those consist of?
A. From my understanding, there have been a few meetings. I don't know if there's been any drafts or anything like that.

Q. I take it you have not been personally involved with those efforts?
A. No, sir.
MR. GOLDSBERRY: Let's do it this way. Go ahead and mark that one 70.
(Exhibit No. 70 was marked.)
MR. ROMAN: Mac, can I grab one?
MR. GOLDSBERRY: Oh, I'm sorry. I got so carried away. Give me one.
MR. DUBOIS: Oh, all right.
MR. ROMAN: Thank you.
MR. GOLDSBERRY: There will be a day when you need to return the favor. They always come around.
Q. (BY MR. GOLDSBERRY) Okay. Are you -- let me -- let me make sure our record is clear. The document that I've just had, Exhibit -- marked as Exhibit 70 is also designated as NM 76889 through NM 76911. Have you had an opportunity to look at that document?
A. Yes, sir.
Q. And what is your understanding of what it represents?
A. These are the rules and regulations governing the appropriation and use of surface waters in the

State of New Mexico. These are rules that are promulgated in New Mexico Administrative Code.

Q. Okay. And have implementing rules within promulgated in District 4 on this topic?

A. These rules are statewide rules, and we do apply them in District 4.

Q. Okay. That wasn't my question. Are there District 4 specific rules that take these rules and regulations further and apply them specifically to that district?

A. Not that I'm aware of, no, sir.

Q. Okay. Are there similar rules and regulations related to groundwater?

A. There are, yes, sir.

Q. What are the current rules dated on groundwater?

A. There's -- there's a set of rules regarding the use of what are termed 72121 domestic wells, which would, of course, be groundwater wells. Those are promulgated. And there's some general rules for underground water administration that are -- have been promulgated. Nothing specific to the lower Rio Grande that I -- that I'm aware of.

Q. Okay.

(Exhibit No. 71 was marked.)

Q. What were the particular issues in the lower Rio Grande that the steering committee was trying to address?
A. Well, as it relates to -- to my role, metering and water use implementation of the metering program, the amount of groundwater being diverted, and any sort of administrative enforcement or compliance actions that may -- may need to be taken or have been taken.
Q. Was the information contained in Exhibit 72 included in your annual report for 2014?
A. The information contained in Exhibit 72 would have been a -- a more updated form of the information than what was contained in my report. The report would have been generated in the spring of that year, 2015.
Q. So 72 is more up to date than what was in your 2014 report?
A. Yes, sir.
Q. Okay.
(Exhibit No. 73 was marked.)
MR. GOLDSBERRY: Is that 3 or --
THE REPORTER: 73.
MR. GOLDSBERRY: 73.
Q. (BY MR. GOLDSBERRY) Okay. Exhibit 73 is a

single-page document designated by New Mexico as 84892. My first question is: Is this an accurate date on this memorandum?

A. It is not.

Q. Okay. Got to love computers.

A. I know.

Q. Databases. Do you know when this document was -- well, first of all, do you recognize this document?

A. I do, yes, sir.

Q. And were you the author of the document?

A. I was.

Q. And what's your best recall of approximately when you created this document?

A. I don't have a good sense of when it was created.

Q. I suppose the original date is still in your -- in your -- on your server somewhere?

A. Absolutely. Yes, sir.

Q. All right. Is this a -- a report that you run for each year or a memorandum or does it just depend on who the state engineer is at the time?

A. It -- it does. We -- in general, we track -- of course, we track this information regularly upon request by either the engineer or the water rights director. We will generate these sorts of memoranda or summaries at various times of the year to -- to be able to show them where we're at in the process.

Q. As I understand your earlier testimony, you've reconciled all prior over diversions of groundwater through what year?

A. Through 2017.

Q. Including 2017, correct?

A. Yes, sir.

Q. Okay. In the first sentence, this is -- of this memo, you indicate, and I quote, "To date, water master staff has mailed out 160 notices of groundwater accounting for 2012 to those water right owners who appear to be the most egregious diversions in need of reconciliation." How do you define "most egregious diversions," as you used it in this memo?

A. At that time from what I recall, an over diversion that equated to a hundred-acre feet or more in excess of their allowable water right.

Q. I sort of asked you part of this question, but I'm going to try it again. Regarding the diversion and use of surface water, diversion and use of groundwater permitting wells and well metering, have there been any regulations promulgated that specifically apply to District 4?

A. From what I can recall, there are not.
Q. Is there any form of written guidance on any of those subjects that pertain specifically to District 4?
A. The Mesilla Valley Administrative Guidelines, which is Exhibit 69 here.
Q. Right. Anything else?
A. As far as promulgated rules, no.
Q. Are there any rules being currently talked about that you're aware of on those subjects?
A. Yes, sir, there are.
Q. Tell me about that.
MR. ROMAN: To the extent the question calls for discussion of anything that's being talked about in conjunction with legal counsel, that would be privileged. I'm going to instruct the witness not to get into that area.
MR. GOLDSBERRY: Fair enough.
Q. (BY MR. GOLDSBERRY) Do you understand the limitation on your ability to answer my question?
A. I do.
Q. Okay. Answer it, please.
A. There's -- there's discussion ongoing about district-specific rules.
Q. And who, other than your counsel, and other

SIGNATURE OF WITNESS

I, RYAN SERRANO, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

____

RYAN SERRANO

Job No. 3197405

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS	)	
	)	
Plaintiff,	)	
	)	Original Action Case
VS.	)	No. 220141
	)	(Original 141)
STATE OF NEW MEXICO,	)	
and STATE OF COLORADO,	)	
	)	
Defendants.	)	

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, RYAN SERRANO, to the interrogatories as indicated were made before me by the said witness after being first duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. GOLDSBERRY - 03:39:23
MR. ROMAN - 00:00:00
MR. WALLACE - 00:00:00
MR. DUBOIS - 00:00:00
MS. BARNCASTLE - 00:00:00
MS. O'BRIEN - 00:00:00
MS. DAVIDSON - 00:00:00
MR. UTTON - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 7th day of March, 2019.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 12-31-19
VERITEXT LEGAL SOLUTIONS
Firm Registration No. 571
300 Throckmorton Street, Suite 1600
Fort Worth, TX 76102
1-800-336-4000

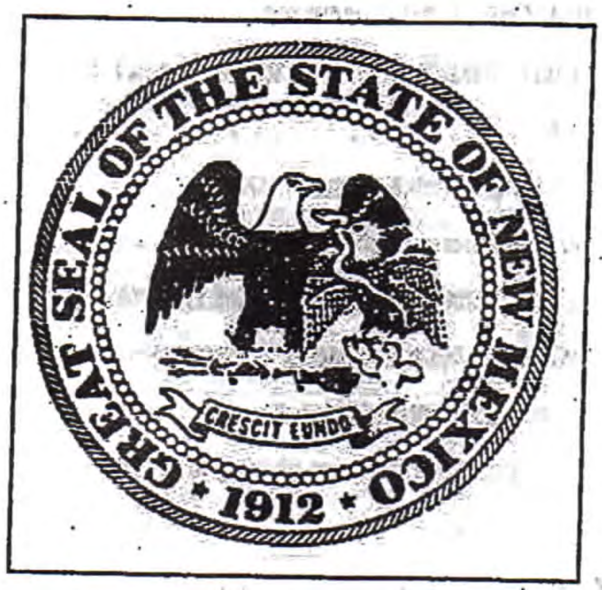
Tab 31

MESILLA VALLEY ADMINISTRATIVE AREA GUIDELINES FOR REVIEW OF WATER RIGHT APPLICATIONS

PREPARED BY

THE OFFICE OF THE NEW MEXICO STATE ENGINEER

FOR INTERNAL USE



THOMAS C. TURNEY

STATE ENGINEER

January 5, 1999

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OFFICE OF THE STATE ENGINEER

MESILLA VALLEY ADMINISTRATIVE AREA GUIDELINES FOR REVIEW OF WATER RIGHTS APPLICATIONS

FOR INTERNAL USE

INTRODUCTION

~~These guidelines for water rights administration have been~~ developed for a specific sub-area within the Lower Rio Grande underground water basin. These guidelines are intended to address both surface and groundwater administration within this sub-area.

This sub-area is called the Mesilla Valley Administrative Area (MVAA) and is shown in Figure 1. The purpose of this document is to provide guidelines to Office of the State Engineer (OSE) personnel on general procedures to follow for processing and acting on water rights applications filed within the MVAA, inclusive of applications submitted pursuant to NMSA Sections 72-12-1 et. seq. (1998), and is intended as a general guide for internal purposes to assist in reviewing applications; however, each water rights application will be evaluated on a case-by-case basis. Factual differences will exist from application to application, but through the guidelines, the OSE hopes to treat all applications fairly and equally.

These criteria apply to applications for new appropriations, applications for supplemental wells, and applications to change point of diversion, and/or place and/or purpose of use.

The State Engineer has developed administrative criteria in order to assure the orderly development of water resources within the MVAA, while meeting statutory obligations regarding non-impairment to existing water rights, availability of unappropriated water, conservation of water within the state, and public welfare of the state.

These guidelines begin with administrative objectives or water resource goals to be achieved. Administrative standards which quantify allowable surface water depletions and water level declines follow. The guidelines end by outlining the application evaluation procedure.

A. ADMINISTRATIVE OBJECTIVES

The State Engineer has identified the following administrative objectives.

1. The Rio Grande stream system is fully allocated and existing rights may not be impaired by proposed appropriations. The system within the MVAA includes the Rio Grande, irrigation canals and laterals, and drains and wasteways. The primary aquifer within the MVAA is recognized as a stream-connected system in which groundwater withdrawals will ultimately result in depletions of surface water sources.

2. Local water level decline rates resulting from proposed appropriations should not impair existing rights. Local water level declines refer to drawdown at nearby wells of other

ownership.

3. The appropriation of water and/or a change in place of use, purpose of use and/or point of diversion shall not be contrary to water conservation within the state nor be detrimental to the public welfare of the state.

4. A groundwater appropriation may be granted to the extent that unappropriated water is available to the well from the aquifer at the proposed point of diversion.

5. Existing water quality for domestic, municipal, agricultural, industrial and other beneficial uses may not be impaired.

6. The existing drains system will not be impaired.

B. ADMINISTRATIVE STANDARDS

To achieve the above objectives, quantitative standards have been selected. These standards are provided below.

1. A surface water depletion of less than 0.10 acre-foot in any year due to a proposed appropriation will be deemed acceptable and no offset of this impact will be required during that year.

2. An average annual local ground water level decline rate of 1.0 foot per year or less due to a proposed appropriation in combination with the exercise of existing water rights will be deemed acceptable when addressing impacts on existing wells of other ownership.

3. Wells completed into the flood plain alluvium or within

one mile of any surface water source can have large and immediate surface water impacts. Depths to groundwater within this area are generally less than 100 feet below land surface. This zone adjacent to the surface water system is referred to as the High Impact Area (HIA) and is shown in Figure 2. The boundaries of the HIA are coincident with the area in which the depth to water is 100 feet or less (New Mexico State Engineer Technical Report No. 43, Plate 16, Wilson and others, 1981).

C. ADMINISTRATIVE CRITERIA

Administrative criteria have been developed to serve as agency guidelines on how to process and evaluate pending applications for surface and groundwater appropriations within the MVAA. Each application will be reviewed on a case-by-case basis.

1. OFFSET OF SURFACE WATER IMPACTS - Applications within the MVAA for groundwater appropriations that impact the surface waters beyond acceptable depletions (see B.1.) must offset 100% of the surface water depletions caused by the appropriation. All wells used to appropriate water, other than wells permitted under NMSA Section 72-12-1 (1998), must meet these requirements. An offset is achieved by acquiring a volume of water through a water right or other contractual obligation in the affected water source and releasing that water to replenish the affected volume in the source that results from exercise of the permitted groundwater appropriation. Offsets must be made before groundwater withdrawals

commence tantamount to surface water effects associated with the full exercise of the permit. Because of the uncertainty in hydrogeologic characteristics, the State Engineer will not require offsets of surface water depletions when the proposed transfer of water rights results in an increased calculated depletion of less than 3% of the total amount of water diverted and consumed. If offset requirements are not achievable, the application will be denied.

2. APPLICATION REQUIRED FOR OFFSET - Offsets may be made by filing application to change point of diversion and/or place and/or purpose of use of valid existing water rights. The State Engineer may alternatively consider other methods for offsetting as proposed by an applicant. The amount credited to offset the surface water effect will be based on the historical use of the water right and the resulting surface water impact.

3. APPLICATIONS FILED PRIOR TO IMPLEMENTATION OF THESE CRITERIA - These criteria are intended to allow the numerous applications currently on file with the Office of the State Engineer to be processed. These applications may be approved if the OSE staff requires, prior to pumping, sufficient water rights to be transferred by permit to offset the additional depletion on the Rio Grande, and the proposed application does not impair existing water rights, is not contrary to conservation of water within the state, and is not contrary to the public welfare of the

State. The applicant shall proceed with due diligence in acquiring offsetting water rights and placing the water to beneficial use.

4. OPTION TO LEASE OFFSET RIGHTS FOR APPROPRIATIONS OUTSIDE OF HIA - Groundwater appropriations located outside of the HIA may have delayed surface water depletions. Due to these possible delays, the full amount of water rights acquired for offset purposes may not be needed for those purposes during early pumping time periods. Rights not immediately needed for offset purposes may be leased and used at a different location or for a different use as provided by statute and rules and regulations governing the appropriation and use of water. Alternately, the rights, if not immediately needed, can be left at the original place of use and may continue to be exercised pursuant to their original purpose.

5. CALCULATION OF SURFACE WATER DEPLETIONS - The calculation of surface water depletions are necessary for the following situations:

a) applications for new groundwater appropriations;

b) applications to transfer water rights;

c) applications to retire water rights for offset purposes;

d) applications for supplemental wells that result in a shift of the pumping center.

Stream effects from discontinuing appropriations in b or c above may persist as surface water impacts (residual impacts) associated with the recovery of the cone of depression. In the evaluation of the application, calculations will be performed to determine whether the residual impacts plus the impacts from the move-to well maintain an allowable level of surface water depletion. The allowable surface water depletion is the amount up to the surface water depletions associated with the use of the retired water right if the water right had continued to be exercised at its original location (Figure 3). Surface water depletions will be estimated through the use of a superposition model based on a model presented in Frenzel-Kaehler (1992), using the procedures described in Barroll (1998), or such improved successor model and procedures as they become available. The calculated reduction in evapotranspiration (ET) will be treated as a surface water depletion because of the uncertainty in ET behavior. Within the HIA, the aquifer depletion for irrigation is the product of the irrigated acreage and recognized average consumptive CIR irrigation requirement. For HIA groundwater appropriations other than irrigation, and appropriations for all purposes outside of the HIA, the aquifer depletion is assumed to be equal to the diversion rate until a return flow plan has been accepted by the State Engineer.

6. CALCULATION ON LOCAL DRAWDOWN IMPACTS - Local drawdown effects due to a proposed appropriation will be evaluated on a case-by-case basis to ensure that impacts on the nearest wells of other ownership are maintained at an average annual rate of decline of 1.0 foot or less (this includes drawdowns due to existing uses,

criterion 7). It will be the applicants burden to show that no impairment results when drawdowns exceed 1 foot per year. In the determination of whether local drawdowns are excessive, available water columns, impacts from existing and proposed uses, and the ability to deepen wells to sustain a freshwater supply will be considered as deemed necessary. Drawdown calculations may be performed using the superposition model, or the Theis equation. The method resulting in the greater impact will govern unless site specific information indicates that a particular method would be more realistic. Aquifer parameters used to calculate drawdowns on nearby wells may be obtained from available groundwater flow models or from site specific information as deemed reasonable. The pumping rate used in the calculations will be the aquifer depletion rate described in the last paragraph of criterion 5. Over 1 foot, average annual drawdown may be allowed based on the facts of the case and the applicant showing that there will be no impairment.

7. DRAWDOWNS DUE TO EXISTING WELLS - For the purpose of determining the water level decline due to existing rights, estimates included in Papadopulos (1987) or Lang and Maddock (1995) may be considered in addition to impacts from subsequently approved applications.

8. DIVERSION AND CONSUMPTIVE USE RATES FOR IRRIGATION WELLS [RESERVED]

9. RETURN FLOW CREDIT - Return flow credits, for other than

irrigation uses, permit a water right owner to divert waters beyond the consumptive use amount to the extent that water diverted over and above the recognized consumptive use amount returns back to the system. Return flow credits are only allowed if specifically requested through application. The return flow credit that the State Engineer may grant will be based on demonstration that waters are actually returning to the system. For groundwater appropriations in which credit is sought for returns back to the aquifer, the applicant will be required to address location, timing and quantification of flows back to the aquifer of origination. For surface water return flow credit, the location and amount measured by the applicant as return flows to the surface water source per method approved by the State Engineer may be considered for credits. Surface water return flow credits accrued may not be carried over to the following year.

10. AVAILABLE TRANSFER AMOUNTS - For applications to change point of diversion and/or place and/or purpose of use, the quantity of water that has been historically available and consumed for beneficial purposes will be taken as the amount which may be considered for transfer to the proposed use. For applications to transfer groundwater rights, the available offset amount will also be limited to the difference between the impacts resulting from the continued use of the move-from well and the residual impacts described in item 5. For applications to transfer rights from

irrigation to other purposes, the historical consumptive use will be considered available for transfer. If surface water rights are to be transferred long distances downstream or upstream, river losses or gains may be considered. Water uses developed from wells permitted under NMSA Section 72-12-1 (1998) shall not qualify as retirement rights.

11. SUPPLEMENTAL WELLS - Wells will be classified as supplemental only if the well is drilled in the same and only the same underground stream or channel, artesian basin, reservoir or lake and does not increase the appropriation of water to an amount above the existing water right. Application for supplemental well(s) may be granted if applicable criteria have been met. These include but are not limited to the issues of local drawdown effects, surface water depletions, conservation and public welfare. Applications for supplemental well(s) for declared water rights may be approved, but only as provided for in criteria 14 and 16 below. Application for supplemental well(s) for permitted water rights that have been perfected, or are currently in development, may be approved for the total permitted water right.

12. CONSERVATION OF WATER - The State Engineer will determine whether an application is contrary to the conservation of water in the state. Water conservation issues will be addressed on a case-by-case basis. Applications and water conservation plans, if any, will be reviewed to ensure that highest and best technology

practically available and economically feasible for the intended use will be utilized to ensure conservation of water.

13. PUBLIC WELFARE - The State Engineer will determine whether an application is detrimental to the public welfare of the state. The state water planning process, statewide and local issues of concern, water quality issues, and information submitted by parties in a protested application will be considered by the State Engineer in making the public welfare determination.

14. REASONABLE QUANTITY OF WATER SOUGHT - Each application will be reviewed to determine whether the well may reasonably obtain the quantity of water sought. A determination of the availability of water from a particular point in the aquifer will be based on the transmissivity/storativity of the aquifer at that location, the proposed well casing diameter, the water column in the well, and the freshwater thickness. In addition, it will be assumed that a well capacity of at least 6 gallons per minute is required per irrigated acre and that a pump can not run more than 60% of the time, unless the applicant demonstrates that a higher percentage is reasonable.

15. 40 YEAR WATER PLAN - Municipalities, counties, public utilities supplying water to municipalities or counties, and universities must file a <u>40 YEAR WATER DEVELOPMENT PLAN</u> pursuant to NMSA Section 72-1-9 (1997), when submitting application to appropriate water or an application to change place and/or purpose

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of use. The plan should support the applicant's request to acquire and hold, unused, water rights provided they can show reasonably projected additional needs within forty years. At a minimum, the plan should include a summary of water rights held by the applicant; quantities of water put to beneficial use; plan of development of water rights sought; conservation measures incorporated by the applicant; and public welfare issues. The State Engineer will review the plan to determine if the proposals appear reasonable.

16. APPLICATIONS ASSOCIATED WITH PRE-BASIN WATER RIGHTS - An application involving declared water rights for a supplemental well, replacement well, change of point of diversion, place of use, or purpose of use may be filed by the applicant. The State Engineer will entertain a proposed change only to the extent that beneficial use has occurred. At the time of action on the application, the State Engineer may characterize the amount of declared water rights recognized.

When characterizing the amount of declared water right recognized, considerations will be given to:

a) date of commencement of works relative to date of declaration of the basin;

b) capacities of diversion works and source of supply;

c) existence of a water development plan, including feasibility of projected demands, in effect prior to declaration of the basin;

d) adherence to and diligence in following that water development plan;

e) the amount of water beneficially used;

f) continuity of actual beneficial use; and

g) period of time since the basin was declared.

17. VERIFICATION OF OWNERSHIP OF TRANSFERRED WATER RIGHTS - Determination of ownership of water rights is not within the jurisdiction of the State Engineer. Unless otherwise notified in writing, the State Engineer will proceed with application processing as if an applicant is the owner or has authorization of the owner of the water right that the applicant proposes to transfer. If a question of water right ownership or owner authorization is raised before final action by the State Engineer, the State Engineer will suspend his decision until the question is resolved by a court of competent jurisdiction or other appropriate legal authority.

18. DECLARATIONS - Any person, firm or corporation claiming to be the owner of a vested water right from any of the underground sources of the Lower Rio Grande Basin, by application of waters therefrom to beneficial use, may make and file a declaration on a form prescribed by the State Engineer. The declaration shall set forth the beneficial use to which said water has been applied; the date of first application to beneficial use; the continuity

thereof; the location of the well; if such water has been used for irrigation purposes, the description of the land upon which such water has been used for irrigation purposes; and the name of the owner. Such records or copies thereof officially certified are prima facie evidence of the truth of their contents. Declarations may be accompanied by affidavits of persons having personal knowledge of the history of the works or by other evidence tending to substantiate the claims and by copies of well logs, if available, but may be rebutted by other evidence. Beneficial uses cited in declarations will be inspected in the field by OSE staff and all works and beneficial uses will be documented.

19. 72-12-1 WELLS - The State Engineer will issue any qualified applicant a permit to drill and use a well as provided in NMSA Section 72-12-1 (1998). With the exception of wells for single household use or livestock use, all wells will be required to be metered and the permittee will be required to submit meter readings to the State Engineer. Permits issued for the drilling and use of wells pursuant to 72-12-1 are subject to such limitations as may be imposed by the courts and lawful municipal and county ordinances which are more restrictive than applicable State Engineer regulations.

20. METERING - As a condition of approval on all permits, with the exception of single household domestic permits and/or livestock use, a measuring device or meter is required and the

volume of water diverted must be reported to the State Engineer.

21. ADJUDICATION - Applications filed subsequent to the water rights being adjudicated by a court will also be subject to these criteria.

22. MAPS - Filing maps, conforming to the State Engineer's latest rules and regulation, will accompany all applications.

23. STATE ENGINEER OPTION TO REVISE GUIDELINES - As new data become available, or as conditions warrant, the State Engineer may revise these guidelines to best achieve the administrative objectives above. If any part of these guidelines is found by a court to be invalid, the remainder shall remain valid and will continue to be used for evaluation purposes.

Adopted this 5th day of January, 1999.

Thomas C. Turney

Thomas C. Turney
State Engineer

REFERENCES

Barroll, Peggy, 1998. Maddock and Papadopulos Models of the Lower Rio Grande. State Engineer Office Memorandum.

Frenzel, Peter F. and Charles A. Kaehler, 1992. Geohydrology and Simulation of Ground-Water Flow in the Mesilla Basin, Dona Ana County, New Mexico, and El Paso County, Texas. U.S. Geological Survey Professional paper 1407-C.

Hamilton, S.L. and T. Maddock III. 1993. Application of a Ground-water Flow Model to the Mesilla Basin, New Mexico and Texas. Department of Hydrology and Water Resources, University of Arizona, HWR No. 93-020.

Papadopulos, S.S. and Associates, 1987. Hydrogeologic Evaluation of Proposed Appropriation of Ground Water from the Lower Rio Grande Underground Water Basin by the City of El Paso. Consultant report prepared for the NM State Engineer Office.

Wilson, Clyde A., Robert R. White, Brennon R. Orr, and R. Gary Roybal, 1981. Water Resources of the Rincon and Mesilla Valleys and Adjacent Areas, New Mexico. State Engineer Technical Report 43.

-Example Conditions of Approval-

FOR APPLICATIONS IN THE LOWER RIO GRANDE BASIN

1. This permit shall not be exercised to the detriment of valid existing water rights, shall not be contrary to conservation of water within the state, and shall not be detrimental to the public welfare of the state of New Mexico.

2. The State Engineer recognizes ______ acre-feet per annum under declaration LRG-_______ and (all) (part) of said water rights are severed therefrom under this permit.

3. The diversion of water from well no(s). LRG ______ shall not exceed ________ acre-feet per annum for __________________ purposes, inclusive of ________ acre-feet per annum for consumptive use. If the permit is for irrigation purposes, the diversion shall be limited to the irrigation of _____ acres of land. In all applications to appropriate, the diversion of water shall be further limited to condition no. 4.

4. Water shall not be diverted under this permit until the permittee transfers ___________ acre-feet (sufficient water rights equivalent to the consumptive use anticipated to result in a surface water depletion caused by the exercise of this permit) to offset the anticipated surface water depletions. The permittee shall proceed with due diligence in acquiring offsetting water rights and placing the water to beneficial use.

5. Well no(s). LRG_______ shall be equipped with a totalizing meter(s) of a type and at a location approved by, and installed in a manner acceptable to the State Engineer. The permittee shall provide in writing, the make, model, serial number, date of installation, initial reading, units, and dates of recalibration of each meter , and any replacement meter used to measure the diversion of water. No water shall be diverted from any well unless equipped with a functional totalizing meter.

6. Records of the amount of water diverted from well no(s). LRG ______ shall be submitted, in writing to the State Engineer on or before the 10th day of the month for the preceding calendar month.

7. The permittee shall utilize the highest and best technology available and economically feasible for the intended use to ensure conservation of water to the maximum extent practical.

8. A well record for well no(s) shall be filed with the State Engineer within ten (10) days of drilling the well (s).

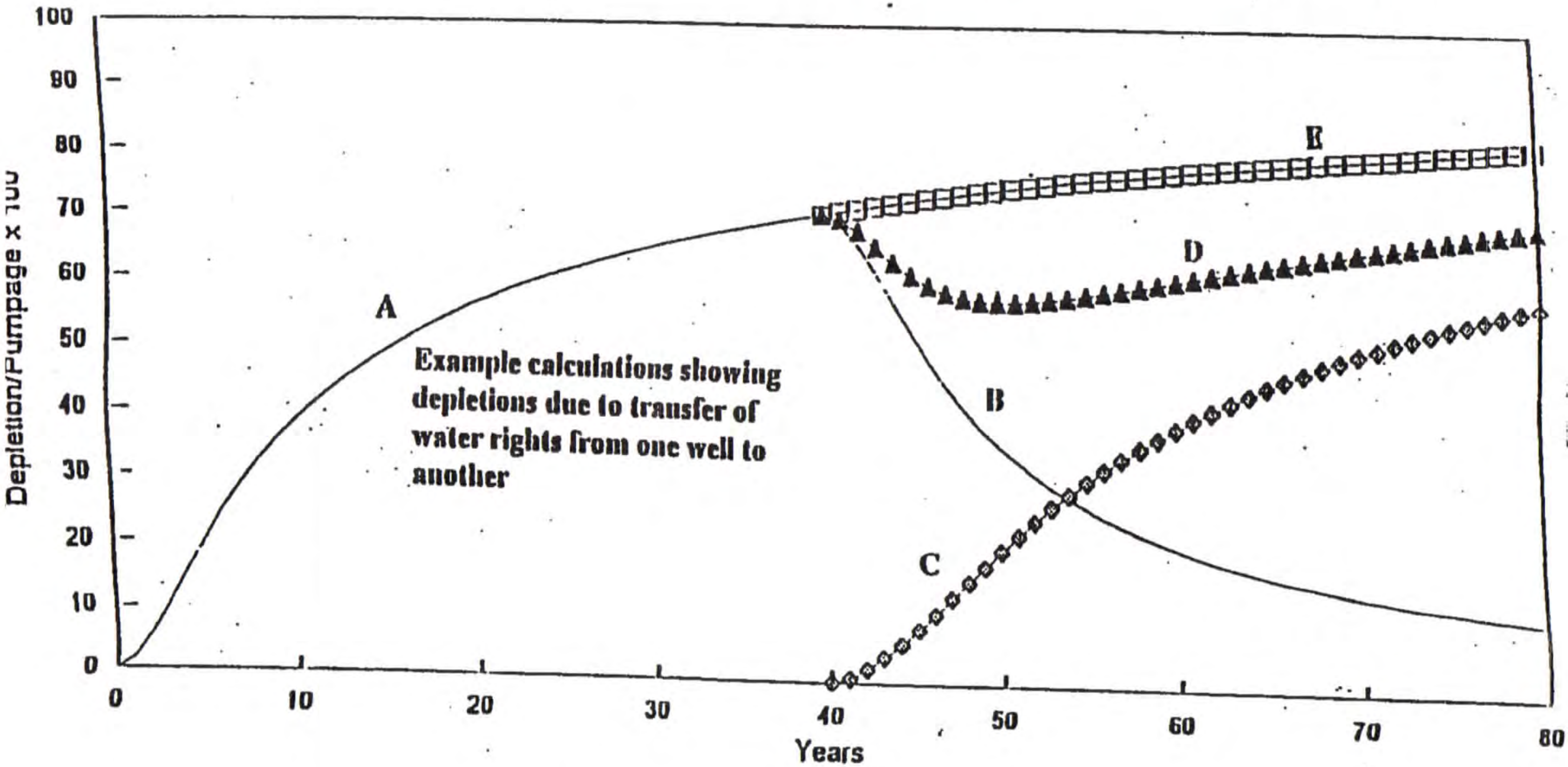
9. Proof of completion of Well(s) shall be filed with the State Engineer on or before (2 years).

10. Proof of Application of Water to Beneficial Use shall be filed with the State Engineer on or before (4 years).

11. Old well no(s). LRG______ shall be plugged or capped in accordance with Article 4-14 of the Rules and Regulations Governing Drilling of Wells and Appropriation and Use of Ground Water in New Mexico. A written record of the plugging or capping shall be filed with the State Engineer within ten (10) days of completion of the plugging or capping.

Maddock Model Predicted Surface Water Depletions

for Transfer of Groundwater Rights



A - Surface water depletion due to pumping well from which water rights will be transferred (move-from well)
B - Residual depletions due to turning off move-from well in year 40
C - Depletion due to the pumping from a new well to which rights were transferred (move-to well) in year 40
D - Total depletion due to the transfer (Curve B + Curve C)
E - Hypothetical depletion resulting from the continued use of the move-from well

FIGURE 3

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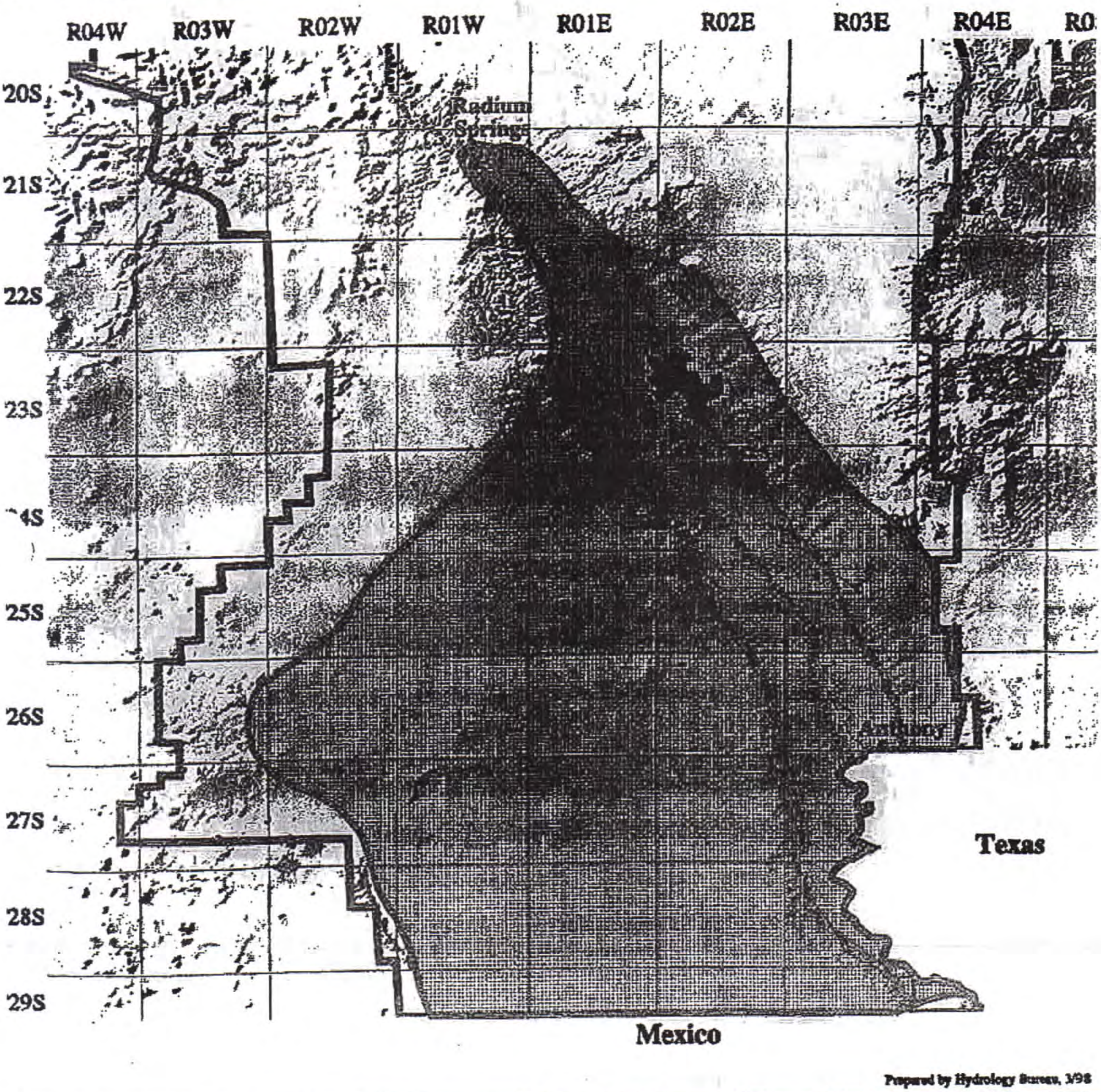
Figure 2: Location of the Mesilla Valley Administrative Area and High Impact Area



Legend

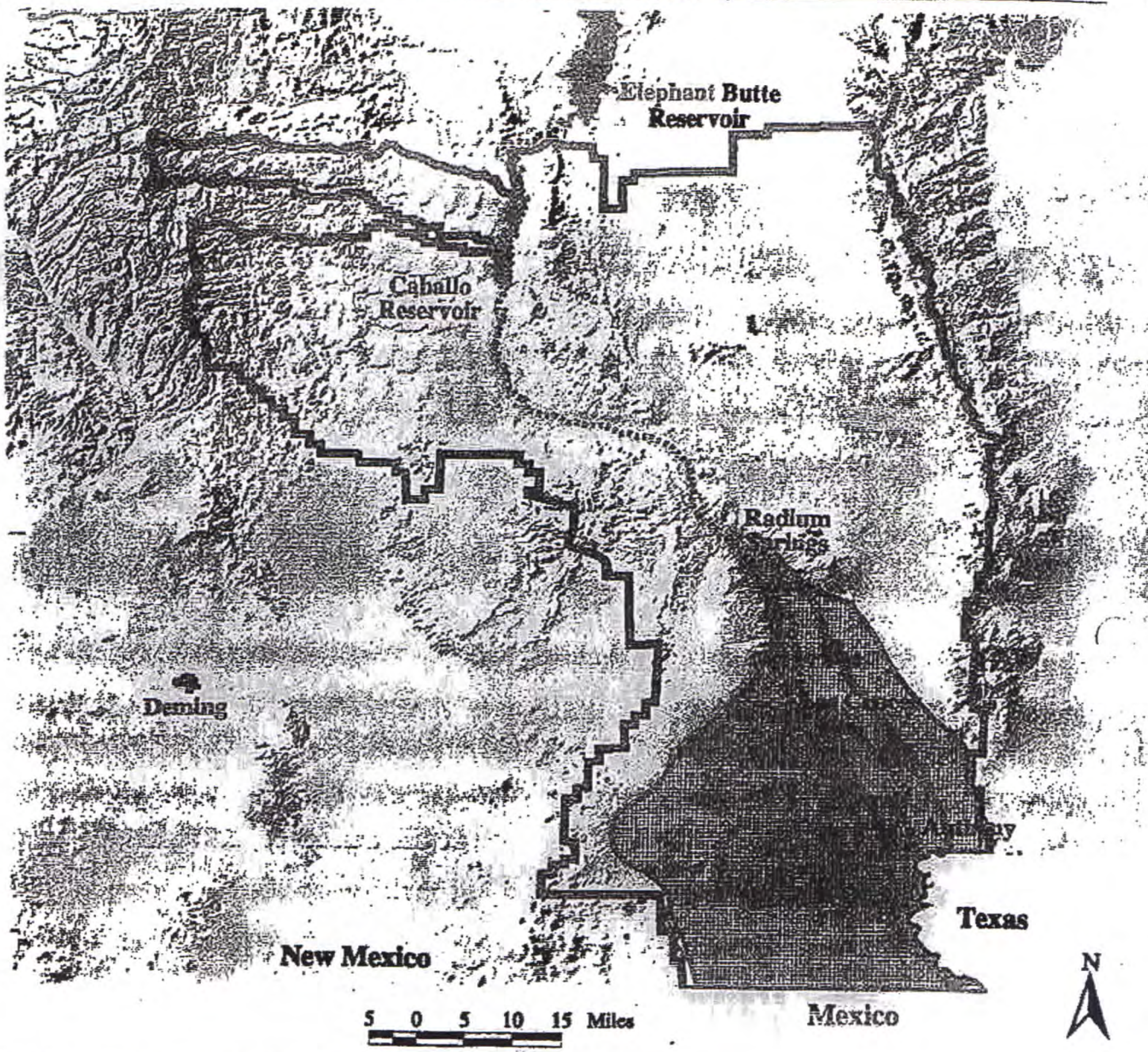
Lower Rio Grande Underground Water Basin

Mesilla Valley Administrative Area

Scale

5 0 5 10 Miles

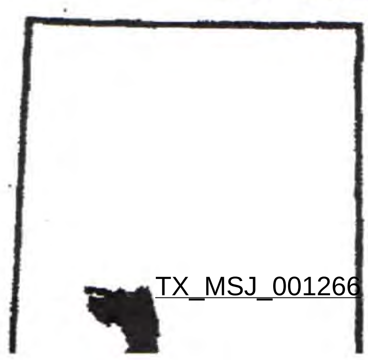
Figure 1: Lower Rio Grande Underground Water Basin



Prepared by Hydrology Bureau, 3/9

Legend

Lower Rio Grande Underground Water Basin
Mesilla Valley Administrative Area
High Impact Area (HIA)
Rio Grande



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Tab 32

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS)
)
Plaintiff,)
) Original Action Case
VS.) No. 220141
) (Original 141)
STATE OF NEW MEXICO,)
and STATE OF COLORADO,)
)
Defendants.)

****
ORAL AND VIDEOTAPED DEPOSITION OF
RYAN SERRANO
APRIL 17, 2019
VOLUME II
****

ORAL AND VIDEOTAPED DEPOSITION of RYAN SERRANO, produced as a witness at the instance of the Plaintiff State of Texas, and duly sworn, was taken in the above-styled and numbered cause on April 17, 2019, from 9:17 a.m. to 4:34 p.m., before Heather L. Garza, CSR, RPR, in and for the State of Texas, recorded by machine shorthand, at the HOTEL ENCANTO DE LAS CRUCES, 705 S. Telshor, Las Cruces, New Mexico, pursuant to the New Mexico Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed.

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ALSO PRESENT:

Mr. Bert Cortez

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WITNESS: RYAN SERRANO

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THE VIDEOGRAPHER: Today is April 17, 2019. The time is approximately 9:17 a.m. We're now on the record beginning Tape 1.

MR. GOLDSBERRY: Let's begin by stating appearances. Francis Goldsberry for the plaintiff, State of Texas.

MS. COLEMAN: Judith Coleman from the United States Department of Justice for the United States.

MR. RICH: Chris Rich from the Office of the Solicitor Department of the Interior.

MR. CORTEZ: Bert Cortez with the Bureau of Reclamation El Paso office.

MR. ROMAN: David Roman and Chris Lindeen for the State of New Mexico.

MR. WALLACE: This is Chad Wallace for the State of Colorado, and I'll note that the video link for remote attendance hasn't started yet.

THE VIDEOGRAPHER: Okay. I'm working on it.

MR. ROMAN: And I should have announced Michael Kopp on the phone as well for the State of New Mexico.

MR. GOLDSBERRY: Is the video feed going or --

THE VIDEOGRAPHER: I'm working on it. It'll be up in a minute. Can we start with the audio or...

MR. GOLDSBERRY: Chad, what's your pleasure?

MR. WALLACE: I don't have anything yet, Mac.

MR. GOLDSBERRY: Okay. Do you want us to wait until we get that connected or can you live with the audio for the first few minutes?

MR. WALLACE: If -- if you want to get started and somebody is working on that remote cam, I'm -- I'm fine with doing it that way.

MR. GOLDSBERRY: All right.

RYAN SERRANO,

having been first duly sworn, testified as follows:

E X A M I N A T I O N

BY MR. GOLDSBERRY:

Q. Good morning, Mr. Serrano.
A. Good morning.
Q. How are you doing today?
A. I'm doing fine. Thank you.
Q. Is there any reason why you shouldn't go forward with this second day of your deposition?
A. No, sir.

Q. Do you understand that this is a continuance of the -- the deposition that we started on February 26th of this year?
A. I do.
Q. Okay. Do you understand -- well, you've just been sworn again so you're clearly still under oath. What did you do, if anything, to prepare for today?
A. Between the last deposition and today, no preparation.
Q. Did you read the transcript of the first day of your deposition?
A. I did not.
Q. Have you signed that transcript?
A. No, sir.
Q. Okay. Okay. Before we get started, I'd like to go through a procedure that we're going to follow today. I have some electronic exhibits that have been placed on memory sticks, one exhibit per memory stick, and the procedure that I propose to use is that for each exhibit, I will announce for the record what it is. These are all documents that have been produced by the State of New Mexico, and then I'll ask the court reporter to give the memory stick an exhibit number. That memory stick will then be plugged into the computer that is in front of me, and you should be

able to see the document that we're looking at. There's a monitor in front of Mr. Serrano and counsel. It's going to be a little tougher for you guys on the telephone, but we will then go through my questions on a particular exhibit, and what I propose is when I finish my questions on one of these exhibits, I will then pass the -- the questioning to the United States to deal with that particular exhibit, not necessarily to the exclusion of plugging the exhibit in later and asking questions further down the road, but I'm hopeful that we can get most of the questions out on an exhibit-by-exhibit basis.

MR. GOLDSBERRY: Counsel, if you have questions that you want to make some sort of clarification about, we'll do that, also, at the same time. Are there any objections to using that -- oh, one other thing, I have provided counsel for the State of New Mexico and -- and counsel for the United States with disks that contain the exhibits that are on the -- on the memory sticks. You have a separate disk for each exhibit that you can mark. And then at the end of the day, we will -- the memory sticks will become the official record and part of the original transcript. Are there any objections to that procedure?

people that you've mentioned were involved in the discussion?

A. That would have been Greg Ridgley.

Q. I'm sorry?

A. Greg Ridgley.

Q. And what position did he hold?

A. At the time, I believe he was deputy general counsel.

Q. Is he still deputy general counsel?

A. No. He's now general counsel. Also, John Romero, water rights director; Andrea Mendoza, the district manager; myself, and there were a few other technical folks, from what I remember, during that discussion that were there, but I can't pinpoint exactly who it was at that time.

Q. Where did the discussion take place?

A. It was a teleconference -- videoconference.

Q. Okay. And all of the people that you've mentioned were on the videoconference?

A. Some -- some were on videoconference in Santa Fe, and myself and Andrea were local here in the district office.

Q. Do you recall any of the discussion as to why the group chose not to use a hundred percent --

MR. ROMAN: I object to the extent that

include -- you're including water user's right to receive water from EBID?

A. Correct.

Q. Now, in the total allowable diversion column, are EBID allotments figured into that -- well, what we're looking at here doesn't include that, but for -- would the total allowable diversion include the EBID allotment?

A. For -- for that respective file, yes, ma'am.

Q. Okay. And is that -- is that number updated throughout the year?

A. If -- if the allotment changes, it is.

Q. So in -- when you're looking at something like irrigation over -- over 110 percent, that -- I'm sorry. Let me withdraw that question.

So the irrigation -- I'm sorry. The information and irrigation over 110 percent in the diversion column would re -- could reflect someone exceeding their EBID surface allotment; is that correct?

A. It -- that number is representative of somebody exceeding their combined total of their groundwater allotment in addition to their surface water allotment.

Q. Okay. Is there -- what is the reason for tracking EBID surface water allotments?

A. For those water rights that are identified in our files as being combined irrigation surface water from EBID and supplemental groundwater, we have to track both of those sources for the purposes of making sure they don't exceed their total combined allotment.

Q. So what is the reason for including the EBID allotment as part of a water right that the state engineer's office tracks?

A. As -- as I understand it, the surface water is what could be considered primary water right, and then the supplemental groundwater in addition to that. And all -- all of those users within EBID that have an irrigation purpose of use would have that surface water component associated with them, and then some of them would also have the groundwater right tied to it. So as a whole, the state engineer's office recognizes both of those sources of water for that water right.

Q. Did you ever create spreadsheets or -- to track non-irrigation use over a particular amount of allowable diversion?

A. I have, yes. Not in 2012, but years after that, I have.

Q. Did you do it in 2018?

A. Yes.

Q. Is there a reason for the change to looking at non-irrigation users?
A. Just as best practice, we wanted to make sure we cover all our bases and look at all of the users.
Q. Do you recall what year you started looking at non-irrigation users over their diversion amounts?
A. I can't recall the particular year.
Q. Is it while you were a water master?
A. Yes, ma'am.
MS. COLEMAN: I think that's all I have.

F U R T H E R E X A M I N A T I O N

BY MR. GOLDSBERRY:
Q. Do you track the actual deliveries to owners by EBID?
A. On occasion, those owners will provide us with what's called a water usage report from EBID that identifies the amount diverted at the farm.
Q. Is that something that you've requested from a particular owner or is it just done as a matter of routine?
A. Usually, as part of reconciling an over diversion, the -- these owners will actively seek out that information from EBID to compare how much they receive versus how much they were allotted.
Q. Okay. And what -- okay. Is there any other

information that -- that you track on a regular basis regarding folks who are entitled to EBID allotments?

A. No, sir.

Q. What is -- what was the -- what was your primary purpose for creating this document that we've labeled Exhibit 91?

A. It served two purposes. One was to establish our end-of-the-year diversion numbers for each of the respective use categories, and then the second was to identify those individual users that had gone over their allowable limit and begin the enforcement process.

Q. And that first purpose is something that you use in preparing your annual report?

A. Yes, sir.

MR. GOLDSBERRY: All right. That's all I've got on this. Do you want to take a five-minute break?

MR. ROMAN: Sure.

THE VIDEOGRAPHER: Off the record, 11:31 a.m., ending Tape 2.

(Break.)

THE VIDEOGRAPHER: Back on the record, 11:40 a.m., beginning Tape 3.

MR. GOLDSBERRY: I'm wondering why we

don't have the spreadsheet up.

THE WITNESS: I see it here.

MR. GOLDSBERRY: You see it there?

THE WITNESS: Uh-huh.

MS. KLAHN: Oh, there it goes.

MR. GOLDSBERRY: There it goes. Just a matter of touching the plug, I guess.

Q. (BY MR. GOLDSBERRY) As I indicated to you at the beginning of our discussion on Exhibit 91, the metadata on this particular document indicates that it was created on February 18th, and it also create -- it indicates that it was last modified on February 22nd. You've testified about correcting errors that we discussed on this particular exhibit. I've gotten the impression that you create new queries rather than going back in and editing this one; is that a correct understanding of the process that you use?

A. Correct. There would be subsequent spreadsheets and workbooks after this one that have corrected data. So we try to save every step of the way after we -- after we do cleanup or make corrections, we'll save a new spreadsheet, that way we can always reference back if we have to.

Q. And why do you do that?

A. So that way we don't lose data. Every step of the process, we know what we started with, and then the new spreadsheet would indicate either what was corrected or what was eliminated.

Q. What would be the circumstances that you'd go into this spreadsheet and edit it? Let me use a different word. What are the circumstances that would have caused someone, you or anyone else that has access to this spreadsheet that you created, what would be the circumstances that caused them to go in and make a modification?

A. For this particular spreadsheet, the modifications would have included doing the -- the formulas to generate the total diverted and the percent diverted and then breaking out the different categories for irrigation and irrigation over 110 percent. There -- thereafter, all modifications should have been done in a -- in a separate spreadsheet.

MR. GOLDSBERRY: Do you have further questions?

MS. COLEMAN: Yes, I have one more question on this.

F U R T H E R E X A M I N A T I O N

BY MS. COLEMAN:

Q. On -- for Column F, scroll up to the heading, at the top, that would have been red flagged and our WRAB bureau would have gone back in there and adjusted those numbers appropriately.

Q. So you're responsible -- are you responsible for doing the quality assurance checks on the OWMAN files that are in the waters database?

A. Partially. They -- the WRAB bureau does, through their abstracting process, they have a quality assurance process that they follow, and then once that's done at different points throughout the year, I'll go in and run quality assurance queries.

Q. Is -- does the WRAB bureau have a quality assurance program that's committed to writing anywhere?

A. From what I understand, they do.

Q. Have you ever seen it?

A. I don't think so, no, sir.

Q. Okay. Do you have any -- in the -- in the water master group, do you have any quality assurance procedures that have been committed to writing?

A. Not that I've been the author of, but I have seen one or two documents.

Q. What are they related to?

A. Meter entry and data assurance -- data quality assurance.

adjudication, SS 97101, and the final order that came out of that adjudication, the lower Rio Grande adjudication generally, New Mexico statutes annotated Chapter 72, and the Rio Grande Compact, correct?

A. That is correct.

Q. Have you ever read the Rio Grande Compact?

A. I have, yes, sir.

Q. What does your office do to implement the terms of the Rio Grande Compact, if any?

A. My office does not do anything locally to effectuate the Compact.

Q. Do you have an understanding of whether or not there's anyone with the -- within the state engineer's office that does have that obligation?

MR. ROMAN: Object to form.

A. Within the Interstate Stream Commission, and also the State Engineer's Office, yes.

Q. (BY MR. GOLDSBERRY) Are you aware of any activities that are conducted by either of those two entities that are related to implementation of the terms of the Rio Grande Compact?

A. Yes, sir.

Q. Okay. And what are those activities?

A. Stream gauging, reservoir accounting, and participation with those individuals with the Bureau

WITNESS CORRECTIONS AND SIGNATURE

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE CORRECTION REASON FOR CHANGE

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RYAN SERRANO, VOLUME II

S I G N A T U R E   O F   W I T N E S S

I, RYAN SERRANO, solemnly swear or affirm under the pains and penalties of perjury that the foregoing pages contain a true and correct transcript of the testimony given by me at the time and place stated with the corrections, if any, and the reasons therefor noted on the foregoing correction page(s).

____

RYAN SERRANO, VOLUME II

Job No. TX 3269298

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS)
)
Plaintiff,)
) Original Action Case
VS.) No. 220141
) (Original 141)
STATE OF NEW MEXICO,)
and STATE OF COLORADO,)
)
Defendants.)

THE STATE OF TEXAS :
COUNTY OF HARRIS :

I, HEATHER L. GARZA, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the facts as stated by me in the caption hereto are true; that the above and foregoing answers of the witness, RYAN SERRANO, to the interrogatories as indicated were made before me by the said witness after being first duly sworn to testify the truth, and same were reduced to typewriting under my direction; that the above and foregoing deposition as set forth in typewriting is a full, true, and correct transcript of the proceedings had at the time of taking of said deposition.

I further certify that I am not, in any capacity, a regular employee of the party in whose

behalf this deposition is taken, nor in the regular employ of this attorney; and I certify that I am not interested in the cause, nor of kin or counsel to either of the parties.

That the amount of time used by each party at the deposition is as follows:

MR. GOLDSBERRY - 04:31:53
MR. ROMAN - 00:00:00
MS. COLEMAN - 00:40:41
MR. WALLACE - 00:00:00

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 2nd day of May, 2019.

HEATHER L. GARZA, CSR, RPR, CRR
Certification No.: 8262
Expiration Date: 12-31-19
VERITEXT LEGAL SOLUTIONS
Firm Registration No. 571
300 Throckmorton Street, Suite 1600
Fort Worth, TX 76102
1-800-336-4000

Tab 33

IN THE SUPREME COURT OF THE UNITED STATES
BEFORE THE OFFICE OF THE SPECIAL MASTER
HON. MICHAEL J. MELLOY

STATE OF TEXAS,	:
	:
Plaintiff,	:
	:
VS.	: Original Action Case
	: No. 220141
STATE OF NEW MEXICO AND	: (Original 141)
STATE OF COLORADO,	:
	:
Defendants.	:

****

ORAL AND VIDEOTAPED DEPOSITION OF
HERMAN ROBERT SETTEMEYER
JULY 30, 2020
VOLUME 1

****

ORAL AND VIDEOTAPED DEPOSITION OF HERMAN ROBERT SETTEMEYER, produced as a witness at the instance of the Defendant State of New Mexico, and duly sworn, was taken in the above-styled and numbered cause on July 30, 2020, from 9:18 a.m. MDT to 4:10 p.m. MDT, via Zoom, before PHYLLIS WALTZ, RMR, CRR, CRC, Texas CSR, TCRR, Louisiana CCR, in and for the State of Texas, recorded by machine shorthand, pursuant to the Federal Rules of Civil Procedure and the provisions stated on the record or attached hereto; that the deposition shall be read and signed before any Notary Public.

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Mr. Christian Barrett

ALSO PRESENT:

Dr. Al Blair
Ms. Suzy Valentine, Texas
Mr. J. Phillip King, New Mexico

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Report of the Rio Grande Compact Commission, 2000, NM_00005402 - NM_00005437

THE VIDEOGRAPHER: The time is 9:18 a.m. and we are on the record.

HERMAN ROBERT SETTEMEYER,

having been first duly sworn, testified as follows:

MS. THOMPSON: Good morning, Mr. Settemeyer.

THE WITNESS: Good morning.

MS. THOMPSON: My name is Lisa Thompson, and I'm the attorney representing the State of New Mexico, and I'm going to be taking your deposition today in this lawsuit Texas V. New Mexico and Colorado. We are taking your deposition remotely, of course, and so I'm going to go ahead and ask, just to start off, that each of the parties enter their appearances and state who -- who is observing the deposition with them today.

So for New Mexico, it's Lisa Thompson. And currently I do not see anyone else joining to observe.

So for Texas?

MR. HOFFMAN: Texas is Robert Hoffman. And from our -- my office, Stuart Somach. From the Attorney General's Office, Priscilla Hubenak. And also observing is Suzy Valentine.

MS. THOMPSON: For the U.S.?

MR. DUBOIS: This is Jim Dubois for the United States, and Shelly Randel from the Solicitor's Office is observing, and I think that's it.

MS. THOMPSON: All right. Colorado?

MR. HARTMAN: Preston Hartman for State of Colorado. Good morning.

MS. THOMPSON: Good morning.

EBID?

EP1?

MR. HICKS: Renea Hicks for El Paso County Water Improvement District No. 1. And Al Blair I don't think is going to call in or link in, but he will be watching the AgileLaw case use.

MS. THOMPSON: Okay, very good.

And then what about Las Cruces?

MR. BROCKMANN: Lisa, this is Jim Brockmann. I'll be joining, I think, most of the day on behalf of the City of Las Cruces and the Albuquerque Bernalillo County Water Utility Authority.

MS. THOMPSON: All right, very good.

Do we have any other amici on?

All right, doesn't sound like it.

All right. Mr. Settemeyer, we're going to be using AgileLaw for me to exhibit the exhibits that I'll be using today, and I just want to make sure you are currently connected to AgileLaw, correct?

THE WITNESS: Yes.

MS. THOMPSON: Very good.

E X A M I N A T I O N

BY MS. THOMPSON:

Q. Will you go ahead and please state your name for the record.

A. Herman Robert Settemeyer.

Q. And what is your current professional title?

A. I am partner of RSA H2O, comma, L.L.C.

Q. And what's your business address?

A. The company address, it's in Austin, Texas. Do you need to know specifically?

Q. If you know it.

A. I don't know it offhand. I'll have to find a business card.

Q. Okay, that's okay. It's no problem.

So you went ahead and you just took an oath, and, therefore, your answers today are sworn testimony, just as if you were testifying at trial. Do you understand that?

A. Yes.

Q. And have you had your deposition taken before?

A. Yes.

Q. How many times?

A. New Mexico took -- took my deposition in the Canadian River Compact litigation. My deposition was taken in the Tarrant Regional versus Oklahoma litigation. I don't -- I don't recall any other depositions related to water rights within the state of Texas. I think those are the only two depositions that I've -- I've taken, although it's possible that I might have had some other depositions taken associated with permitting, but those are the two major ones, the Canadian River Compact litigation and the Tarrant Regional litigation versus Oklahoma.

Q. Okay. All right. I'll ask you about both of those in just a minute. But before we get to that, since I suspect it's been a few years since you've had your deposition, I'm going to go ahead and go over just a few of the general rules right off the bat, to make sure you and I are on the same page, okay?

A. Okay.

Q. All right. So if I ask a question and, for any reason, you don't hear it or you don't understand the question, please let me know and, if you'd like, you can ask me to rephrase it, okay?

A. Okay.

Q. And you can request a break at any time except for if there is a question pending, okay?

Q. Okay. And then on the last bullet, the process applications for water rights, was that just part of the -- of the initial step of the adjudication process?

A. No, that's -- that's back -- that's processing an application from an entity that wants a new water right or an amendment to the water right. That's separate from the adjudication.

Q. So this would be after the adjudication had occurred?

A. Well, I didn't -- I didn't do any of the permitting until -- I mean, I didn't do any of the permitting until after I had done the adjudications on the Bosque, Trinity, Neches, and Red. And then subsequent to doing that is when I did enforcement and permitting. So, basically -- so, basically, like I said, if somebody came in and asked for a water right or an amendment, then I was -- I was part of the group that would process those applications.

Q. Okay. And these are applications for a permit, right?

A. For a permit or an -- or an amendment to an existing permit.

Q. Okay. I see. And during this time, the 12-year period we've been talking about, did you have

any work duties related to the Rio Grande basin?

A. I don't -- I don't recall. During this period of time, I don't recall.

Q. Did the -- did the agency split up the state into different geographic areas that different engineers would work in?

A. Only -- only for the adjudication process. So during -- for the enforcement and the permitting process, you know, when those -- when those applications or those issues came before the agency, then they were -- they were assigned to various individuals working on -- on -- on -- in that field.

Q. Okay. We're going to jump forward, then, to the next entry where you spent 25 years, and the entry listed is "Texas Commission on Environmental Quality Engineer Advisor/Manager." Do you see that entry on your screen?

A. Yes.

Q. Actually, before we go to that, just one other follow-up question related to when you were doing one of the water rights work. Did you ever, as part of any of your duties, have to look at impacts to the surface water stream from groundwater pumping?

A. No.

Q. So then on the -- the next entry that I just

mentioned for the next 25 years, is what you've entered here, the "Engineer Advisor/Manager," are those two separate duties or two separate titles that you held?

A. Well, beginning in 1987 is when I started doing the work related to the interstate compacts, and I was the Engineer Adviser for the Canadian, Pecos, Red, Rio Grande, and Sabine River Compacts. Although for a portion of that time, I only became the, quote, official Engineer Adviser on the Rio Grande during the tenure of the commissioner before Pat Gordon. We used to have a -- a staff out in El Paso of an engineer and administrative assistant and -- and that was the official -- that engineer was the official Engineer Adviser for the Rio Grande up until, like I said, during the tenure of the commissioner preceding Pat Gordon, whose name escapes me at the moment.

But, anyway, but I was always Engineer Adviser for the Canadian, Pecos, Red, and Sabine River Compacts and then for the Rio Grande for I don't know how long that was, 18 years, ten years, something like that. But -- but even during that period of time, from 1987 forward, while I was not the official Engineer Adviser, I was kind of -- I was -- I was an additional Engineer Adviser, and the -- the other gentleman would actually sign the Engineer Adviser's reports during that time, until, like I said, during the time when that position was done away with under the commissioner previous to Commissioner Gordon.

Q. Okay. So when you say you were an additional Engineer Adviser, what I may use sometimes the shorthand of EA, does that mean you attended all of those EA meetings?

A. Yes. Yeah.

Q. And then would you help develop the Engineer Adviser reports?

A. Yes.

Q. And during this time when you were working on the interstate compacts, did you have separate duties as a manager that you've listed here?

A. There was -- yeah, there was a short -- there was a period of time, I don't remember exactly how long it lasted, where I was the section manager of the -- of -- of the -- of that -- of a group that included water rights permitting and other -- other issues, and it became -- it became too much of a burden. I could -- I couldn't do it all is what I -- is, basically, what I'm saying. So I gave up the management of the section to continue to be the Engineer Adviser to all the compacts. But I was -- I was section manager of the -- of the permitting group for a period of time and section manager of all these compacts, I guess section manager of myself for that time. Anyway, if that makes sense.

Q. Sounds like you were --

A. I, basically -- yeah, I basically decided I didn't want to do the section manager job because it -- it was going to get in the way of doing the compacts.

Q. Is there a specific division of TCEQ that -- that you worked within for the interstate compacts?

A. Well, the ans- -- simple answer is yes.

Q. Do you remember what the name of that division was?

A. No. I mean, it -- it changed periodically.

Q. Describe for me how your role as the EA varied between these different compacts.

A. I mean, generally, they were -- they were pretty much the same. I provided technical engineering advice to the -- to the Texas Compact Commissioner. So I was the Engineer Adviser, and I would provide technical advice to the Compact Commissioner.

Q. And so for each one of these compacts, would you have to attend an annual EA meeting?

A. No. The only one that had an official EA meeting, Engineer Adviser meeting, was the Rio Grande. Well, and then the -- the Red River Compact would actually have a -- an EA meeting, but it was, like, the day before the Compact Commission meeting. So -- so, you know, peri- -- periodically the EAs would -- of all these compacts might get together and have a phone call or something like that, but the -- the EA meeting associated with the Rio Grande was much more extensive than any of the Engineer Adviser meetings associated with the others.

Q. Okay. Did you generally, for each of these compacts, review Compact accounting?

A. Not -- not in the extent that the Rio Grande does. I mean, the -- the Canadian is a storage Compact. The Pecos -- the Pecos River Compact does -- I'm sure you know, is -- the accounting is done by the -- by the River Master. The Red -- the Red and Sabine really don't -- don't have issues that require Compact accounting.

Q. So it sounds like, overall, for the Rio Grande, the duties were somewhat more extensive than they were for the other compacts?

A. That's -- that's correct, except early on the Pecos was rather extensive. As you -- as you can see, in 1987 was kind of the end of the Pecos River litigation.

Q. And as part of your duties as the Engineer Adviser, did you have to review each of the compacts and

the Compact?
A. It had state line delivery --
MR. HOFFMAN: Which state are you talking about?
Q. (BY MS. THOMPSON) The New Mexico-Texas state line.
A. Well, the Compact incorporate -- the Rio Grande Compact incorporated the Rio Grande Project. And by the Compact incorporating the Rio Grande Pro- -- Project, it provided water to Texas.
Q. And how did it do that?
A. How did it -- be more -- can you be more specific?
Q. Sure. I was just following up on your statement that, "And by the Compact incorporating the Rio Grande Project, it provided water to Texas." When you say "it provided water to Texas," I assume you mean the Rio Grande Project provided water to Texas; is that right?
A. No. The -- the Rio Grande Compact incorporated the Rio Grande Project and -- and the water use associated with the Rio Grande Project by Texas and New Mexico. So by incorporating that project, it provided water to Texas associated with its portion of the Rio Grande Project.

Q. And what portion, then, was allocated to Texas?

A. Well, the Rio Grande Project is apportioned 57 -- 57 percent to -- to New Mexico and 43 percent to Texas. So the portion that Texas got associated with the Rio Grande Project was the -- was the 43 percent.

Q. And describe for me what that's 43 percent of. Is it 43 percent of the water in storage?

A. No, the -- the Bureau of Reclamation operates the Rio Grande Project and, as such, they make an allocation each and every year to -- to New Mexico and to Texas, EBID EP No. 1, they make an allocation and those -- that allocation is split 57/43 between the two districts, basically, between the two states.

Q. Is that 43 percent, though, of the deliveries, or is it of the storage?

A. Well, there are -- there are curves used by the Bureau of Reclamation that determine under various conditions when you release X amount of water out Elephant Butte, then that produces X amount of water for EBID and EP No. 1. You know, during a full allotment year, a release of water will provide, actually, more than that release to the -- to the two districts based on return flows that come back from the project.

Q. And so it's 43 percent of that whatever is on

the curve that Texas is entitled to?

A. Yes, that's my recollection.

Q. And when you say "the curve," are you referring to what's sometimes referred to as the D-1 and D-2 curves?

A. Yes.

Q. Did you have any involvement with the development of those curves with Reclamation?

A. No.

Q. Do you know who developed those curves?

A. No.

Q. As the Engineer Adviser, would you review and determine whether or not Texas had received that 43 percent each year?

A. No.

Q. And why not?

A. The engineer -- the Engineer Advisers were -- were report -- calculated the inflows into and storage into Elephant Butte. There has never been -- or there hasn't been, to my recollection, an accounting of water below Elephant Butte by the Engineer Advisers.

Q. So it wasn't part of your duty, then, to independently verify how much water was delivered to Texas?

A. Well, we knew how much water was delivered to

Texas because it was measured at the various streamflow gauges, so... But -- but, you know, the -- the issue obviously came up that Texas wasn't getting its fair share.

Q. And when do you recall that that issue came up?

A. Initially?

Q. Yes.

A. I -- I think I heard -- I heard allegations to that my entire career.

Q. Did you personally raise that at any of the Engineer Adviser meetings for the Rio Grande?

A. I don't recall.

Q. Do you recall whether or not you personally included concerns about Texas not receiving its water in the Engineer Adviser reports?

A. I don't -- I don't recall. It's possible that they may have been included in some of the later Engineer Adviser's reports.

Q. So on the -- the Pecos Compact, we were just talking about 1947 condition. Was there anything similar for the Rio Grande, a similar type of year condition?

MR. HOFFMAN: Objection; calls for a legal conclusion.

A. I don't recall. I don't think so.

Q. (BY MS. THOMPSON) And when you say "I don't think so," why is that?

MR. HOFFMAN: Objection. The answer speaks for itself.

Q. (BY MS. THOMPSON) You can go ahead.

A. Repeat the question, please.

Q. When you said "I don't think so," I was just asking you --

MR. HOFFMAN: The question is argumentative, also.

Q. (BY MS. THOMPSON) So I just asked you the question, do you recall whether or not you personally included -- sorry, hang on. My realtime is stuck.

Oh, I just asked, so on the Pecos Compact, we were just talking about the 1947 condition, was there anything similar for the Rio Grande, a similar type of year condition?

And you said, "I don't recall. I don't think so."

And I was just asking you to explain more why you said, "I don't think so."

MR. HOFFMAN: The question is argumentative.

A. There is not a specific date similar to the

WITNESS CORRECTIONS AND SIGNATURE

HERMAN ROBERT SETTEMEYER JULY 31, 2020

Please indicate changes on this sheet of paper, giving the change, page number, line number and reason for the change. Please sign each page of changes.

PAGE/LINE	CORRECTION	REASON FOR CHANGE
24/17	EBID should be GPI	Correction
65/4	take out "a"	Correction
65/5	insert credit after accrual	correction
76/21	Colorado should be New Mexico	Correction
77/22	take out why	Correction
83/24	insert New Mexico before Engineer	Correction
89/12	change whatever to one every	correction
91/17	Kathy Lane should be Kathleen	Correction
136/25	1978 should be 1938	Correction

HERMAN ROBERT SETTEMEYER, VOLUME 2

I, HERMAN ROBERT SETTEMEYER, have read the foregoing deposition and hereby affix my signature that same is true and correct, except as noted above.

HERMAN ROBERT SETTEMEYER, VOLUME 2

STATE OF T E X A S)
COUNTY OF Llano)

Before me, Susan Rae Jones, on this day personally appeared HERMAN ROBERT SETTEMEYER, known to me, or proved to me under oath or through Tx Drivers License) (description of identity card or other document)), to be the person whose name is subscribed to the foregoing instrument and acknowledged to me that they executed the same for the purposes and consideration therein expressed.

Given under my hand and seal of office on this, the 2nd day of September, 2020.

Susan Rae Jones
NOTARY PUBLIC IN AND FOR THE
STATE OF TEXAS

My Commission Expires: 06-28-2024

SUSAN RAE JONES
NOTARY PUBLIC
STATE OF TEXAS
ID # 126480780
My Comm. Expires 06/28/2024

therefor;

_____was not requested by the deponent or a party before the completion of the deposition.

I further certify that I am neither counsel for, related to, nor employed by any of the parties or attorneys to the action in which this proceeding was taken. Further, I am not a relative or employee of any attorney of record in this cause, nor am I financially or otherwise interested in the outcome of the action.

GIVEN UNDER MY HAND AND SEAL OF OFFICE, on this, the 19TH day of AUGUST, 2020.

Phyllis Waltz

PHYLLIS WALTZ, RMR, CRR, CRC
Expiration Date: 12/31/20
TEXAS CSR, TCRR NO. 6813
Expiration Date: 12/31/21
LOUISIANA CCR NO. 2011010
Expiration Date: 12/31/20

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