OPTIMAL UTILIZATION OF WATER RESOURCES
OF A COMPLEX OVERDRAWN BASIN
IN A SEMIARID IRRIGATED AREA

A Dissertation

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by

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ABSTRACT

Aquifers enclosed or confined by sediments that impede or retard the vertical movement of groundwater generally leak. This report is about the optimal utilization of a composite system of interacting aquifers, in which one aquifer leaks into another, and a surface-water subsystem from the point of view of maximization of the value added to the system due to the operation of the system over a long period of time. The problem is solved through dynamic programming, a sequential decision-making approach. Stochastic recharges, base flow, and natural discharge from the system are considered in addition to the interaquifer leakage.

The model thus developed is applied to the coupled leaky aquifer and surface-water system of the Roswell basin which forms part of the Pecos River basin in New Mexico, and which is believed to be one of the largest naturally recharging multiaquifer systems in the world. A hydrologic analysis of the basin is also performed and the results are fed into the dynamic programming model as inputs.

The optimal operating policies for the two aquifers of the Roswell basin are derived by taking into consideration the physical characteristics of the system and the extent of the areas to be irrigated with the water drawn from the system. The optimal operating policies are strongly influenced by the interaquifer leakage. As a result, coupled leaky aquifers should be considered for conjunctive utilization only.

A mathematical model for the prediction of drawdowns due to the operation of well fields in coupled leaky aquifers is also presented as an appendix.

ACKNOWLEDGEMENTS

The writer expresses his deepest appreciation to Professor C. E. Jacob for suggesting the study, for his advice, constant encouragement, and guidance throughout the investigation, and for reviewing the report. I would also like to thank Dr. M. S. Hantush for useful discussions about the boundary-value problems. I express my appreciation and thanks also to the members of the dissertation committee, Dr. Gross, Dr. Friberg, and Dr. McGehee for their valuable time. Dr. Thomas A. Nartker, Director of the Computer Center, New Mexico Institute of Mining & Technology, was very cooperative and provided part of the computer time.

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I. INTRODUCTION

Background and Purpose of the Study

The optimal utilization of surface reservoirs and of aquifers separately, and the conjunctive utilization of surface reservoirs with aquifers have been studied in the past by several authors [Little, 1955; Moran, 1959; Mass, et al., 1962; Buras, 1963; Burt, 1964; Young, 1967; and Hall et al., 1968]. The investigations of Buras and of Burt were related to single aquifers and single surface reservoirs. They were hypothetical and the results were not applied to any specific basin. Nor did they consider the pumping costs arising from the draw-downs at the pumping wells.

The present investigation is concerned with the optimal operation of two coupled leaky aquifers and a surface-water system as a function of time. Preliminary results of part of this study have been presented elsewhere [Saleem and Jacob, 1968].

The study is specifically based on a complex overdrawn basin, and the results of the investigation are applied to the Roswell basin in southeastern New Mexico, which forms part of the Pecos River basin (see Figure 1). The Roswell Basin consists of two coupled leaky aquifers and associated sources of surface water, mainly the Pecos River system. Water levels in both aquifers have been declining since the agricultural development of the basin because of a continuing overdraft.

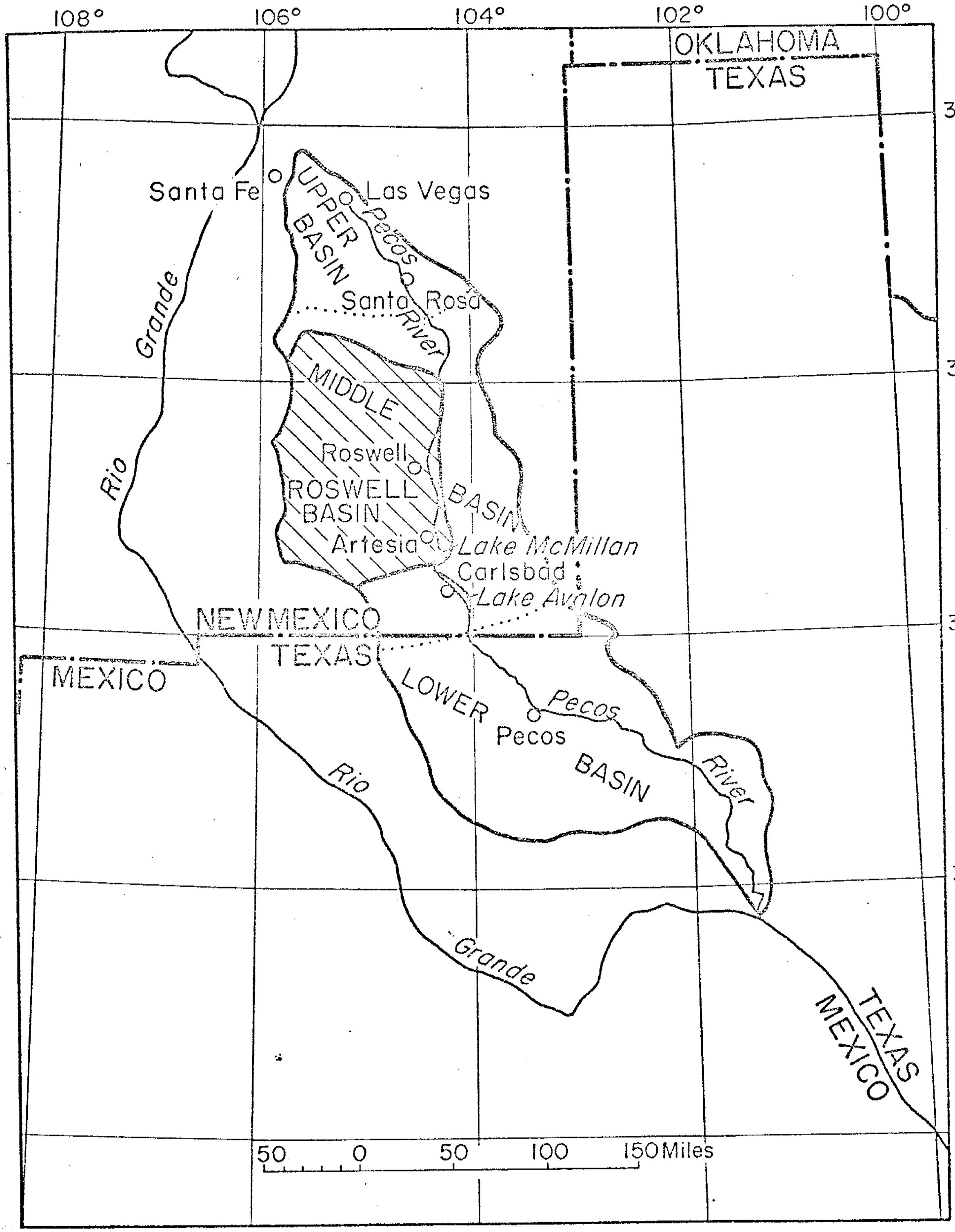


FIGURE I

LOCATION MAP OF ROSWELL BASIN

The purpose of the application of the study to the Roswell basin was to derive optimal operating policies for the basin so that the value added to the basin would be maximized over a long period of time. The optimal operating policies are derived taking into consideration the physical characteristics of the basin.

Approach and Presentation

The problem of two coupled leaky aquifers and a surface-water system from the point of view of optimal operation is formulated mathematically. The particular technique selected is dynamic programming.

Two dynamic programming derivations are described, the first for optimization of the system as a function of time and the second for optimization in space. The results obtained with these models are discussed and some conclusions are drawn.

A hydrologic description of the Roswell basin is given and some of the hydrologic analyses performed are discussed. A mathematical model for predicting the response of the system to the operation of well fields in coupled leaky aquifers is derived and is presented in Appendix A.

Sources of Data

The basic data, most of them unpublished, were provided by the U. S. Geological Survey, the offices of the State Engineer in Roswell and Santa Fe, U. S. Bureau of Reclamation, Smith Machinery Company of Roswell, Pecos Valley Artesian Conservancy District, Hagerman Canal Company, and some individual farmers in the basin.

II. THE ROSWELL BASIN, DESCRIPTION AND ANALYSIS

A description and analysis of the components of the hydrologic cycle of the Roswell basin are presented in this chapter. Some of the derivations and data are presented in appendices.

Previous Studies

The geology and hydrology of the Roswell basin have been studied frequently during the last three or more decades. The information gathered in those reports is fairly valuable from the point of view of a qualitative understanding of the basin and helpful to predictions of future responses of the system to various stresses using modern techniques.

One of the earliest reports, by Means and Gardner [1900], is primarily concerned with the soil conditions. It has a water-table map of the Roswell area. Fisher [1906] published a reconnaissance study of the area. The most thorough investigation was carried out by Fiedler and Nye [1933] from 1925 to 1928. Their work contains many valuable data relating to groundwater conditions at that time. Unfortunately, many of the modern techniques of hydrologic analysis were not available to them. Morgan [1938] published a report about the shallow-water resources in the basin.

An extensive investigation of the surface-water resources was published by the National Resources Planning Board [1942]. Theis' work on the origin of base flow and the flow in Major Johnson Springs at the southern end of the basin was published in 1938. Theis [1951] also investigated the relation of the Hondo reservoir to the artesian aquifer. Bean's report about the geology of the Roswell basin and its relation to the Hondo reservoir appeared in 1949. In 1952, the State Bureau of Mines and Mineral Resources (a Division of New Mexico Institute of Mining and Technology) published a report on the groundwater resources of Eddy County which includes the southern part of the basin. Hantush [1955] carried out a quantitative study of the basin during 1954-55. He applied the theory of leaky aquifers to the basin and estimated the characteristics of the aquifers at several locations. From recharge and discharge studies, he concluded that aquifers were being overdrawn.

Reports of the investigations of Thomas [1963], of Hood [1963], of Motts and Cushman [1964], and of Mower et al. [1964] have been published as Water Supply Papers of the U. S. Geological Survey. Hood et al. [1960] studied saline water occurrence in the basin. There are several unpublished reports about the basin, one of significance, about the pumpage in the basin, is by Mower [1958].

The U. S. Geological Survey has been working on an analog model of the basin since 1963. Four recent publications relating to the basin are by Spiegel [1967], by Havenor [1968], by Kinney et al. [1968], and by Maddox [1969]. A bibliography pertaining to the Pecos River basin was compiled by Hernandez and Eaton [1968].

Location, Topography and Climate

The Pecos River basin is conveniently subdivided [Thomas, 1963] into an upper basin, above Alamogordo Reservoir in New Mexico, a middle basin, above Red Bluff Reservoir also in New Mexico, and a lower basin in Texas, as shown in Figure 1. The Roswell basin forms most of the middle Pecos River basin and is the most important area of the basin from the point of view of water-resource utilization and economic productivity.

The basin is bounded on the east by the High Plains, about 25 miles east of the Pecos River, on the south by the Seven River Cuesta, and on the west by the high Sacramento Mountains, and extends to the north near Mesa. A print of a relief model of the basin is shown in Figure 2.

The basin has a semiarid climate. The winters are usually cold enough but too dry for appreciable snow accumulation, and summers are dry with frequent thundershowers. The average frost-free period at Roswell extends from April 7 to October 30. More than 75 percent of the total annual precipitation falls during this period, which is also the growing season. Because the average rainfalls at Roswell and at Artesia are 11.7 and 11.2 inches respectively, and the deviations from the average are large, irrigation is essential in all parts of the basin for crop production.

Yearly averages of the totals of the precipitation at Roswell and Artesia are shown in Table I.

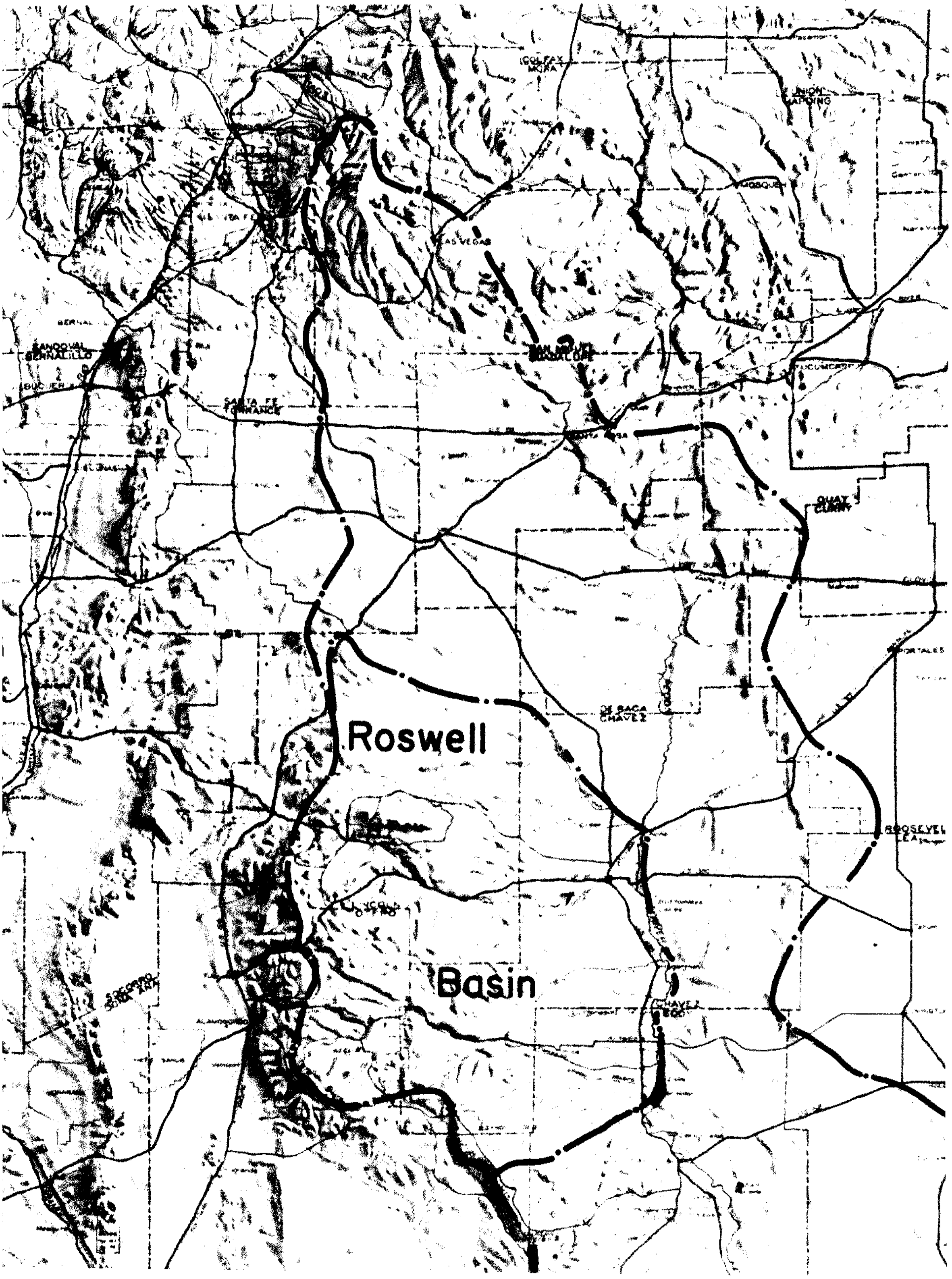


FIGURE 2

10 0 10 20 30 40 50 Miles

TABLE I

AVERAGE RAINFALL AT ROSWELL AND ARTESIA, ARRANGED IN ASCENDING ORDER

Order No. (m)	Year	Rainfall ($\bar{R}$) (Inches)	$\frac{m}{1+n}$ (*)	Order No. (m)	Year	Rainfall ($\bar{R}$) (Inches)	$\frac{m}{1+n}$
1	1917	5.09	0.0145	35	1930	11.49	0.5072
2	1910	5.16	.0290	36	1936	11.54	.5217
3	1924	5.63	.0435	37	1946	11.55	.5362
4	1956	5.68	.0580	38	1962	11.56	.5507
5	1927	5.71	.0725	39	1937	12.29	.5652
6	1964	6.06	.0870	40	1929	12.43	.5797
7	1963	6.12	.1014	41	1940	12.49	.5942
8	1934	6.61	.1159	42	1944	12.55	.6087
9	1945	6.64	.1304	43	1913	12.87	.6232
10	1947	6.66	.1449	44	1960	13.04	.6377
11	1922	6.78	.1594	45	1921	13.30	.6522
12	1951	7.12	.1739	46	1920	13.61	.6667
13	1965	7.19	.1884	47	1942	13.81	.6812
14	1953	7.33	.2029	48	1950	13.91	.6957
15	1961	7.42	.2174	49	1907	14.03	.7101
16	1933	7.61	.2319	50	1906	14.12	.7246
17	1957	7.64	.2464	51	1904	14.35	.7391
18	1952	7.69	.2609	52	1949	14.58	.7536
19	1959	7.81	.2754	53	1968	14.82	.7681
20	1909	8.22	.2899	54	1915	14.86	.7826
21	1967	8.24	.3043	55	1928	15.08	.7971
22	1918	8.34	.3188	56	1914	15.36	.8116
23	1903	8.40	.3333	57	1916	15.37	.8261
24	1955	9.05	.3478	58	1902	15.70	.8406
25	1943	9.55	.3623	59	1931	16.12	.8551
26	1954	9.74	.3768	60	1926	16.17	.8696
27	1948	10.20	.3913	61	1901	16.33	.8841
28	1925	10.28	.4058	62	1958	16.63	.8986
29	1935	10.57	.4203	63	1923	17.02	.9130
30	1966	10.57	.4348	64	1911	17.88	.9275
31	1908	10.62	.4493	65	1932	19.88	.9420
32	1938	10.81	.4638	66	1919	20.42	.9565
33	1939	10.96	.4783	67	1905	21.37	.9710
34	1912	11.21	0.4928	68	1941	34.61	0.9855

(*) n = 68.

Hydrogeology

A geologic section at the latitude of Roswell is shown in Figure 3. The main aquifers in the basin occur in the three geological formations, the alluvium, the Artesia Group, and the San Andres Limestone. Figure 4 shows the boundaries of the various aquifers in the Roswell basin.

Alluvium (Shallow Aquifer)

Valley-fill materials of Tertiary and Quaternary age occur almost wholly west of the Pecos River in an area of from 12 to 20 miles in width and from 60 to 70 miles in length. They are mostly conglomerates, gravel, sand, and clay, and are very heterogenous. The alluvium and, near Roswell, the top part of the underlying Artesia Group constitute the Shallow Aquifer of the Roswell basin. The thickness of the Shallow Aquifer ranges from more than 400 feet just east of the river to zero along its western boundary. An average north-south cross section and an average east-west cross section based on the three isopach maps of the principal aquifers [Hale,personal communication; Kinney, et al., 1968] are shown in Figures 5 and 6.

During 1967 and 1968 the pumpage from the Shallow Aquifer was about 30 percent of the total amount of groundwater pumped.

Artesia Group (Shallow Confined Aquifer)

The Artesia Group embraces five formations of Permian age occurring in eastern New Mexico and West Texas [Tait et al., 1962].

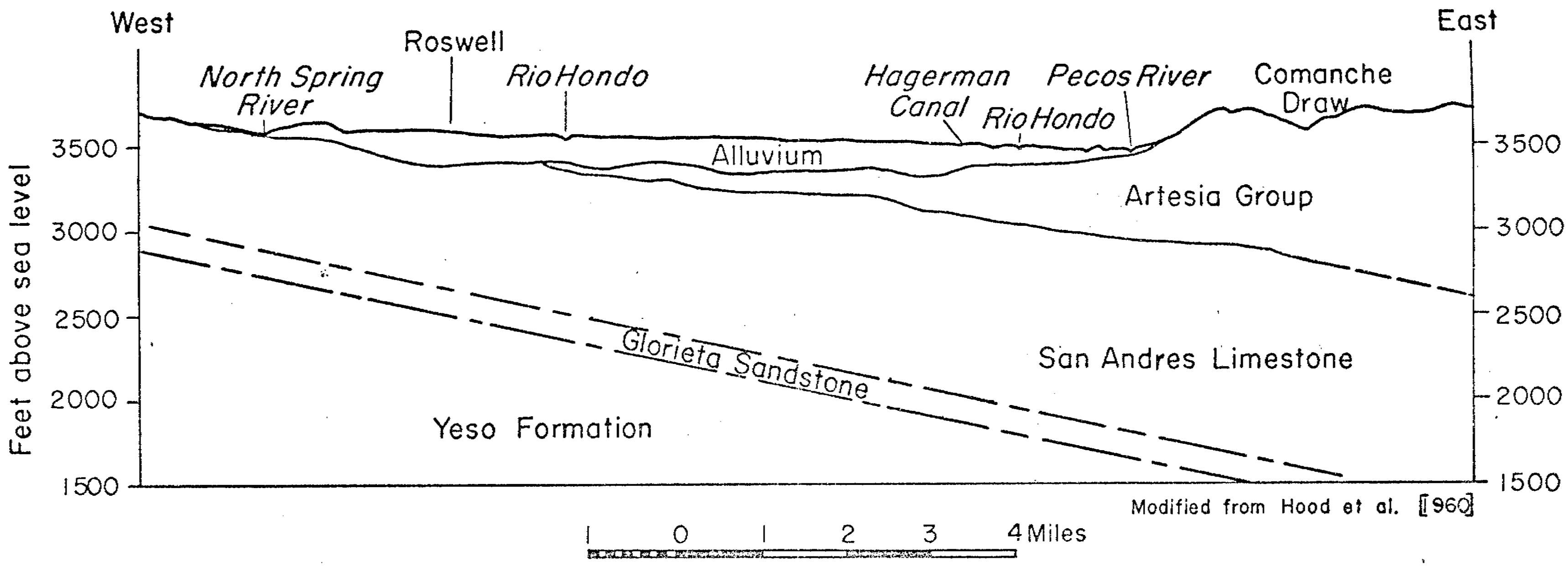
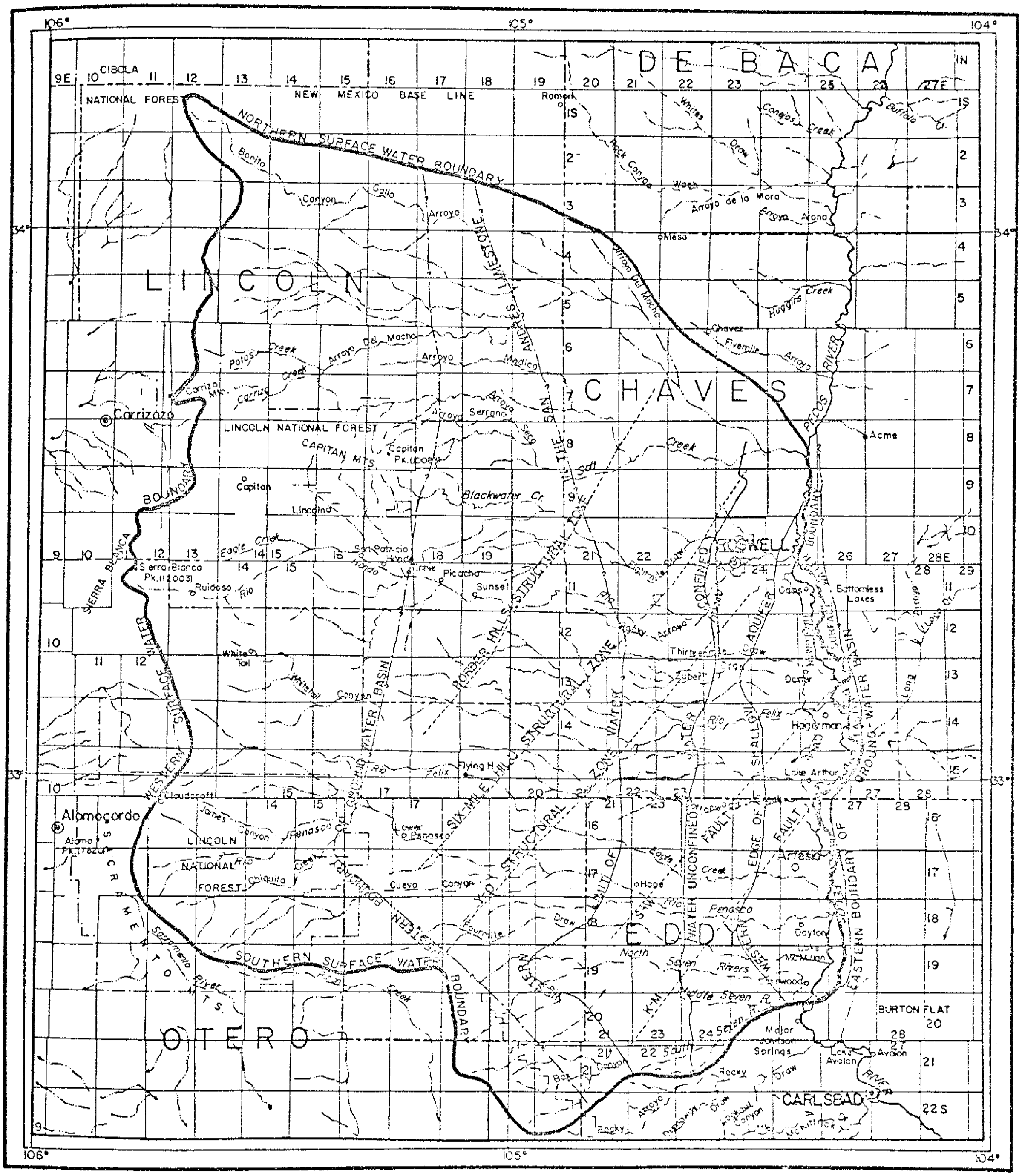


FIGURE 3

GEOLOGIC SECTION AT THE LATITUDE OF ROSWELL
ROSWELL BASIN, NEW MEXICO



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10 0 10 MILES

FIGURE 4

BOUNDARIES OF THE VARIOUS AQUIFERS IN THE ROSWELL BASIN, NEW MEXICO

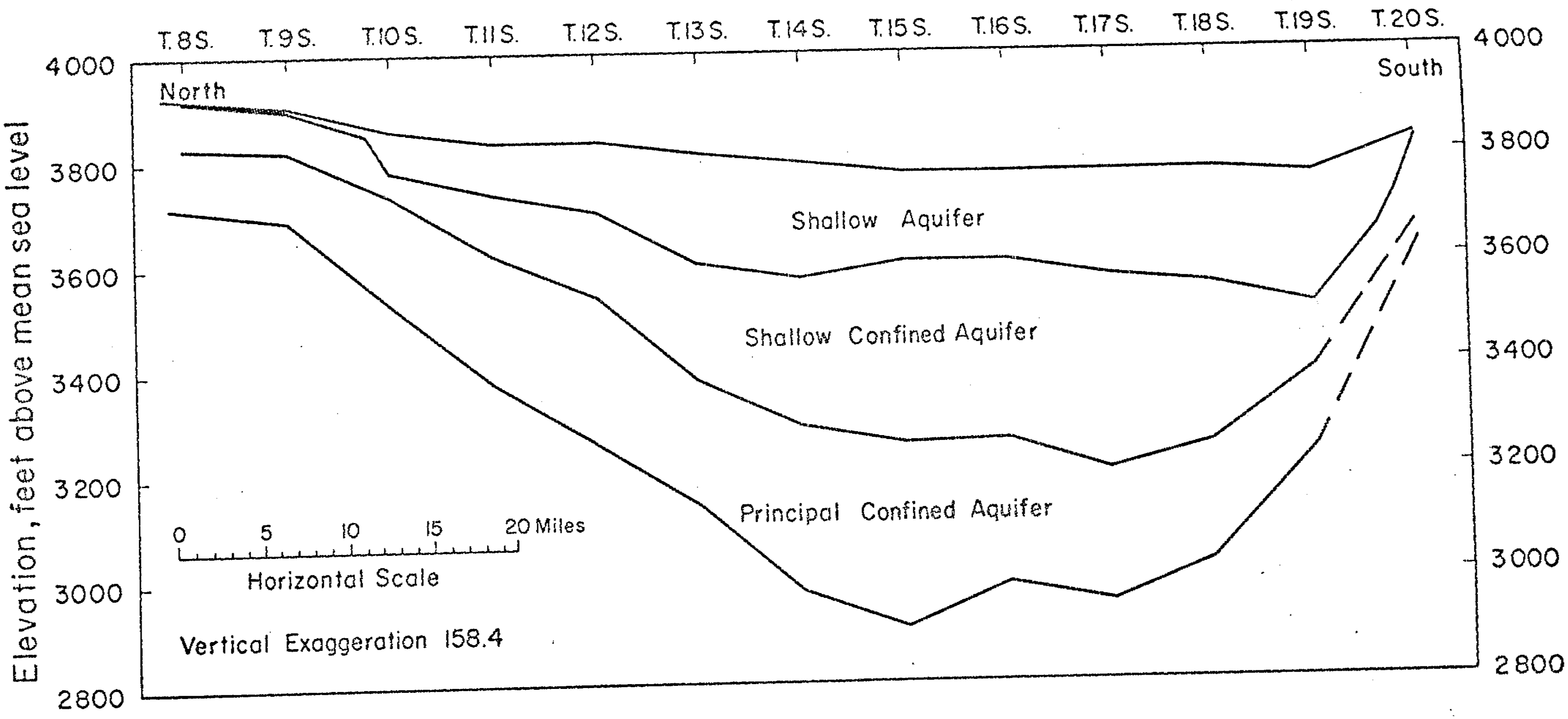

FIGURE 5

AVERAGE NORTH-SOUTH CROSS SECTION OF THE ROSWELL BASIN

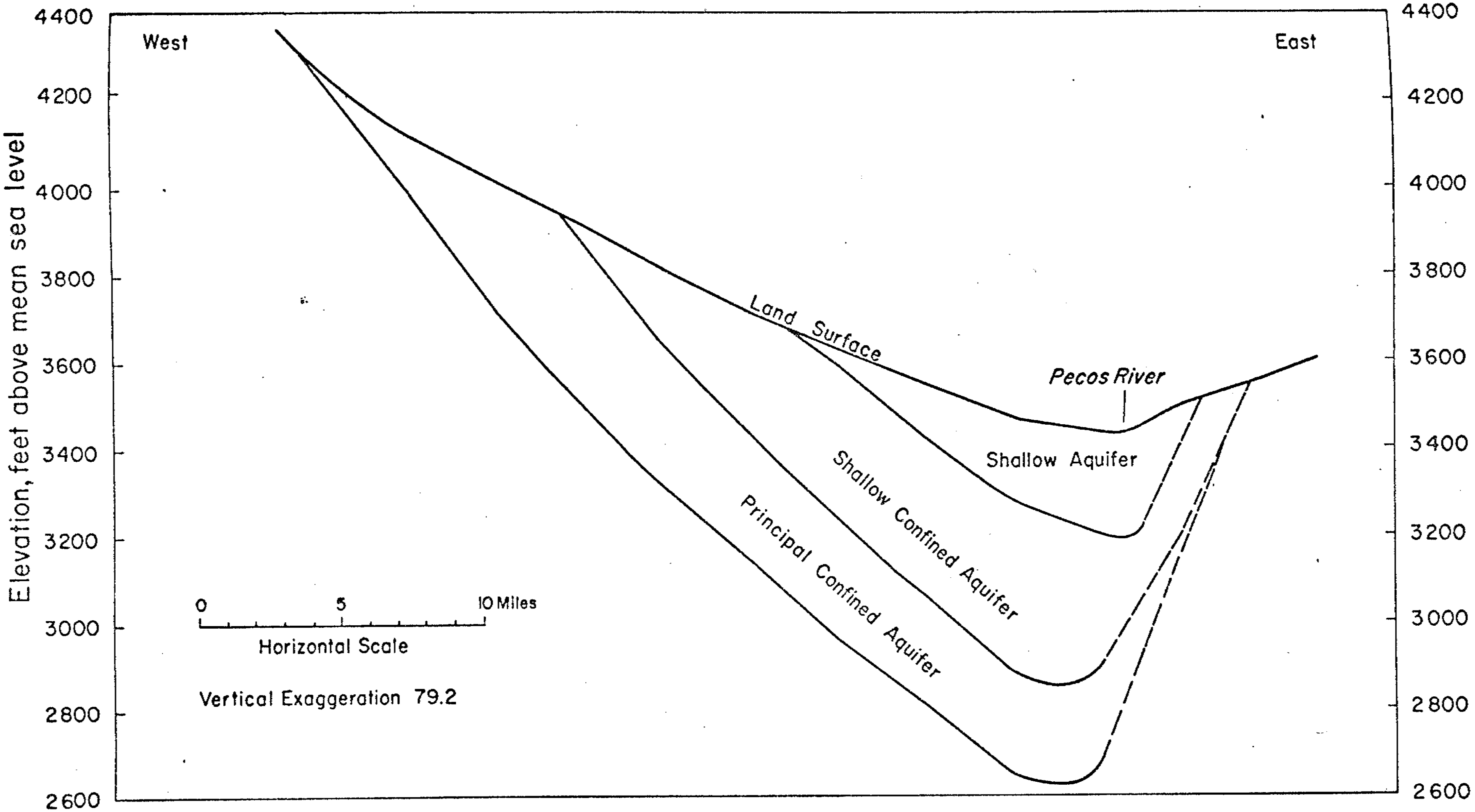

FIGURE 6

AVERAGE EAST-WEST CROSS SECTION OF THE ROSWELL BASIN

It separates the underlying San Andres Limestone from the overlying alluvium and acts mostly as an "aquitard" (i.e., it transmits appreciable quantities of water but has a low storativity).

The Shallow Confined Aquifer is in the Artesia Group except that a small upper part of it near Roswell has been incorporated into the Principal Confined Aquifer. It has a maximum thickness of over 600 feet in the southern part of the basin near Artesia and is like a wedge, getting thinner to the north near Roswell.

The groundwater extracted from the Shallow Confined Aquifer is less than 7 percent of the total annual amount of groundwater pumped in the Roswell basin.

San Andres Limestone (Principal Confined Aquifer)

The San Andres Limestone, of Permian age, conformably overlies the Glorieta Sandstone, also of Permian age, and is overlain by the Artesia Group. It is composed almost entirely of limestone, anhydrite, and anhydritic limestone. The San Andres Limestone is very widespread, correlative units having been recognized in New Mexico, West Texas, and parts of eastern Arizona [see Havenor, 1968, and Maddox, 1969, for details].

The Principal Confined Aquifer occurs in San Andres Limestone except in the southern part of the basin, where the bottom part of the Artesia Group is also included in it [Maddox, 1969]. The maximum thickness of the Principal Confined Aquifer is over 500 feet near Artesia, and on the average the thickness varies from about 150 feet to about 300 feet.

The Principal Confined Aquifer contributes more than 60 percent of the total groundwater pumped in the basin.

Surface Hydrology

The Pecos River and its tributaries drain the Roswell basin. The Pecos River gains water from the Roswell basin as groundwater inflow and loses water through evaporation and some water is also diverted from the Pecos River system for irrigation. Saltcedars along the banks of the river consume considerable amounts of water. Table II shows the base flow from the Roswell basin, between the gaging stations at Acme and at Artesia, to the Pecos River on a monthly basis. The annual base flow has been decreasing from more than 60,000 acre-feet per year in the thirties to less than 30,000 acre-feet per year during the last few years. The base flow is depleted because of saltcedar consumption and because of the surface water diversions in the basin. Figure 16 shows the yearly base flows corrected for depletion because of the surface-water diversions.

I estimate that the Pecos River system loses about 10,000 acre-feet of water per year through evaporation in the Roswell basin. This estimate does not include losses from the McMillan Reservoir (Fig. 1).

Surface Water

Before the large-scale utilization of groundwater, surface water was used for irrigation along the Pecos River and along the lower reaches of some tributaries of the Pecos River in the Roswell basin.

TABLE II

ESTIMATED PECOS RIVER BASE FLOWS FROM ACME TO ARTESIA, NEW MEXICO
IN THOUSANDS OF ACRE FEET

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1919	8.4	7.4	5.8	5.6	5.2	4.6	5.2	3.9	4.0	8.5	12.0	13.8	84.4
1920	13.4	10.0	7.8	6.1	5.4	4.0	2.5	2.8	3.0	4.4	6.8	9.0	75.2
1921	9.8	7.8	6.7	4.0	3.1	3.4	3.6	3.7	4.0	5.4	7.7	8.3	67.5
1922	8.6	7.5	8.1	4.8	4.1	3.6	3.1	3.4	2.8	2.8	5.4	6.1	60.3
1923	6.4	5.8	5.5	4.2	4.2	2.4	1.5	1.5	2.4	5.4	8.6	9.8	57.7
1924	10.3	8.2	7.0	6.3	6.2	3.7	3.0	4.0	3.5	4.3	5.8	7.7	70.0
1925	8.2	5.4	4.4	2.4	2.6	2.3	1.8	3.2	4.8	7.6	8.6	9.0	60.3
1926	8.7	6.8	7.4	7.8	7.6	4.4	2.7	3.1	4.0	6.4	7.3	8.7	74.9
1927	9.5	7.8	7.3	5.9	3.7	1.6	3.3	3.0	4.0	4.8	4.2	6.0	61.1
1928	7.7	7.6	7.1	4.7	2.6	2.4	2.5	3.8	4.0	5.3	7.7	9.3	64.7
1929	9.6	7.9	8.6	4.3	3.9	2.6	3.9	5.0	5.6	6.4	7.3	7.3	72.4
1930	6.8	4.8	5.4	5.3	5.1	3.9	2.6	4.1	2.1	5.1	8.7	9.2	63.1
1931	9.8	8.5	7.0	4.3	4.5	2.5	3.9	3.0	4.3	6.1	8.2	9.7	71.8
1932	10.2	7.9	8.4	8.1	6.5	5.8	4.7	4.6	4.2	7.4	9.9	10.6	88.3
1933	10.3	8.5	8.1	4.7	3.2	2.6	2.7	2.7	4.0	6.3	6.8	6.8	66.7
1934	6.8	5.9	6.5	6.0	5.1	2.0	0.5	0.5	1.1	2.7	3.6	5.4	46.1
1935	6.5	5.2	5.8	5.0	4.4	5.7	2.6	3.0	3.9	4.8	5.2	7.6	59.7
1936	8.1	7.0	7.6	4.5	3.7	2.9	2.5	3.7	2.9	3.6	4.6	6.8	57.9
1937	8.6	8.2	8.7	7.7	6.3	3.9	4.2	4.9	5.3	6.2	7.6	7.3	78.9
1938	6.8	5.9	5.7	4.2	4.4	2.9	2.4	2.0	3.0	5.0	6.6	5.5	54.4
1939	6.8	6.7	5.2	4.2	3.4	1.8	1.2	1.4	1.7	3.1	4.4	6.2	46.1
1940	6.1	5.0	4.4	3.2	3.1	3.1	3.2	1.9	2.2	3.2	5.1	5.9	46.4
1941	5.2	4.9	4.6	4.2	4.1	4.1	5.8	8.5	10.7	13.8	16.5	18.9	101.3
1942	17.2	13.0	11.7	9.0	7.4	5.7	5.2	5.1	7.2	9.1	9.4	10.9	110.9
1943	10.6	7.2	6.7	4.3	3.3	2.6	2.9	2.9	3.0	3.6	5.0	7.7	59.8
1944	9.8	6.9	5.7	4.2	3.3	2.3	3.2	2.5	3.7	6.0	6.6	7.3	61.5
1945	6.6	5.5	5.8	3.5	2.9	2.0	3.8	1.7	1.8	4.2	4.8	5.6	48.2

(continued)

TABLE II (continued)

1946	5.9	5.2	5.2	3.5	3.2	1.8	2.3	1.5	1.8	5.2	7.3	8.8	51.7
1947	7.6	5.0	4.1	2.9	3.1	2.3	1.4	1.9	2.2	2.0	4.5	6.0	43.0
1948	4.9	4.8	4.8	2.7	2.9	2.9	2.5	1.3	2.7	3.1	4.7	5.6	42.9
1949	5.9	5.5	3.7	2.5	2.7	2.4	3.0	2.6	3.0	4.6	6.4	7.4	49.7
1950	5.8	4.0	2.5	2.7	3.1	2.0	2.3	2.7	1.9	3.2	4.6	4.8	39.6
1951	4.5	3.9	3.7	3.2	2.6	2.2	1.7	2.1	2.1	1.8	3.9	5.3	37.0
1952	4.7	3.6	3.1	3.6	3.2	1.6	1.1	2.1	2.5	1.7	3.3	3.8	34.2
1953	3.6	3.8	2.4	3.2	2.9	2.2	1.0	1.1	2.5	1.9	3.2	3.8	31.6
1954	3.5	3.4	3.5	2.3	2.3	2.3	1.6	1.4	2.1	6.2	8.4	6.5	43.5
1955	5.5	4.4	3.3	3.0	2.3	1.9	1.4	1.6	1.6	3.4	4.2	5.4	38.0
1956	4.0	3.9	3.3	3.4	2.9	1.4	1.2	1.2	2.7	2.0	2.4	3.6	32.0
1957	3.6	3.0	2.7	3.1	2.4	2.0	1.6	1.2	1.4	1.7	3.2	3.9	29.8
1958	3.0	3.1	2.8	1.8	1.5	1.5	1.2	1.3	2.1	3.6	3.6	4.3	29.8
1959	3.2	3.0	3.2	2.9	1.2	1.1	.9	1.1	1.6	1.6	2.2	2.5	24.5
1960	4.2	3.8	3.4	2.3	1.7	1.2	.4	1.4	2.1	2.4	3.6	4.8	31.3
1961	4.6	3.7	4.5	3.3	2.2	1.4	1.0	1.8	1.5	.9	3.3	3.6	31.8
1962	3.5	3.0	2.9	3.0	2.2	1.2	1.3	1.5	2.0	2.6	3.0	2.9	29.1
1963	3.2	2.9	2.8	2.9	2.3	0	0	0	1.3	1.5	2.2	2.9	22.0
1964	2.4	2.3	2.1	1.7	1.3	.8	.9	.4	.6	.6	1.8	2.4	17.3
1965	2.1	1.7	1.9	1.5	1.0	.9	.6	.6	.6	.7	1.7	2.4	15.7
1966	2.3	4.7	3.4	1.7	1.9	1.0	.5	2.7	2.4	3.1	1.9	2.1	27.7
1967	2.3	2.5	2.1	1.1	0.5	1.1	.9	1.6	1.3	1.0	1.3	1.9	17.6
1968	2.6	2.8	2.7	1.7	1.6	1.6	.4	.9	1.0	1.0	2.0	2.0	20.3
Mean 1919–1968	6.6	5.6	5.2	4.0	3.4	2.5	2.3	2.5	2.9	4.2	5.5	6.5	51.0

* From records in the office of the New Mexico State Engineer, Santa Fe.

Some of these tributaries near Roswell were fed by several springs, described elsewhere in this report.

In the early 1900's several artesian wells were drilled and the artesian heads were lowered as a consequence. Some of the springs started drying up, and the lands which used to be irrigated from the streams were either abandoned or started relying upon groundwater partially or completely.

Almost all of the surface water used in the Roswell basin is for irrigation. During 1967 and 1968 only 3.8 percent and 3.1 percent, respectively, of the total water used for irrigation was surface water. Surface water is used mostly in the Roswell-East Grand Plains area and in the Dexter-Hagerman area of the Roswell basin. The sources of surface water are: (1) Hagerman Canal, which in turn gets water through diversions from the Rio Hondo and some groundwater, (2) private drains which get their water mostly from the Pecos River, and (3) some direct pumpage from the river. Table III shows the monthly and yearly totals of the surface water used in the basin for several years.

Depletion of River Flow in the Middle Basin

The inflow to the middle basin (Fig. 7) has been decreasing for the last four decades [see Thomas, 1963]. Major factors for the depletion are: (1) repeated droughts in the area since 1942; (2) gradual increase in groundwater exploitation in the middle basin; and (3) consumptive waste use by saltcedars.

Figure 8 shows the cumulative streamflow/precipitation relation in the Pecos River middle basin. The precipitation is the average of the

TABLE III

MONTHLY SURFACE-WATER DIVERSIONS IN THE ROSWELL BASIN, ACRE-FEET

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1955	56	87	470	696	754	979	2584	1652	1126	237	329	147	9,114
1956	39	120	597	1297	1036	1344	2972	1926	1165	316	434	89	11,334
1957	2311	2996	5075	4493	3934	3906	5984	5267	3917	1898	272	417	40,470
1958	1232	2428	4643	4916	4540	4923	5047	5435	3438	774	113	220	37,709
1959	2158	2907	4905	5164	4537	4998	6078	6307	4309	2703	2538	1450	48,054
1960	47	1041	3755	4955	4302	3895	4068	5158	3299	1496	43	62	32,122
1961	4	354	3948	4719	4098	4577	4603	4785	3477	2341	563	38	33,506
1962	43	2288	4800	4627	3956	4176	4816	4546	4388	1176	276	45	34,838
1963	768	2129	5984	4871	4125	4586	5628	5513	3986	2484	126	33	40,233
1964	1996	2369	3808	5966	3420	3504	4831	3096	3431	2197	1699	1046	37,363
1965	1353	1887	4258	3954	3582	4863	4565	4870	3902	1483	593	14	35,324
1966	0	804	4180	3244	2634	3471	3399	3805	2828	1867	1415	1555	29,202
1967	787	1895	2359	2347	4003	3148	3925	3697	2389	536	243	201	25,528
1968	5	26	1936	3176	2799	3292	3240	3428	2515	1396	568	46	22,429
Mean 1955-68	771	1524	3623	3888	3387	3690	4410	4249	3155	1493	658	383	31,231
Per-centage	2.47	4.88	11.60	12.45	10.84	11.81	14.12	13.61	10.10	4.78	2.11	1.23	100.00

Source: Based on the Watermaster Reports, Pecos Valley Surface Water District.

Note: Total flow of Hagerman Canal, which consists of surface-water diversions and some ground water, was used in the computations.

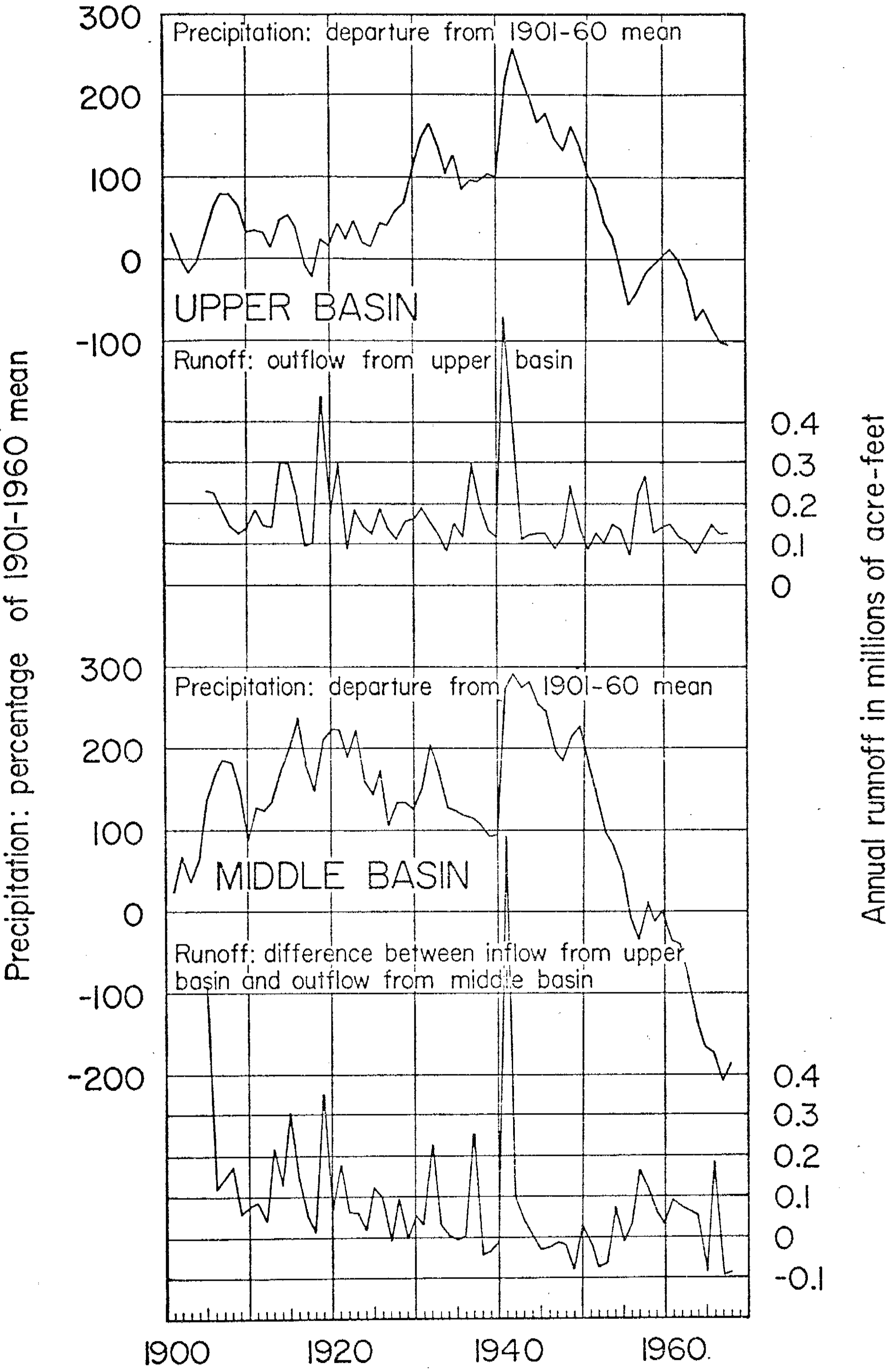

FIGURE 7

CUMULATIVE PERCENTAGE DEPARTURE FROM MEAN PRECIPITATION AND STREAMFLOW, 1905-1968, MIDDLE AND UPPER PECOS RIVER BASINS, NEW MEXICO

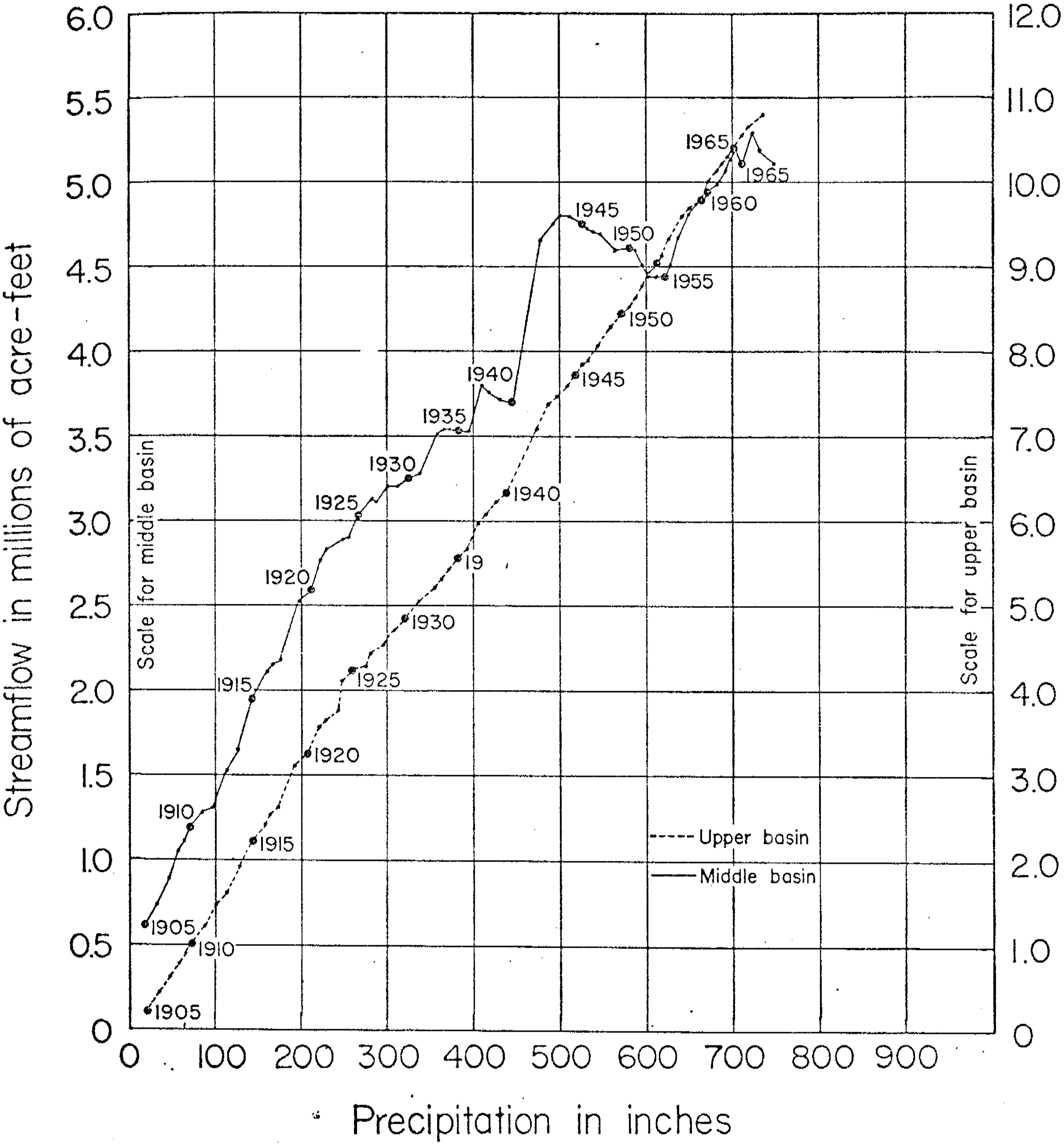

FIGURE 8

CUMULATIVE MASS CURVES OF STREAMFLOW VS. PRECIPITATION IN THE PECOS RIVER MIDDLE AND UPPER BASINS, 1905-1968 precipitation at Roswell, Artesia, and Carlsbad. The streamflow is the outflow of the Pecos River from the middle basin and is the sum of flows of the Pecos and Delaware rivers as recorded at the Red Bluff gaging stations. The figure shows a gradual decrease in the slope (runoff per unit precipitation) of the curve since 1925 and a negative slope from 1943 to 1955 and from 1966 to 1968. These are caused partly by droughts.

Figure 7 shows a cumulative departure from the 60-year mean precipitation (1901 through 1960) at the three station in the middle basin. In the 52 years from 1916 through 1967, the departure in precipitation from the mean is about four and a half times the mean, and is indicated in the runoff graph of the middle basin. The runoff graph shows the difference between the measured inflow and outflow of the middle basin.

The other two causes of depletion are discussed elsewhere in this report. It may be pointed out here that groundwater exploitation in the middle basin has increased not only in the Roswell basin but also in the Carlsbad area (Fig. 1).

Geohydrology

The Principal Confined Aquifer is coupled to the Shallow Aquifer through the Shallow Confined Aquifer, and water leaks from one aquifer to the other, depending on the differences of head between the two aquifers. The rate of leakage from one aquifer to the other is a function of time as well as space and depends on the hydraulic conditions. This portion of the report discusses evaluation of the various components of the subsurface hydrology of the Roswell basin and how they interact.

Aquifer Characteristics

Previous Studies

The hydraulic characteristics of the aquifers, namely, transmissivity, storativity, and leakance, had not been determined until Hantush [1955] made his analysis, except for estimates by Hale (reported in Hantush, 1955) and by Theis [1951], of the transmissivities of the valley fill and of the San Andres Limestone near Hondo reservoir. Theis [1951] also estimated the storativity of the San Andres Limestone near Hondo reservoir. Hantush [1955] ran four pumping tests in the Principal Confined Aquifer and six pumping tests in the Shallow Aquifer in the basin and applied the theory of leaky aquifers developed by him and Jacob [1955]. From his analysis he estimated the transmissivities and storativities of the two main aquifers and leakances for the Shallow Confined Aquifer at different locations in the basin.

Summers [personal communication, 1968] ran some step-drawdown tests in the flowing wells in the northern half of the basin in early 1968 and obtained transmissivity values for the Principal Confined Aquifer that were close to the values obtained by Hantush.

Transmissivities of the Aquifers

Step-drawdown tests. The theory of step-drawdown tests was developed by Jacob [1947]. For details, the reader is referred to the original paper.

Briefly, the drawdown, s_W, in a well can be expressed according to Jacob as

$$s_W = B(r_W,t)Q + CQ^2 \tag{1}$$

where $B(s_W,t)$ is the head loss in the formation per unit discharge. For nonleaky artesian aquifers,

$$B(r_W,t) = \frac{1}{4\pi T} W(u_W) \tag{2}$$

where $u_W = r_W^2 S/4\pi T$, r_W is the radius of the well, t is time since the well started pumping, S is the storativity of the aquifer, and T is the transmissivity of the aquifer, and W(u) is the well function for nonleaky confined aquifers. The term $B(r_W,t)Q$ expresses the part of the drawdown due to the resistance of the formation and is called formation loss. The term CQ^2 expresses the head loss due to turbulence in the well and in the formation. C is referred to as the "well loss coefficient."

Rorabaugh [1953] suggested that the head loss associated with turbulence should be expressed as CQ^n, where n is a constant, which is greater than 1 and which may exceed 2, and which is to be determined for individual wells.

If B is assumed to remain constant during the test period, then B and C can be evaluated from a step-drawdown test. In such a test a well is pumped during successive periods at uniform but differing rates which are fractions of the full capacity, and the drawdown is observed in the well. From these data, using (1), one gets a set of linear equations with B and C as unknowns which can readily be determined.

Step-drawdown tests in the Roswell basin. Data for the step-drawdown tests in the Roswell basin were taken from the files of Smith Machinery Company of Roswell who routinely run such tests to determine the optimum size of a pump needed for a well.

A well is pumped at a fraction of full capacity and then the discharge is increased in three or more steps, each step being of 30 to 40 minutes' duration. Sometimes the well is started at the maximum capacity and the discharge is then decreased in steps.

Since the duration of a typical routine test in the Roswell basin is small (and reasonably constant from one test to another) and since the transmissivities are in general high, the following assumptions are made:

1) the effects of leakage are negligible and B is given by Eq. (2).
2) any changes in the values of B from place to place in any particular aquifer are due to changes in the transmissivity values. This is based on the assumption that the parameter $V(=r_w^2 S/4T)$ is assumed constant for each aquifer.
3) the effects of partial penetration of the wells are neglected.

More than 340 step-drawdown tests of wells tapping the three different aquifers in the basin were analyzed on the digital computer. These wells are scattered all over the basin. Values of B and C were calculated. Each well was classified according to depth and casing information as belonging to one of the three aquifers. Some wells tapped more than one aquifer and were classified as multiple-aquifer wells.

Curves of B versus T were plotted on logarithmic paper using and treating V as a parameter (Fig. 9). Estimates of V were made using S values derived by Hantush [1955] and values of T were obtained for each test, using calculated values of B. Estimated transmissivities were logarithmically averaged for each township and are shown in Table IV.

The accuracy of the calculated transmissivities depends upon the validation of the assumptions stated earlier. Since the tests were of short duration, the effects of leakage are negligible and the effects of partial penetration of the wells are also negligible in all the aquifers except the Shallow Aquifer. This conclusion is based on the criterion given by Hantush [1964] for the effect of partial penetration of wells on the drawdown at the face of a well. The criterion is that if the duration of the test t is less than $Sb(1-\ell/2b)^2 5K_z$, then the effect of partial penetration is negligible. In this expression, S is the storativity, b is the thickness of the aquifer, K_z is the vertical hydraulic conductivity, and ℓ is the length of penetration.

Using the average values of the quantities involved, the above expression is about 3 hours for the Principal Confined Aquifer, and about one second for the Shallow Aquifer. Since the average duration for a step-drawdown test was about 1-1/2 to 2 hours, the Shallow Aquifer transmissivities calculated from such tests on partially penetrating wells are probably too low.

The errors resulting from assumption (2) are believed to be small because the drawdown varies as the logarithms of S, t, and r_w.

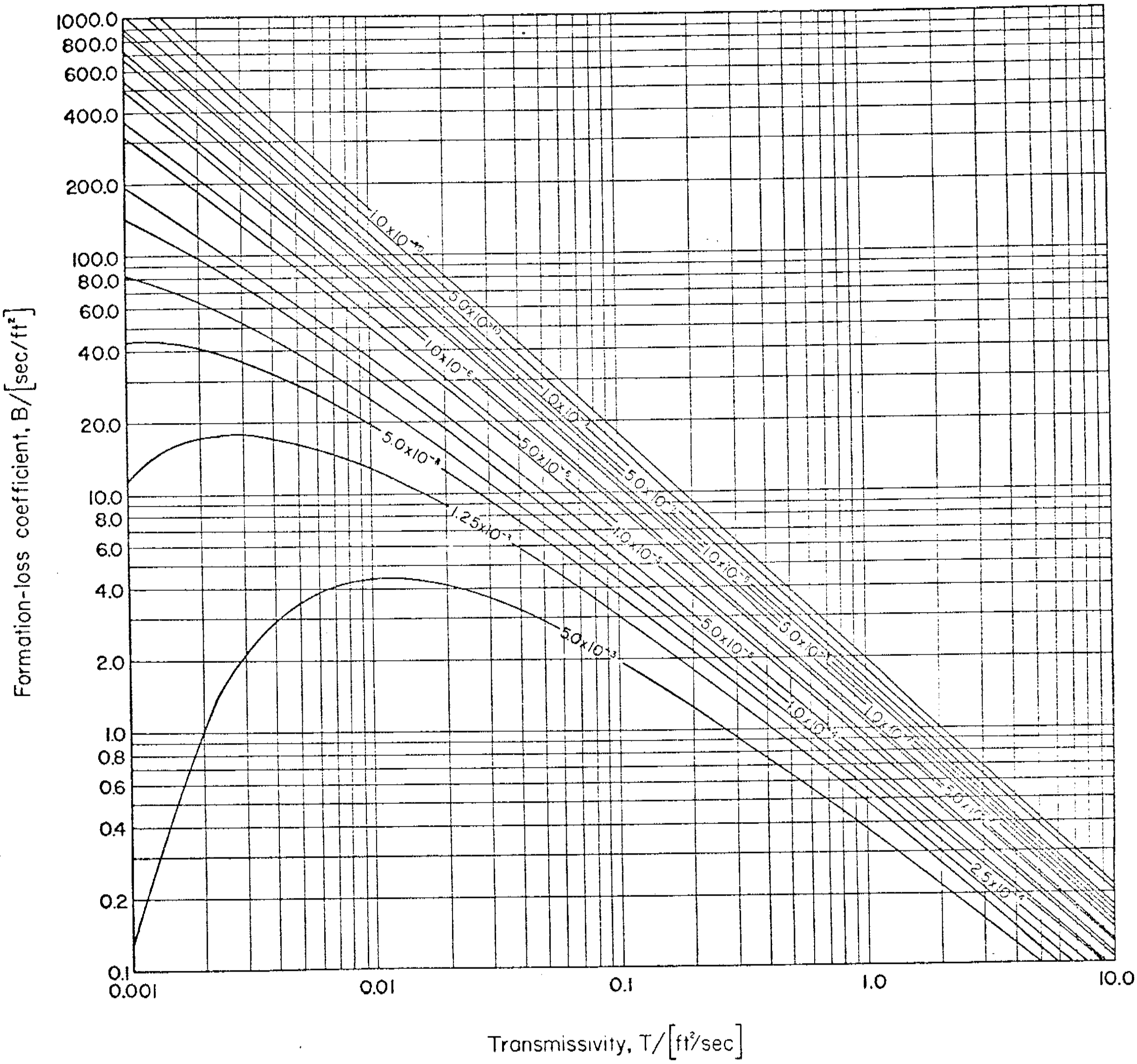

FIGURE 9

CURVES OF FORMATION-LOSS COEFFICIENT VS. TRANSMISSIVITY
FOR DIFFERENT VALUES OF PARAMETER $V = r_w^2 S/4t$

TABLE IV

LOGARITHMIC AVERAGE TRANSMISSIVITIES
IN THOUSANDS FT^2/DAY
ROSWELL BASIN, NEW MEXICO

	AQUIFER								
	Principal Confined				Shallow Confined		Shallow		
	Range East								
Township South	23	24	25	26	24	25	24	25	26
8	-	31	-	-	15	-	-	-	-
9	-	16	-	-	37	-	-	-	-
10	34	50	-	-	-	10	3	-	-
11	56	45	34	-	58	11	6	3	-
12	39	37	302	-	-	35	-	3	6
13	-	-	61	54	3	18	-	9	4
14	-	-	-	32	19	12	-	12	15
15	-	-	14	195	-	-	-	-	20
16	-	96	63?	17	-	-	-	6	4
17	-	-	-	20	-	-	-	-	15
18	-	-	-	30	-	-	-	-	12
19	-	-	-	3	-	-	-	-	-
20	-	-	-	-	-	-	-	-	16

The transmissivities calculated by this method are believed to be local transmissivities for the aquifer. The Principal Confined Aquifer is known to be cavernous, thus giving rise to sudden changes in T values from place to place.

Hydraulic Characteristics of the Intake Area

Fiedler and Nye [1933] called the area lying just west of the pinch-out of the confining beds of the Roswell basin and south of T. 9 S. the 'principal intake area'. The storativity of the Principal Confined Aquifer is very small ($\sim 10^{-5}$) in the confined part of the aquifer. If we assume that the aquifer should not be dewatered to the extent that the groundwater becomes unconfined in the valley area, then the storage in the valley part of the aquifer is negligible compared to the storage in the principal intake area where storativity is about 1000 times higher and the aquifer is unconfined.

The water levels have been declining in the intake area since 1944 and all this water has been discharging across the western limit of the confined area. Hantush [1955] has given a solution for the intake-area boundary-value problem, treating it as a slit

$$s(x,t) = 814\ q\ x/T\ \left[\ \frac{e^{-u_x}}{\sqrt{u_x}} - \sqrt{\pi}\ \mathrm{erfc}(\sqrt{u_x})\right] \qquad (3)$$

where s is the drawdown, which is small compared to the original depth of flow; q = 0.045 gpd/ft, average discharge per unit length of the intake area; x = 2 miles, average distance of the observation wells from the slit; $u_x = 1.87x^2/tT$; erfc(x) = complementary error function $= 1 - \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-y^2} dy$; t = time in days.

Method of Analysis. A method for the evaluation of aquifer characteristics is presented here. The method is based on the classical technique of least squares and is probably applied in many of the physical sciences. The sum of the squares of differences between the observed drawdowns and the drawdowns calculated using theoretical drawdown equations for the flow system under consideration is minimized, treating the aquifer parameters as decision variables. This becomes a problem of finding the minimum of a non-linear objective function which is a function of several variables and, therefore, is a typical nonlinear programming problem. A brief discussion of nonlinear programming is given in the next chapter. The method can be applied to any flow system for which analytical expressions to calculate drawdowns corresponding to the observed drawdowns are known.

Expressing the problem in a mathematical form, one obtains

$$\theta(T,S,\beta) = \sum_{i=1}^{M} \sum_{j=1}^{N_i} \omega_{ij}[d_{ij} - s_{ij}(T,S,\beta)]^2 \qquad (4)$$

where,

$\theta(T,S,\beta)$ = the objective function to be minimized.

M, N = the number of observation wells and the number of observations in each observation well respectively. Note that N can be different for each well.

i, j = running indices for M and N, respectively.

d, $s(T,S,\beta)$ = observed and calculated drawdowns, respectively.

T = transmissivity of the aquifer in the area.

S = storativity of the aquifer in the area.

$\beta = K'/b'$, leakance or leakage coefficient; K' and b' are hydraulic conductivity and thickness of the aquitard. Leakance is zero for non-leaky flow systems.

ω_{ij} = weight assigned to the j^{th} observation in the i^{th} well.

The values of aquifer parameters which minimize the objective function are the optimum values.

The objective function defined by (4) is for flow systems where T, S, and K'/b' are to be determined. If the drawdown is dependent on parameters other than the above three, they can also be considered as components of the set comprising the decision variables, and these parameters can be appropriately expressed in the analytical expression for the drawdown. The method was applied to analyze four pumping tests in non-leaky, leaky, and anisotropic non-leaky flow systems. The results are compared with those obtained by classical methods and are given in Table V. All observations were assigned equal weights. Contours of the objective function θ (sum of the square of deviations), as a function of aquifer parameters, for the test at Arrowsmith are shown in Figure 10. The aquifer parameters obtained both by the classical type-curve method and by the new computer method are marked on the figure.

Application to the Intake Area. The computer method described in the last section was applied to obtain the best estimates of average aquifer parameters, namely storativity and transmissivity. The objective function was defined as in Eq. (4), where β is zero and $\underline{s}$ is given by (3). The observed drawdowns were used in the wells on which

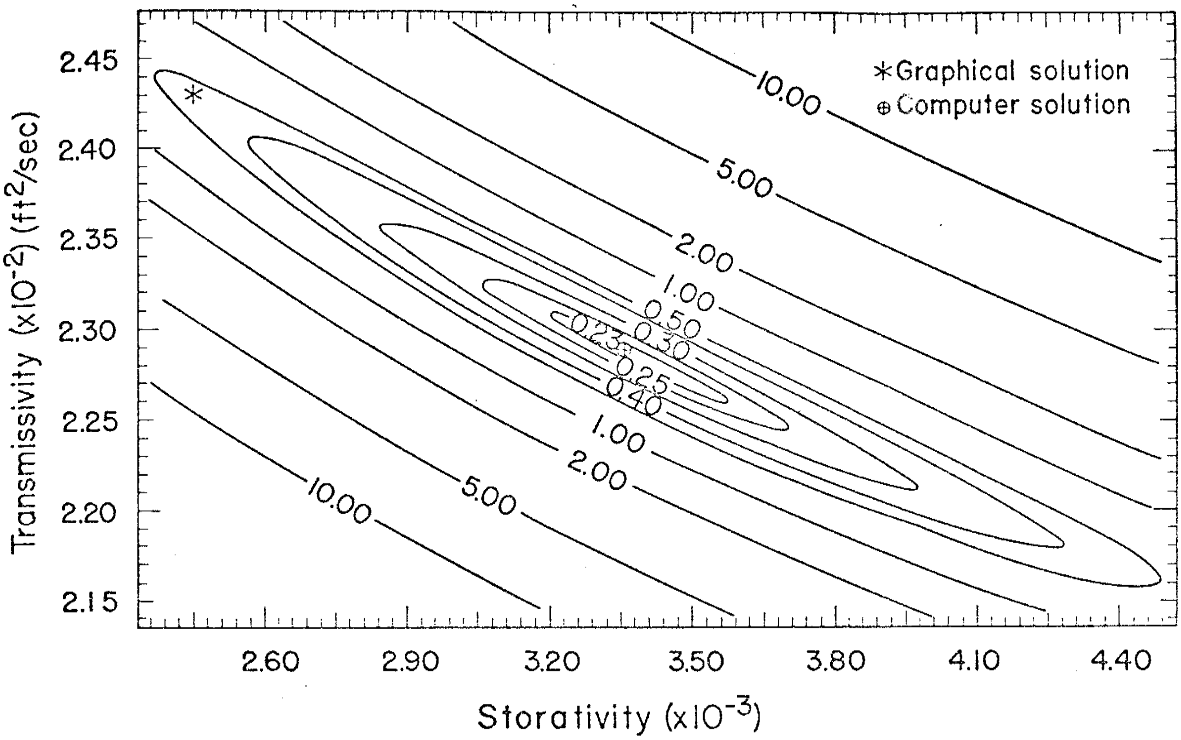

FIGURE 10

OBJECTIVE FUNCTION FOR PUMPING-TEST AT ARROWSMITH, ILLINOIS

TABLE V

PUMPING TEST ANALYSIS BY GRAPHICAL METHODS AND BY COMPUTER METHOD

Type of System	Aquifer Parameter	Parameter Values: Graphical	Parameter Values: Computer	Difference in %	Location of Test and Author
Nonleaky	T in ft^2/sec	.02430	.02289	6.16	Arrowsmith, McLean Co. Illinois.
Confined	S	2.54×10^{-3}	3.352×10^{-3}	24.22	Bruin and Hudson (1958)
Nonleaky	T in ft^2/sec	.01563	.01534	1.89	Gridley, McLean Co. Illinois.
Confined	S	2.0×10^{-5}	2.09×10^{-5}	4.30	Walton (1962)
Leaky	T in ft^2/sec	.002337	.002786	16.12	Dieterich, Effingham Co.
	S	2.0×10^{-4}	1.8×10^{-4}	11.11	Illinois.
Confined	r/B*	0.220	0.155	41.94	Walton (1962)
Anisotropic	T_{xx}** in ft^2/sec	.02691	.02731	1.46	
Nonleaky	T_{yy} in ft^2/sec	.02691	.02750	2.15	Papadopulos (1965)
Confined	T_{xy} in ft^2/sec	-.01615	-.01696	4.82	
	S	1.00×10^{-4}	0.9773×10^{-4}	2.27	

* B is leakage factor = $\sqrt{T/(K'/b')}$ and r is the distance from the pumped well.

** T_{xx}, T_{yy}, and T_{xy} are components of the transmissivity tensor.

the Pecos Valley Artesian Conservancy District (PVACD) maintains recorders and in the U.S.G.S. wells in the intake area. These wells are located at different distances from the "slit". The maximum value for time was 21 years and maximum value for the distance from the "slit" was 16 miles.

The average values calculated by the computer method for storativity and transmissivity in the intake area are 0.025 or 2.5% and 8,700 ft^2/day, respectively. Theis [1951] calculated a value of 0.05 or 5% for the intake area near Hondo Reservoir. Hantush [1955] used a value of 10,000 ft^2/day for transmissivity in the intake area.

Storativity and transmissivity values calculated by the above methods are based on the assumption that Eq. (3) describes the drawdown in the intake area. However, in the derivation of Eq.(3) , the discharge was assumed to be constant, which may not be strictly true. Moreover, the average value for $\underline{q}$ of 0.045 gpd/ft may be somewhat off. Therefore, the calculated values for the parameters of the intake area may also be off.

Recharge to the Aquifers

Recharge to the Principal Confined Aquifer in the Roswell basin is derived from precipitation on the outcrop area of the San Andres Limestone. Additional replenishment comes from upward leakage from the underlying formations, namely the Glorieta Sandstone and the Yeso Formation. The main sources of replenishment to the Shallow Aquifer are, (1) local precipitation, (2) surface drainage and irrigation losses, and (3) upward leakage from the Principal Confined Aquifer.

Recharge to the Principal Confined Aquifer

An aquifer is in a steady state when its inflow equals outflow. The inflow or recharge to the Principal Confined Aquifer when it is in a steady state can be estimated from its outflow which is equal to pumpage plus leakage to the Shallow Aquifer. Hantush [1955] considered the flow in the aquifer in "dynamic equilibrium" during 1928, 1936, and 1944. For these three years, he estimated the leakages and then calculated the recharge during these years.

Jacob [1944] defined effective precipitation as "the rate of precipitation which, had it been maintained uninterruptedly throughout the past, would have produced the same water-table profile as actually existed at that particular time." Following Jacob, Hantush [1955] calculated the effective average rate of precipitation by

$$\bar{R}_n = \sum_{i=1}^{k} \frac{2(k+1-i)}{k(k+1)} R_{(n+1-i)} \tag{5}$$

where

$\bar{R}_n$ = the effective average rate of precipitation at the end of the n^{th} year, inches per year

R = annual precipitation during any year, inches per year

k = the number of years the rainfall of a given year is effective.

Correlating the effective precipitation with the recharge during the three years mentioned above, he obtained the following for the recharge to the Principal Artesian Aquifer:

$$\text{Recharge} = 21{,}000 \text{ (acre-feet/inch) } \bar{R}_n \tag{6}$$

where the recharge during any year is in acre-feet, and $\bar{R}_n$ is the three-year effective average rate of precipitation in inches computed by (5), using the annual average rainfalls at Roswell and Artesia. Justification for using three-year effective average rainfall is given in Appendix B.

The values of recharge to the Principal Confined Aquifer were calculated for the period 1903-1968 and are tabulated in ascending order in Table VI, and in Figure 11. The average rate of recharge for the Roswell basin in this table is 240,000 acre-feet per year.

Replenishment to the Shallow Aquifer

(1) Local Precipitation. The average rate of precipitation at Roswell and Artesia is 11.48 inches per year. Of the total precipitation on the alluvium, part runs off through the surface drainage, part evapotranspirates, and the remainder percolates to the Shallow Aquifer. By comparison with the recharge estimate made by Theis [1937] for the High Plains, which lie just east of the Roswell basin, Morgan [1938] deduced that the recharge averages somewhat less than half an inch a year or about 530 acre-feet for each one-mile strip across the basin. The average rate of recharge to the Shallow Aquifer from precipitation percolation is thus about 28,000 acre-feet a year. The average of yearly precipitations from the Roswell and Artesia stations of the U. S. Weather Bureau is shown in ascending order in Table I and the recharge is shown in Figure 12.

(2) Surface Drainage and Irrigation Losses. The Roswell basin is crossed by numerous ephemeral streams, some of which head in the mountains to the west. During the summer months, when most of the rain falls, then streams flow, and part of the flow percolates down to the groundwater reservoir.

TABLE VI

THREE-YEAR EFFECTIVE AVERAGE RAINFALL (INCHES) AT ROSWELL AND ARTESIA, RECHARGE TO PRINCIPAL CONFINED AQUIFER, AND RECHARGE PROBABILITIES

ARRANGED IN ASCENDING ORDER

m	Year	Rainfall $\bar{R}_3$ (inches)	Recharge** (acre-ft)	$\frac{m}{1+n}$(*)	m	Year	Rainfall $\bar{R}_3$ (inches)	Recharge (acre-ft)	$\frac{m}{1+n}$
1	1965	6.638	139400	.0149	34	1937	11.753	246800	.5075
2	1964	7.001	147000	.0299	35	1944	11.763	247000	.5224
3	1910	7.093	149000	.0448	36	1949	11.803	247900	.5373
4	1957	7.222	151700	.0597	37	1958	11.811	248000	.5522
5	1953	7.418	155800	.0746	38	1960	11.898	249800	.5672
6	1956	7.481	157100	.0896	39	1968	11.917	250300	.5821
7	1963	8.153	171200	.1045	40	1911	12.034	252700	.5970
8	1947	8.288	174100	.1194	41	1928	12.141	255000	.6119
9	1918	8.432	177100	.1343	42	1903	12.158	255300	.6269
10	1952	8.538	179300	.1493	43	1929	12.195	256100	.6418
11	1954	8.599	180600	.1642	44	1908	12.345	259200	.6567
12	1966	8.693	182500	.1791	45	1930	12.403	260500	.6716
13	1935	8.759	183900	.1940	46	1912	12.428	261000	.6866
14	1967	8.839	185600	.2090	47	1926	12.452	261500	.7015
15	1955	8.996	188900	.2239	48	1904	12.595	264500	.7164
16	1945	9.096	191000	.2388	49	1923	12.989	272800	.7313
17	1934	9.159	192300	.2537	50	1933	13.121	275500	.7463
18	1948	9.246	194200	.2687	51	1913	13.155	276300	.7612
19	1961	9.362	196600	.2836	52	1950	13.517	283900	.7761
20	1924	9.619	202000	.2985	53	1914	13.840	290600	.7910
21	1925	9.856	207000	.3134	54	1919	13.840	290600	.8060
22	1927	9.959	209100	.3284	55	1931	13.962	293200	.8209
23	1909	9.991	209800	.3433	56	1921	14.593	306400	.8358
24	1946	10.083	211700	.3582	57	1915	14.698	308700	.8507
25	1922	10.096	212000	.3731	58	1920	15.003	315100	.8657
26	1917	10.148	213100	.3881	59	1943	15.152	318200	.8806
27	1936	10.396	218300	.4030	60	1916	15.203	319300	.8955
28	1962	10.428	219000	.4179	61	1907	15.288	321000	.9104
29	1951	10.630	223200	.4328	62	1906	16.578	348100	.9254
30	1959	10.726	225200	.4478	63	1905	16.870	354300	.9403
31	1939	11.133	233800	.4627	64	1932	17.228	361800	.9552
32	1938	11.428	240000	.4776	65	1942	20.528	431100	.9701
33	1940	11.701	245700	.4925	66	1941	23.298	489200	.9851

(*) n = 66.

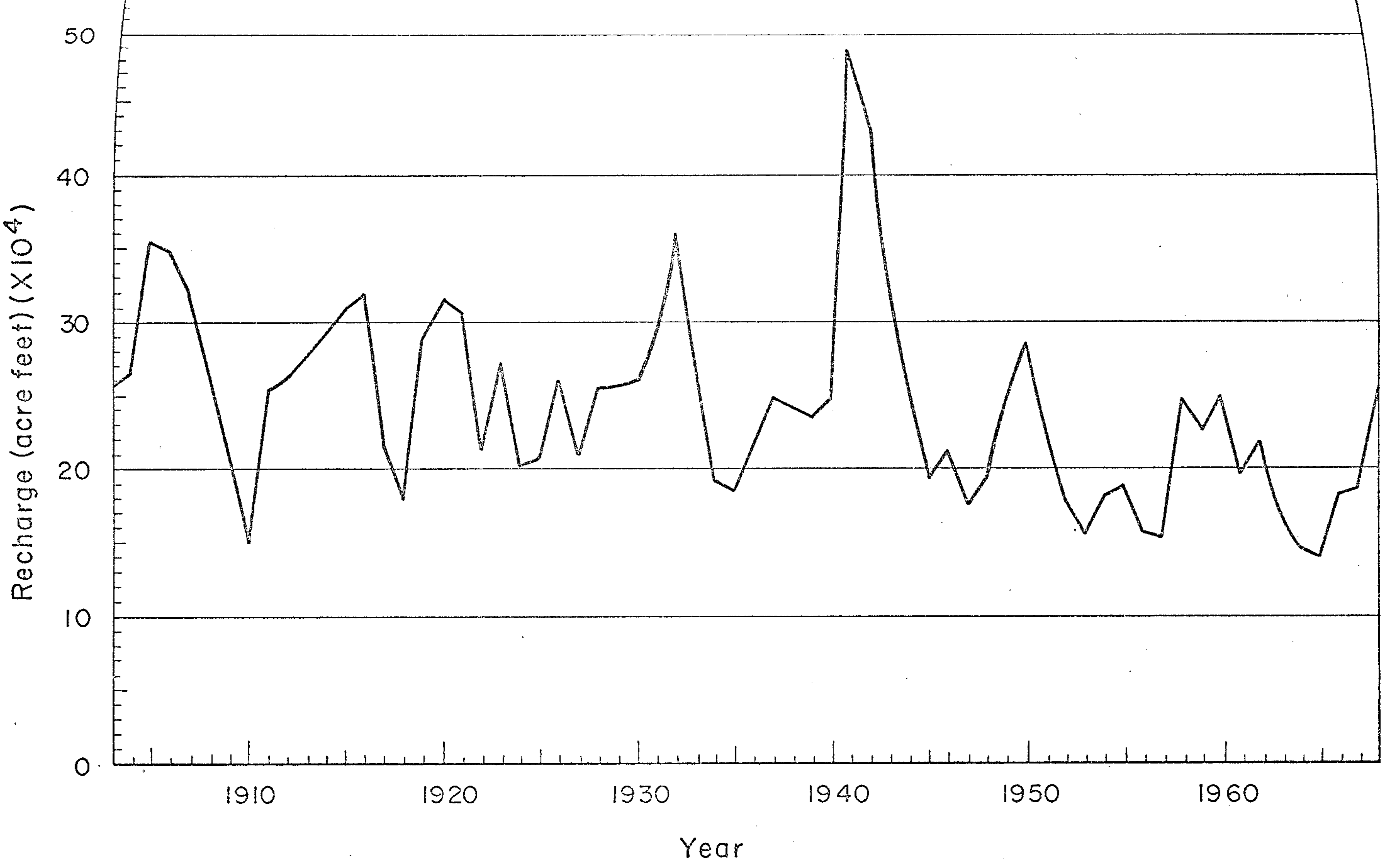

FIGURE II

RECHARGE TO THE PRINCIPAL CONFINED AQUIFER
ROSWELL, NEW MEXICO

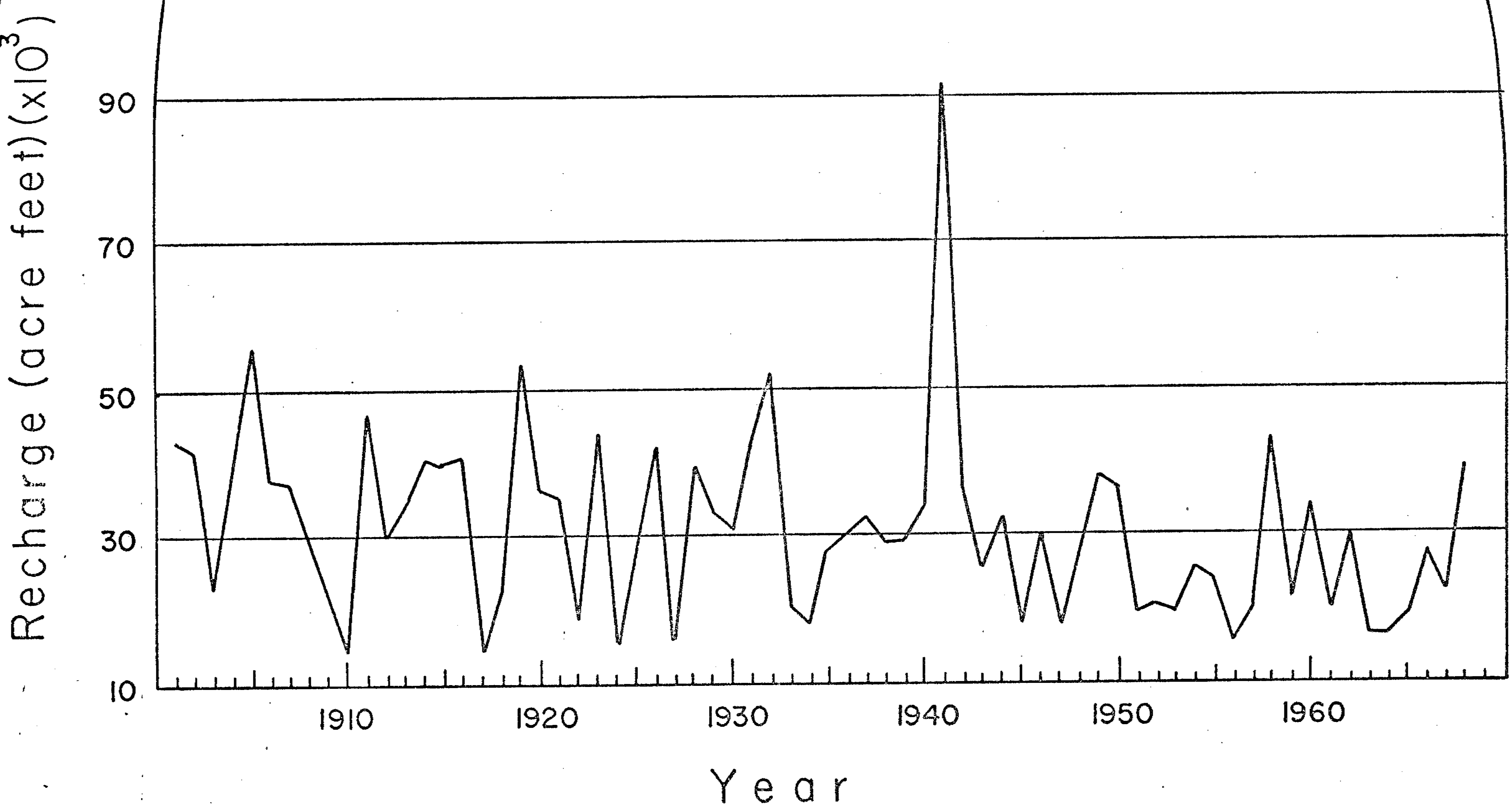

FIGURE 12

RECHARGE FROM LOCAL PRECIPITATION TO THE SHALLOW AQUIFER, ROSWELL BASIN, NEW MEXICO

The recharge from irrigation is made up of seepage from irrigated lands, from reservoirs, and from ditches. The amount of recharge from surface drainage and from irrigation losses has not been previously estimated. Information in the files of the U. S. Geological Survey based on the studies in areas with similar soil conditions indicates that the replenishment is about 20 percent of the total amount of irrigation water applied. An average loss of 10 percent is assumed between the farm-headgate and the field. The total amounts of water used for irrigation during 1967 and 1968 were 388,000 and 339,000 acre-feet, respectively. We thus get estimates of recharge of 116,000 and 102,000 acre-feet during 1967 and 1968, respectively.

Leakage

Leakage from one aquifer to the other in the coupled leaky-aquifer system of the Roswell basin is a function of both time and space. The direction of leakage is determined by the difference in the hydraulic heads of the two aquifers, the direction of leakage being from the aquifer with higher head to the aquifer with lower head. Leakage is directly proportional to the product of the difference in the heads of the two main aquifers and the leakance of the aquitard in a given area.

The amount of leakage can be determined by:

$$Q = K'A\Delta h/b' \qquad (7)$$

where Q is the volumetric rate of leakage through a vertical column of the Shallow Confined Aquifer with a basal area A. Δh is the difference between the average heads of the two main aquifers in that area A. K'/b' is the leakance or leakage coefficient or the ratio of the hydraulic conductivity (K') of the aquitard to its thickness (b') in the area under consideration.

Equation (7) was used to calculate leakage for January of the six years for which water table and potentiometric surface maps were constructed. The January leakage, as well as the leakage coefficients used to calculate leakage, are shown in Table VII. The leakage was positive in all cases. This is because normally the average January elevation of the potentiometric surface in the Principal Confined Aquifer is higher than the average January elevation of the water table in the Shallow Aquifer. However, this is not necessarily true during the pumping season, and the direction of leakage can then be reversed.

Natural Discharge

The natural discharge from the coupled leaky aquifers and the Pecos River system of the Roswell basin can be divided into three components: (1) base flow, (2) flow from springs, and (3) consumptive use by phreatophytes. All components are discussed below.

(1) Base flow

The Pecos River gains water as it flows through the Roswell basin, as is apparent from the record of gaging stations at Acme and at Artesia (see Tables VIII and IX). The former is located just north of the basin whereas the latter is located in the southern part of the basin.

The base flow into the Pecos River between Acme and Artesia is estimated from the analysis of hydrographs (obtained by plotting daily

TABLE VII

ROSWELL BASIN, N. M., LEAKAGE FROM PRINCIPAL CONFINED AQUIFER TO SHALLOW AQUIFER DURING JANUARY OF DIFFERENT YEARS (THOUSANDS OF ACRE-FEET)

Area	Leakance acre-ft/mo	1926	1944	1954	1964	1969
Roswell Townships 10, 11	4.5×10^{-3}	10.7	12.4	8.8	5.2	5.6
Dexter Twps. 12, 13, 14	2.5×10^{-4}	1.1	1.2	1.2	0.8	1.3
Artesia Twps. 15 and 16	9.0×10^{-4}	2.0	2.6	1.1	0.6	1.8
Lakewood Twps. 17, 18, 19, 20	3.9×10^{-4}	3.0	3.2	1.5	0.2	1.0
Total		16.8	19.4	12.6	6.8	9.7

DISCHARGE OF PECOS RIVER NEAR ACME, IN THOUSANDS OF ACRE-FEET

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1938	.7	.4	18.7	.7	.2	33.1	12.5	15.1	14.3	8.7	1.0	1.5	107.5
1939	1.1	.2	22.0	11.0	24.1	23.3	19.4	11.4	21.3	2.1	.7	1.0	138.1
1940	1.1	.7	29.3	19.4	6.8	19.4	11.2	17.6	17.0	.6	.7	.4	124.7
1941	.2	.2	36.5	40.7	164.8	130.1	69.2	44.6	209.9	135.3	30.1	14.5	876.5
1942	11.6	12.9	3.6	72.4	51.8	14.8	13.7	16.4	138.2	12.2	51.0	7.8	406.8
1943	10.3	1.6	6.9	12.1	1.3	29.7	4.4	29.1	17.5	2.2	2.3	2.7	120.7
1944	1.8	1.0	31.1	1.4	.9	30.8	8.4	2.8	8.9	6.9	2.4	1.4	98.4
1945	1.2	.3	.1	35.1	.6	16.1	.2	5.4	14.1	2.3	1.4	.6	77.7
1946	1.0	.1	.1	23.2	.1	.3	9.5	.7	40.8	3.8	2.3	1.1	83.4
1947	.9	.1	8.0	18.5	4.5	0	23.3	.1	0	0	0	0	55.4
1948	0	.5	0	33.7	.4	3.8	19.5	16.2	0	0	.3	0	74.8
1949	.1	.4	0	27.2	7.0	26.5	13.4	13.2	48.4	21.6	3.9	2.2	164.4
1950	4.8	4.5	3.9	12.8	5.7	37.7	52.0	11.6	9.2	12.4	12.4	.7	156.5
1951	.8	.6	26.3	4.8	13.5	19.5	35.0	5.5	1.3	1.2	1.1	.3	110.4
1952	.2	.3	3.0	24.3	.1	14.9	17.8	33.5	.3	.9	.4	.2	96.4
1953	.1	0	2.9	21.0	.3	.2	14.4	27.6	6.1	.1	.3	0	73.2
1954	.1	0	0	19.0	16.0	.7	0	14.0	.2	71.8	3.2	1.8	127.2
1955	1.8	1.6	1.2	.9	5.0	18.9	36.0	2.0	69.6	13.2	1.5	.9	153.1
1956	1.0	1.3	.8	.6	4.4	14.6	24.6	33.9	1.7	0	2.4	.2	85.9
1957	.3	.2	11.3	.4	4.5	4.0	14.4	29.3	12.8	2.8	.6	.2	85.9
1958	.7	.1	19.0	25.2	65.6	24.6	7.7	31.6	33.6	6.0	5.0	5.5	225.1
1959	2.4	4.4	2.2	1.5	19.5	4.5	28.2	31.3	.5	.8	2.0	1.7	99.5
1960	1.3	.4	18.1	5.1	23.2	16.2	99.0	12.7	2.9	25.1	5.9	7.6	218.1
1961	7.6	6.0	4.4	4.8	7.2	19.2	38.7	21.6	1.8	2.6	3.9	2.7	121.2
1962	1.9	1.1	27.1	1.8	7.1	30.4	10.5	7.4	17.9	.9	.9	1.1	108.7
1963	.9	1.2	24.8	1.2	.3	24.9	29.0	25.9	7.0	.8	.9	.6	118.2
1964	.5	.7	.7	21.4	.6	.6	13.8	.2	.1	0	1.8	.3	40.9
1965	.1	.1	21.9	2.9	5.0	11.7	28.1	2.1	2.6	.4	.5	.2	76.2
1966	.1	.1	26.9	1.6	.4	30.8	16.3	33.2	6.2	.8	1.0	.5	118.6
1967	.5	.6	.5	.2	49.2	4.0	1.7	23.9	.8	.4	.7	.7	83.7
1968	.9	.5	24.3	6.0	.9	16.1	19.5	3.4	2.7	.8	.7	.4	76.2

DISCHARGE OF PECOS RIVER NEAR ARTESIA, IN THOUSANDS OF ACRE-FEET

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1906	27.0	19.0	11.9	31.5	38.5	18.3	39.5	16.6	7.0	11.7	23.3	36.8	281.1
1907	28.8	21.9	8.5	12.5	21.6	33.4	28.5	20.6	16.1	27.4	24.9	26.1	270.3
1908	22.9	15.9	4.8	6.5	8.5	5.4	29.4	95.9	16.1	2.8	9.2	22.3	239.7
1909	21.2	10.3	6.7	2.9	3.4	6.4	10.1	10.9	28.3	6.8	7.9	22.3	137.2
1910	18.3	12.8	6.7	4.8	10.5	11.0	3.9	87.9	8.4	5.7	8.9	14.4	193.5
1911	19.2	14.1	11.1	9.7	25.0	10.9	90.4	21.8	12.0	22.0	19.5	18.9	275.0
1912	16.6	13.8	10.3	10.0	30.5	52.5	9.8	9.7	12.3	9.8	7.5	15.2	198.0
1913	21.1	16.8	8.6	8.6	5.9	80.3	18.0	5.3	6.9	13.3	11.7	18.9	215.7
1914	16.8	14.1	9.8	9.6	102.0	44.8	81.2	29.3	7.3	18.5	18.0	22.3	374.0
1915	24.3	20.9	20.3	219.9	40.6	31.7	42.3	34.8	13.3	17.2	10.4	17.5	493.2
1916	20.3	16.7	14.9	26.4	49.7	13.2	2.7	48.3	21.9	17.2	15.5	18.3	265.0
1917	21.5	14.2	9.0	5.3	7.9	4.6	2.3	26.1	21.1	5.3	7.4	11.7	136.5
1918	19.7	12.5	7.4	5.8	6.6	15.5	4.6	31.3	10.6	33.2	14.4	19.1	180.8
1919	23.2	13.1	139.2	40.9	57.2	70.8	84.6	36.3	186.6	55.7	23.4	23.4	754.4
1920	26.7	20.6	13.6	9.6	41.2	44.8	18.5	14.8	7.1	5.7	12.4	14.3	262.9
1921	17.5	12.9	9.9	5.6	55.8	169.0	70.7	67.6	13.1	5.9	9.5	12.1	449.7
1922	14.4	11.2	11.7	8.2	18.1	29.2	13.5	2.5	4.8	3.8	8.6	10.1	123.2
1923	11.6	14.9	12.2	19.9	12.0	19.0	9.9	18.1	16.8	97.1	27.1	30.9	289.5
1924	25.8	17.1	12.7	23.3	29.3	21.3	28.0	9.4	4.3	8.8	9.2	15.8	204.9
1925	16.8	9.3	5.7	3.3	4.3	3.8	43.5	74.1	47.2	17.0	13.7	12.0	250.7
1926	13.7	9.8	10.8	17.7	60.9	48.0	32.2	6.8	34.2	16.5	13.5	17.2	281.4
1927	16.4	11.4	8.0	6.6	7.4	15.8	13.9	41.8	19.3	6.6	4.2	8.0	159.6
1928	11.2	9.2	6.7	4.4	33.1	16.0	17.8	28.6	14.8	56.6	26.7	18.0	243.3
1929	14.4	13.8	11.6	5.6	22.6	16.3	9.2	22.3	24.6	16.0	14.1	11.6	182.4
1930	13.6	9.3	6.7	6.9	9.6	22.2	24.7	19.8	6.3	113.0	14.1	15.1	261.6
1931	16.6	13.8	9.8	24.7	24.5	16.2	10.4	34.5	12.5	18.5	14.2	19.4	215.2
1932	17.5	13.5	11.7	14.0	44.8	17.8	22.2	9.4	109.9	62.6	18.7	17.3	360.1
1933	16.8	13.3	9.8	4.4	2.7	16.6	24.5	39.0	21.3	8.2	9.8	9.3	176.0
1934	10.8	9.7	9.4	7.5	7.8	3.5	.6	10.1	12.6	4.2	8.8	8.9	93.7
1935	9.0	9.5	6.9	3.5	30.1	19.8	8.4	45.3	29.1	7.1	9.1	12.3	190.5

Continued

1936	15.2	2.7	9.3	3.5	21.5	26.6	32.1	7.5	29.8	15.8	11.2	17.1	292.9
1937	17.9	19.4	20.2	30.2	182.7	208.0	38.3	12.8	25.8	8.7	8.9	8.3	581.6
1938	7.8	6.6	23.3	4.9	3.6	35.5	22.5	13.6	24.5	17.1	8.4	7.0	175.4
1939	8.2	6.7	25.1	15.9	27.5	24.3	23.8	19.9	20.6	5.3	5.0	7.2	189.6
1940	7.1	6.5	33.1	19.1	20.6	22.9	13.3	23.3	17.8	3.9	5.7	6.4	179.8
1941	5.6	5.1	47.2	54.4	235.8	150.2	89.3	54.1	339.4	258.4	73.7	37.7	1,351.0
1942	30.6	27.9	13.6	76.9	67.1	19.1	17.5	18.3	134.3	23.8	62.2	20.0	511.7
1943	21.6	9.7	9.1	19.1	5.1	31.8	15.8	27.8	17.9	6.1	7.5	11.8	183.9
1944	12.7	8.4	34.4	5.4	4.5	30.5	9.9	4.2	12.2	14.8	9.3	9.2	155.8
1945	8.1	6.0	4.9	34.6	3.7	13.7	3.0	2.5	17.1	7.2	6.6	6.2	114.1
1946	6.9	5.3	4.3	23.9	2.8	5.0	10.0	2.6	47.6	17.2	10.0	9.8	146.0
1947	8.8	4.7	8.4	23.1	10.5	.9	20.6	.4	.5	2.0	4.4	6.0	90.6
1948	4.9	5.6	3.3	31.6	4.3	28.0	15.9	18.3	1.1	2.6	5.1	5.5	127.7
1949	5.7	5.6	2.6	26.5	11.4	40.0	35.1	20.0	55.0	25.8	10.7	9.3	248.2
1950	10.8	8.7	6.6	13.5	4.5	26.6	64.1	15.4	15.5	14.2	5.6	5.5	191.5
1951	5.3	4.8	24.1	5.7	16.6	14.8	37.6	3.5	1.1	2.4	5.8	5.9	128.1
1952	4.7	2.9	3.5	22.5	2.4	9.7	18.4	30.5	1.1	2.7	3.5	4.2	106.6
1953	3.2	2.8	3.0	19.7	2.1	1.4	9.4	18.5	9.0	1.3	3.3	3.6	77.8
1954	3.2	2.3	2.4	15.6	19.1	.9	.1	19.8	2.0	152.7	12.4	8.6	239.6
1955	7.2	5.9	4.4	3.2	6.8	14.9	38.8	4.9	60.8	32.1	6.0	6.4	191.9
1956	5.1	6.6	3.7	2.5	5.2	9.4	24.0	26.7	3.8	1.1	4.2	3.6	96.4
1957	3.8	2.9	10.9	1.9	6.6	5.4	10.6	27.5	9.8	5.4	4.3	4.1	93.5
1958	4.5	3.5	20.7	22.3	70.7	23.2	11.6	27.4	30.3	12.4	8.9	8.7	244.8
1959	6.0	6.5	3.8	2.4	15.9	4.0	28.4	27.7	.7	1.5	3.5	4.1	105.1
1960	5.3	4.0	15.5	7.1	18.7	20.0	89.3	12.1	18.4	26.0	10.6	12.1	224.6
1961	12.4	9.6	7.4	5.4	7.3	18.7	31.2	20.9	1.9	2.1	7.4	6.3	131.2
1962	5.4	3.7	25.3	2.8	4.1	29.9	10.8	8.6	20.7	3.9	3.5	4.1	123.5
1963	4.1	3.7	22.1	1.6	2.7	20.8	21.7	22.9	9.4	1.3	2.7	3.2	116.8
1964	2.7	2.6	1.8	17.8	1.1	3.4	10.0	0	0	.1	2.1	2.1	44.1
1965	2.1	1.6	17.3	5.3	4.0	8.5	32.9	6.8	2.6	.9	2.7	2.7	87.9
1966	2.6	2.4	23.3	3.2	1.4	24.1	17.4	46.0	12.5	2.7	2.8	2.0	141.0
1967	2.8	2.7	1.4	.6	40.7	5.8	1.2	21.6	1.0	.8	1.8	2.5	83.4
1968	3.8	3.1	20.8	8.5	1.7	10.8	31.3	1.3	3.4	1.2	2.2	2.5	90.6

stream flows versus day of the year on semi-log paper) at Artesia minus those at Acme with a suitable time lag. The estimated monthly base flows and yearly totals since 1919 are shown in Table II .

The base flow has been decreasing steadily since the development of the Shallow Aquifer in 1938, except during 1941 to 1944 when it increased because of heavy rains. The average yearly base flow for the period 1919-1968 is 51,000 acre-feet. The rate of base flow is least during the pumping season and increases during the winter months. The monthly averages show that during July and January the Pecos River receives the smallest average amount (2,300 acre-feet) and the highest average amount (6,600 acre-feet), respectively.

(2) Spring flow

Before the development of the basin there were a few artesian springs in the northern part of the basin near Roswell and the Major Johnson Springs, which still flow, at the southern tip of the basin. Besides these, there reportedly were some springs in the lower reaches of Penasco and Felix creeks. The information on the springs has been gathered by the U. S. Geological Survey (Welder, personal communication, 1968) and is described here.

a) Berrendo Springs. Berrendo Springs originally flowed 65 cfs (47,060 acre-ft/yr) from three springs. Each was estimated to have an equal flow of about 21.7 cfs (15,790 acre-ft/yr) in 1900.

(i) North Berrendo Spring. (NE¼, SW¼, SE¼, Section 5, T. 10 S., R. 24 E.) The flow of North Berrendo Spring decreased to 5 cfs (3,620 acre-ft/yr) by 1926 and stopped by 1932.

(ii) Middle Berrendo Spring. (SW¼, SW¼, NE¼, Sec. 17, T. 10 S., R. 24 E.) The flow of Middle Berrendo Spring decreased to only 3 cfs (2,172 acre-ft/yr) by 1926 and ceased by 1932.

(iii) South Berrendo Spring. SW¼, SW¼, NE¼, Sec. 17, T. 10 S., R. 24 E.) South Berrendo Spring stopped flowing by 1926.

b) North Spring. (NW¼, SE¼, NE¼, Sec. 36, T. 10 S., R. 23 E.) North Spring was originally flowing at the rate of 85 cfs (61,540 acre-ft/yr) and the flow decreased to 77 cfs (55,748 acre-ft/yr) in 1901 and eventually stopped flowing by 1926.

c) South Spring. (SE¼, SE¼, NE¼, Sec. 22, T. 11 S., R. 24 E.) South Spring had an original flow of 60 cfs (43,440 acre-ft/yr) which diminished to 28 cfs (20,272 acre-ft/yr) in 1902 and stopped flowing by 1904.

d) Major Johnson Springs. (NE¼, NE¼, NW¼, Sec. 21, T. 20 S., R. 25 E.) Major Johnson Springs have been studied by Theis [1938] and Reeder [1963]. They discharged 40 cfs (28,960 acre-ft/yr) until 1938, when the discharge started to diminish. The rate of flow in 1964 was 10 cfs (7,240 acre-ft/yr).

(3) Consumptive use by saltcedars

Saltcedars were first observed in the basin near Lake McMillan in 1914. In the beginning they were welcome because they helped cut down the transport of sediments into the lake. Starting with about 500 acres in 1915, in the Middle basin of the Pecos River, the area covered by saltcedar increased to 15,000 acres by 1939, 25,000 acres by 1946, and 40,000 acres by 1957 [Thompson, 1959].

Saltcedars are located mainly along the Pecos River channel and they consume mostly the shallow groundwater. The amounts of water consumed by phreatophytes in the Roswell basin during 1966, 1967, and 1968 are estimated to be 121,000, 132,000, and 107,000 acre-feet, respectively. The amount of water consumed during 1968 has decreased from the preceding two years because of the eradication program of the Bureau of Reclamation, which started in 1967. Yearly estimates of consumptive use by saltcedars were made using the data on saltcedar acreages provided by the Bureau of Reclamation [Smith, personal communication, 1969], and are shown in Table X .

The estimates of saltcedar acreages given in Table X are lower than the estimates of the National Planning Board [1942] and of Thompson [1959]. Therefore, it is believed here that the estimates of saltcedar consumption in Table X are low. The discrepancy is believed to be higher for the earlier years.

Pumpage from the Aquifers

Ground water is withdrawn in the basin mainly from the two principal aquifers, namely, the Shallow Aquifer and the Principal Confined Aquifer. Less than 10 percent of the groundwater pumped in the basin comes from the aquitard, also called in this report the Shallow Confined Aquifer.

A tabulation of total number of wells tapping various aquifers and the amounts of water withdrawn from 1900 through 1968 are presented in Tables XI and XII, respectively. The rates of discharge for 748 wells were obtained from the well schedules which are available in the office of the State Engineer at Roswell. Tables XIII and XIV and Figures 13 and 14 were prepared from this information as well as from information about the metered pumpage for individual wells, also provided by the same office.

TABLE X

YEARLY ESTIMATES OF CONSUMPTIVE USE OF WATER BY SALTCEDARS IN THE ROSWELL BASIN*

Year	Saltcedar Area (acres)		Consumptive Use (acre-feet)	
	Gross	K = 1.0	Per Acre	Total
1937	9,100	7,400	3.86	28,500
1938	10,600	8,400	4.03	34,000
1939	11,800	9,400	4.00	37,400
1940	12,800	10,200	3.83	39,100
1941	13,800	11,100	1.46	16,200
1942	14,700	11,900	3.63	43,100
1943	15,600	12,700	4.18	53,100
1944	16,500	13,500	3.80	51,200
1945	17,300	14,300	4.51	64,300
1946	18,400	15,300	4.12	63,200
1947	19,000	15,800	4.49	70,900
1948	19,800	16,600	4.16	68,900
1949	20,600	17,300	3.68	63,700
1950	20,600	17,100	3.91	66,700
1951	22,100	18,800	4.55	85,400
1952	22,800	19,500	4.46	86,900
1953	23,600	20,200	4.57	92,400
1954	24,300	21,000	4.44	93,100
1955	25,000	21,700	4.34	94,000
1956	25,400	22,400	4.70	105,200
1957	26,400	23,100	4.52	104,200
1958	28,800	25,500	3.64	92,700
1959	27,800	24,500	4.48	109,500
1960	28,400	25,200	3.93	99,000
1961	29,100	25,800	4.43	114,400
1962	29,800	26,500	4.13	109,700
1963	30,400	27,200	4.67	127,100
1964	30,400	27,100	4.62	125,200
1965	31,700	28,600	4.56	130,300
1966	32,400	29,200	4.14	120,700
1967	33,000	29,900	4.42	132,000
1968	33,600	30,500	3.52	107,400

* Estimates are based on information supplied by the Bureau of Reclamation, Albuquerque.

TABLE XI

AVERAGE DAYS OF USE AND AVERAGE DISCHARGE OF WELLS

TAPPING VARIOUS AQUIFERS IN THE ROSWELL BASIN, NEW MEXICO, 1967

Aquifer*	Total Number of Wells	Wells Analyzed	Average Days	Average discharge(gpm)
1	814	473	82.6	1080
2	91	46	100.3	627
3	480	229	97.4	556
12	33	23	96.9	847
13	11	7	120.8	694
23	125	75	99.0	643
123	5	3	104.5	1007

* Aquifer code numbers 1, 2, and 3 denote Principal Confined Aquifer, Shallow Confined Aquifer, and Shallow Aquifer, respectively. Two or three digits represent multiple aquifers.

TABLE XII

ROSWELL BASIN ANNUAL PUMPAGE BY AQUIFER*

Year	Shallow Aquifer	Shallow Confined Aquifer	Principal Confined Aquifer	Total
1900-1937	0	14,500	185,500	200,000
1938	93,960	23,300	185,740	303,000
39	98,920	24,530	195,550	319,000
40	97,990	24,300	193,710	316,000
1941	58,610	14,530	115,860	189,000
42	105,430	26,150	208,420	340,000
43	114,740	28,450	226,810	370,000
44	106,670	26,450	210,870	344,000
45	125,900	31,220	248,880	406,000
1946	116,290	28,840	229,880	375,000
47	129,000	31,990	255,010	416,000
48	113,480	31,870	260,650	406,000
49	108,170	30,380	248,450	387,000
50	110,120	30,930	252,950	394,000
1951	133,600	37,520	306,880	478,000
52	124,940	35,090	286,970	447,000
53	129,690	36,420	297,890	464,000
54	131,920	37,050	303,020	472,000
55	125,780	35,330	288,900	450,000
1956	138,630	38,940	318,430	496,000
57	135,280	37,990	310,730	484,000
58	107,050	30,070	245,890	383,000
59	125,780	35,330	288,900	450,000
60	118,510	33,280	272,210	424,000
1961	125,500	35,250	288,260	449,000
62	137,730	36,500	290,760	465,000
63	150,770	39,960	318,280	509,000
64	158,760	42,080	335,160	536,000
65	132,400	35,090	279,510	447,000
1966	115,520	30,620	243,870	390,000
67	110,480	29,280	233,240	373,000
68	97,450	25,830	205,720	329,000
Mean 1938-1968	118,680	31,760	256,370	406,810

* In acre-feet.

TABLE XIII

DAYS OF USE OF WELLS TAPPING VARIOUS AQUIFERS DURING 1967

IN THE ROSWELL BASIN, NEW MEXICO

Days	Number of Wells Analyzed		
	Principal Confined Aquifer	Shallow Confined Aquifer	Shallow Aquifer
0 to 20	20		4
21 to 40	62	5	26
41 to 60	70	9	36
61 to 80	101	5	36
81 to 100	83	4	36
101 to 120	52	6	28
more than 120	85	17	64
Total	473	46	229

TABLE XIV

DISCHARGE OF WELLS TAPPING VARIOUS AQUIFERS IN THE ROSWELL BASIN, NEW MEXICO, FROM THE WELL SCHEDULES

Discharge in gpm	Number of Wells Analyzed		
	Principal Confined Aquifer	Shallow Confined Aquifer	Shallow Aquifer
0 to 200	7	3	17
201 to 400	25	8	69
401 to 600	45	13	53
601 to 800	57	13	43
801 to 1000	77	5	23
1001 to 1200	80	2	11
1201 to 1400	62	2	9
1401 to 1600	34		1
1601 to 1800	38		2
1801 to 2000	26		1
more than 2000	22		
Total	473	46	229

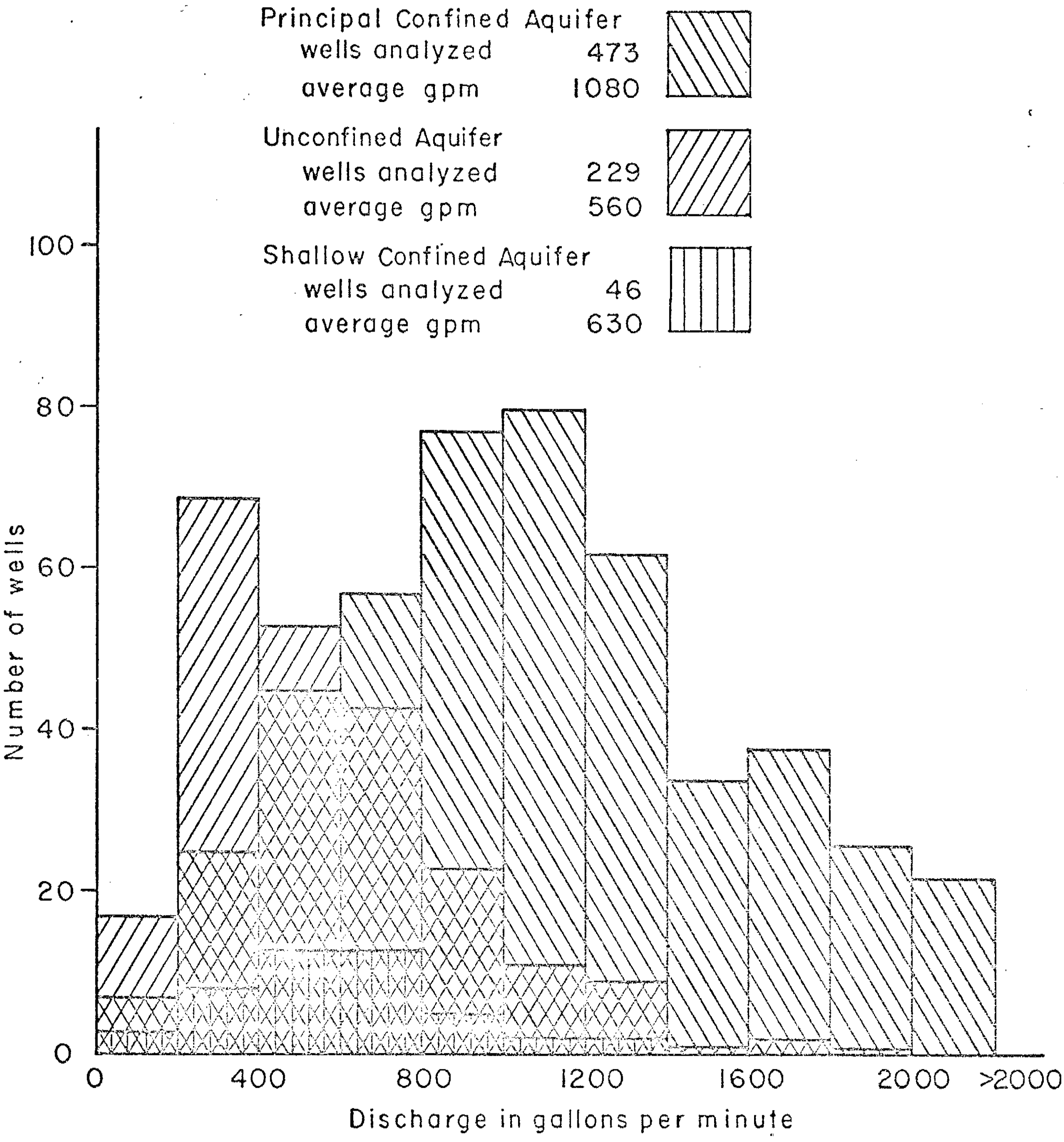

FIGURE 13
DISCHARGE OF WELLS TAPPING VARIOUS AQUIFERS
IN ROSWELL BASIN, NEW MEXICO

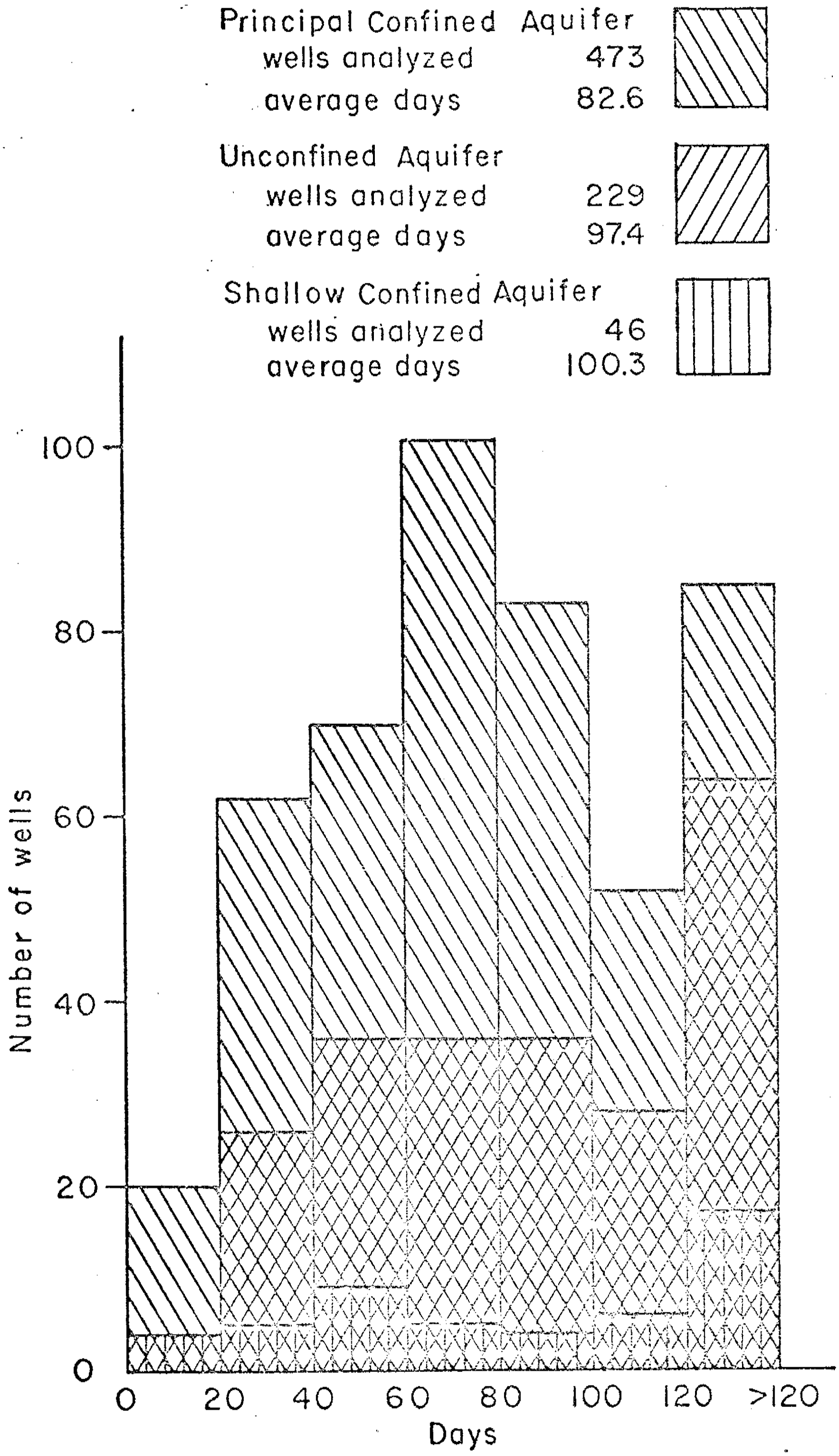

FIGURE 14

DAYS OF USE OF WELLS TAPPING VARIOUS AQUIFERS DURING 1967 IN ROSWELL BASIN, NEW MEXICO

The total annual pumpage is distributed according to sources and periods as shown in Table XV . These percentages are based on the history of the development of the basin [Welder, personal communication, 1968].

TABLE XV

PERCENTAGE DISTRIBUTION OF TOTAL ANNUAL PUMPAGE ACCORDING TO SOURCE

Period	SOURCE		
	Principal Confined Aquifer	Shallow Confined Aquifer	Shallow Aquifer
1900-37	92.75	7.25	-
1938-47	61.30	7.69	31.01
1948-61	64.20	7.85	27.95
1962-68	62.53	7.85	29.62

The yearly amounts of pumpage by source based on Table XV are shown in Table XII. The pumpage estimates have been derived by Mower [1958] and Welder [personal communication, 1968]. Table XII is based on the information in these sources as well as on metered pumpage for the years 1967 and 1968 provided by the Office of the State Engineer in Roswell.

Use of Groundwater

Before large-scale development of the basin, groundwater in the Roswell basin was used mainly from domestic and stock wells. However, the groundwater was not extensively exploited until large-scale irrigation was begun in the beginning of this century.

During 1967 and 1968, only 4.3 percent and 4.6 percent, respectively, of the total groundwater pumped was used for municipal, commercial, and industrial purposes. More than 95 percent of the groundwater is utilized for farming.

Irrigated Acreage

The Roswell basin is located in Chaves County and in the northern part of Eddy County. Alfalfa and cotton are the major crops of the basin, followed by sorghum. Some small grains and commercial vegetables, etc. are also grown. During 1968, alfalfa, cotton, and sorghum accounted for 95.4 percent of the total acreage in Chaves County. Tables XVI and XVII show yearly acreages of irrigated crops in Chaves and Eddy Counties, New Mexico. These tables are based on estimates made by the U. S. Department of Agriculture and New Mexico Department of Agriculture.

Consumptive Irrigation Requirement by Crops

By "consumptive irrigation requirement" is meant here the amount of water required for consumptive use by a crop per unit area minus effective precipitation in that area during the period of time under consideration. Effective precipitation is that part of total precipitation which enters the soil and becomes available for plant use.

Consumptive use is defined by Blaney and Hanson [1965] as, "the unit amount of water used on a given area in transpiration, building of plant tissue, and evaporated from adjacent water surface, snow, or

TABLE XVI

ACREAGES OF IRRIGATED CROPS IN CHAVES COUNTY, NEW MEXICO*

Year	Alfalfa	Cotton	Sorghum	Small Grains	Total
1923	16,500	10,100	1,700	7,100	35,400
1924	14,900	17,000	1,400	5,500	38,900
1925	14,200	19,200	1,300	5,400	40,100
1926	15,300	18,000	1,300	7,500	42,100
1927	15,600	16,800	1,400	7,200	41,000
1928	13,800	20,800	1,700	5,600	41,900
1929	13,300	21,500	2,000	5,500	42,400
1937	15,000	38,000	13,000	10,000	76,000
1938	22,700	22,000	24,600	7,300	76,600
1939	19,000	23,000	18,500	12,100	72,700
1940	24,200	24,500	22,000	6,400	77,100
1941	24,000	24,300	28,300	7,500	84,100
1942	23,000	26,500	23,400	7,800	80,700
1943	26,000	26,600	29,300	7,900	89,800
1944	29,500	27,700	24,000	9,900	91,200
1945	30,000	33,000	21,000	8,200	92,200
1946	30,000	33,000	23,000	10,600	96,700
1947	24,500	46,400	18,500	8,000	97,400
1948	24,000	52,300	16,000	4,000	96,300
1949	24,000	55,000	23,000	2,500	104,500
1950	35,000	35,900	21,000	12,000	103,900
1951	32,000	58,000	15,000	4,000	109,000
1952	35,000	51,000	15,000	5,500	106,500
1953	35,000	59,100	12,000	6,000	112,100
1954	35,000	38,700	25,000	13,000	111,700
1955	35,000	32,300	25,000	16,000	108,300
1956	35,000	32,200	25,000	16,000	108,200
1957	35,000	31,600	27,000	17,200	110,800
1958	35,000	32,800	27,000	18,000	112,800
1959	27,600	32,400	5,600	9,300	75,000
1960	30,500	40,500	6,000	18,100	95,100
1961	34,000	35,000	9,100	19,200	97,300
1962	31,700	35,200	9,500	20,000	98,400
1963	33,200	31,400	11,500	19,000	95,100
1964	35,800	31,400	11,000	16,800	96,600
1965	41,000	30,800	8,000	9,000	88,800
1966	41,600	24,700	10,000	9,800	86,100
1967	38,400	22,200	9,000	8,600	78,200
1968	41,400	26,500	8,300	3,600	79,900

* Compiled from records of the N. M. Dept. of Agriculture, Roswell Chamber of Commerce, and the report by Mower (1960).

TABLE XVII

ACREAGES OF IRRIGATED CROPS IN EDDY COUNTY, NEW MEXICO*

Year	Alfalfa	Cotton	Sorghum	Small Grains*	Total
1959	23,800	29,500	2,700	7,200	63,200
1960	25,000	32,100	2,800	8,500	68,400
1961	27,500	30,300	2,300	8,200	68,300
1962	27,000	29,900	2,200	7,800	66,900
1963	28,500	26,900	2,200	7,800	65,400
1964	26,400	24,400	1,000	1,900	53,700
1965	32,000	25,600	1,700	3,000	62,300
1966	31,700	20,800	1,700	4,100	58,200
1967	31,700	19,200	0	1,000	52,200
1968	35,000	22,900	1,300	1,000	60,200

* Compiled from records of the New Mexico Department of Agriculture.

intercepted precipitation in any specified time. Consumptive use may be expressed in volume per unit area such as acre-inches or acre-feet per acre, or simply in depth such as in inches or millimeters or feet."

Values of monthly consumptive use were calculated by the Blaney-Criddle method (1962) from 1905 to 1968 for the climatological data from the Roswell and Artesia stations. The Blaney-Criddle formula is expressed as follows:

$$u = kf, \tag{8}$$

where

u = monthly consumptive use in inches

k = monthly empirical crop consumptive-use coefficient

f = t x p/100 = monthly consumptive-use factor, t is mean monthly temperature in degrees Fahrenheit, and p is monthly percent of daytime hours of the year

Estimated values for k are given by Blaney and Hanson [1965].

Monthly effective precipitations for each month were calculated by using the following polynomial relation between the total monthly precipitation and the corresponding effective precipitation:

$$P_e = ap + bp^2 + cp^3 + dp^4 \tag{9}$$

where p = total amount of monthly precipitation; a, b, c, and d are constants where $a = 0.94574$, $b = 0.27926 \times 10^{-1}$, $c = -0.18451 \times 10^{-1}$, $d = 0.10224 \times 10^{-2}$; p_e = monthly effective precipitation corresponding to p.

Relation (9) was derived from data used by the U. S. Bureau of Reclamation [Blaney and Hanson, 1965] for calculation of p_e from p.

A computer program was developed to calculate montly consumptive irrigation requirements ($u - p_e$) for alfalfa, cotton, sorghum, and small grains. Monthly irrigation requirements for these four crops in the Roswell and Artesia areas for the period 1905 to 1968 are given in Appendix D, along with other tables of related data.

The irrigated acreages for the years prior to 1959 in Eddy County are not available and the crop pattern in the part of the basin located in Eddy County is more closely related to the pattern in Chaves County. Therefore, yearly consumptive irrigation requirements (CIR) for crops in the Roswell basin were estimated by multiplying CIR for crops in Chaves County by:

$$1.43 = \frac{\text{2 year (1967-68) total ground water pumped in Roswell basin}}{\text{2 year (1967-68) total ground water pumped in Chaves County}}$$

Table XVIII shows yearly CIR values for the Roswell basin. Yearly irrigation efficiency was obtained by dividing the yearly CIR value by the total water used for irrigation that year. The estimated yearly irrigation efficiencies are also shown in the table. The average of the irrigation efficiencies from 1943 through 1968 in the Roswell basin is 55 percent. These values may be somewhat off because of errors in estimating the total irrigation water applied and/or in estimating the yearly CIR values for the Roswell basin.

Decline of Water Levels

Water-table maps of the Shallow Aquifer were drawn for 1926, 1938, 1944, 1954, 1964, and 1969 on a scale of one inch equals two miles

TABLE XVIII

YEARLY IRRIGATION WATER APPLIED, CONSUMPTIVE IRRIGATION REQUIREMENT (CIR), AND IRRIGATION EFFICIENCIES, ROSWELL BASIN, NEW MEXICO

Year	Water Applied*		Consumptive Requirement*		Efficiency Percentage
	Groundwater	Total	Chaves County	Roswell Basin	
1943	370.0	384.0	152.0	217.4	56.6
1944	344.0	358.0	139.1	198.9	57.8
1945	406.0	420.0	177.1	253.2	60.2
1946	375.0	389.0	149.4	213.6	54.9
1947	416.0	430.0	178.0	254.6	59.2
1948	406.0	420.0	176.5	252.4	60.1
1949	387.0	401.0	144.6	206.8	51.6
1950	394.0	408.0	136.7	195.5	47.9
1951	478.0	492.0	234.5	335.3	68.2
1952	447.0	461.0	212.1	303.4	65.8
1953	464.0	478.0	230.6	329.7	69.0
1954	472.0	486.0	195.8	280.0	57.6
1955	450.0	464.0	182.9	261.5	56.4
1956	496.0	510.0	222.7	318.5	62.5
1957	484.0	498.0	178.3	255.0	51.2
1958	383.0	397.0	154.2	220.6	55.6
1959	450.0	464.0	142.1	203.2	43.8
1960	424.0	438.0	138.3	197.8	45.2
1961	449.0	463.0	172.7	247.0	53.3
1962	465.0	479.0	143.0	204.4	42.7
1963	509.0	523.0	184.7	264.1	50.5
1964	536.0	550.0	184.1	263.3	47.9
1965	447.0	461.0	191.4	273.7	59.4
1966	390.0	404.0	165.5	236.7	58.6
1967	373.0	387.0	144.1	206.1	53.3
1968	329.0	343.0	114.8	164.2	47.9
Average	425.3	435.6	168.2	240.6	55.2

* In thousands of acre-feet.

Potentiometric-surface maps of the Principal Confined Aquifer were drawn for 1926, 1944, 1954, 1964, and 1969 on the same scale as the water-table maps. All the above maps are based on measurements made during January of each year.

Since 1938 the water table has been lowered conspicuously in three areas, forming cones of depression. They are, one near Artesia, one near Hagerman, and one just north of Dexter. The decline is more than 100 feet in some places.

The decline in the potentiometric surface is also significant. It has been lowered as much as 100 feet at some places in the Roswell basin. The decline in the potentiometric surface is not concentrated in the form of significant cones of depression because the transmissivity of the Principal Confined Aquifer is very high ($\sim$ 200,000 ft^2/day in the Roswell area) compared to the transmissivity of the Shallow Aquifer ($\sim$ 13,000 ft^2/day in the Roswell area). More than 40 percent of the pumpage from the Principal Confined Aquifer is concentrated in the Roswell area. Fig. 15 shows the average hydrograph for four recorder wells in the Principal Confined Aquifer.

Average elevations of the water table in the Shallow Aquifer and average elevations of the potentiometric surface in the Principal Confined Aquifer were estimated from the above-mentioned maps for different years and are shown in Table XIX. The average elevation of the land surface in the same area is estimated to be about 3465 feet above mean sea level.

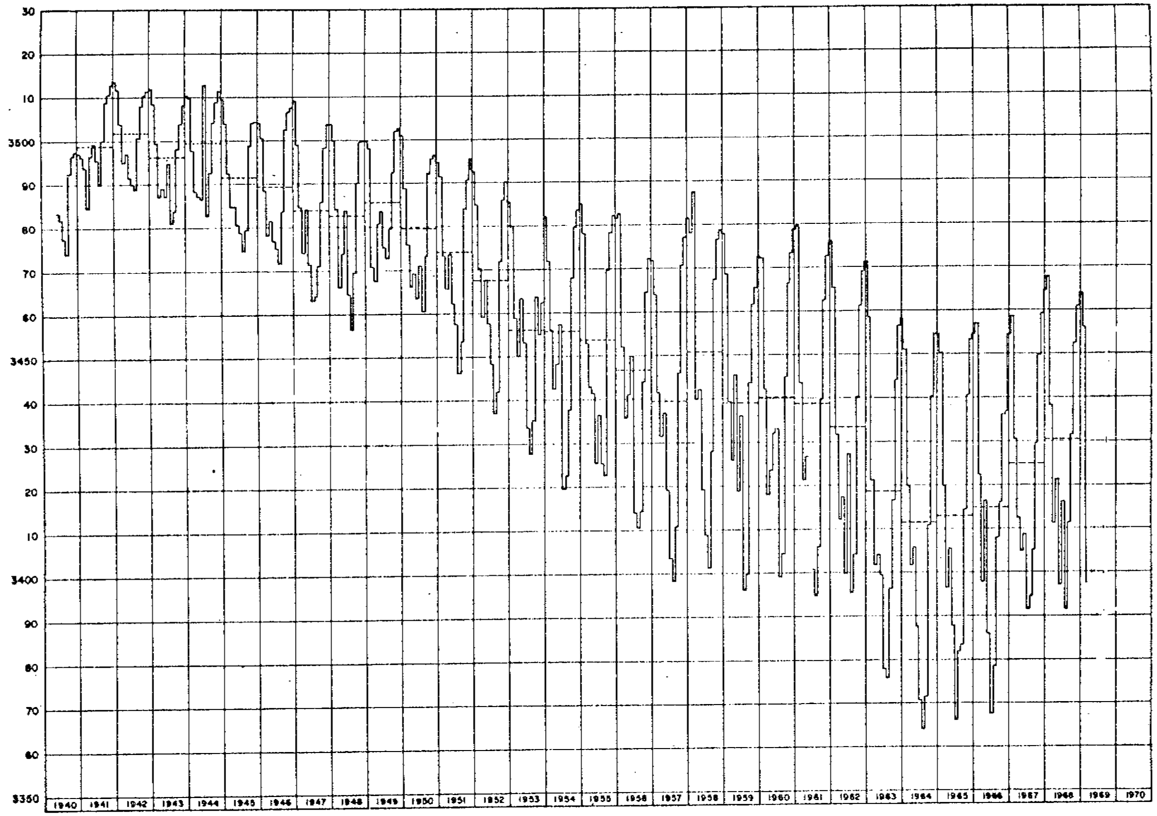

FIGURE 15

RECORDER WELLS	
Berrendo Smith	10. 24. 21.222
Orchard Park	12. 25. 23.113
Greenfield	13. 13. 25.211
Artesia	18. 26. 6.442

HYDROGRAPH SHOWING AVERAGE MEAN MONTHLY AND MEAN ANNUAL ARTESIAN HEAD IN FOUR OBSERVATION WELLS IN THE ROSWELL BASIN, CHAVES AND EDDY COUNTIES, NEW MEXICO.

New Mexico State Engineer Office

TABLE XIX

ESTIMATED AVERAGE JANUARY ELEVATIONS OF WATER TABLE AND POTENTIOMETRIC SURFACE IN THE TWO AQUIFERS OF THE ROSWELL BASIN, NEW MEXICO *

Aquifer / Year	1926	1944	1954	1964	1969
Shallow	3407	3407	3384	3374	3367
Principal Confined	3451	3461	34.7	3397	3403

* Feet above mean sea level.

The average water table declined 40 feet in twenty-five years from 1944 to 1969. The average potentiometric surface sank 64 feet in twenty years, from 1944 to 1964, and then rose six feet in five years, from 1964 to 1969. This rise is attributed to an increase in precipitation and a decrease in groundwater pumpage during the last two years.

The interpretation of changes in water levels or changes in potentiometric surface in a coupled leaky aquifer system is complex. Pumping from one aquifer induces drawdown in the other. The amount of induced drawdown in a given time depends on the rate of discharge, on the hydraulic characteristics of both aquifers, and on the hydraulic characteristics of the aquitard which separates the two aquifers.

Water Budgets

In this section, a review is made of the analysis of water budgets of the Roswell basin. The water budgets were estimated for four consecutive periods: 1926 through 1943; 1944 through 1953; 1954 through 1963; and 1964 through 1968. The water budgets were estimated using the hydrologic equations for the two aquifers which are simply water-inventory equations.

Hydrologic Equations

The hydrologic equation for the Principal Confined Aquifer for any period can be written as follows:

$$R + \Delta S_1 - P_1 = L + F \tag{10}$$

where $\underline{R}$ is recharge, $\underline{\Delta S_1}$ is change in storage during the period, $\underline{P_1}$ is pumpage from this aquifer, $\underline{L}$ is leakage between the Principal Confined Aquifer and the Shallow Aquifer, and $\underline{F}$ is the groundwater flow to the east beyond the boundary of the basin; it is considered negligible compared to the other terms.

The hydrologic equation for the Shallow Aquifer can be written as:

$$R_p + R_f + L + \Delta S_2 - P_2 = D \tag{11}$$

where $\underline{R_p}$ is recharge from local precipitation, $\underline{R_f}$ is replenishment from return flow, $\underline{\Delta S_2}$ is change in storage in the aquifer, $\underline{P_2}$ is pumpage from this aquifer, and $\underline{D}$ is the total natural discharge from this aquifer and includes the groundwater inflow to the Pecos River and the consumptive use of groundwater by saltcedars and other natural vegetation.

Change in Aquifer Storage

The water table and potentiometric surface maps were drawn for January of 1926, 1944, 1954, 1964, and 1969. The change in storage in the Shallow Aquifer was calculated from these maps. On all water table maps, elevations were interpolated at the section corners. The storage change was determined from map to map as follows. The elevation difference at each section corner was multiplied by the associated area, the products were added algebraically and multiplied by the average ultimate specific yield (estimated at 20 percent).

The change in storage in the confined part of the Principal Confined Aquifer is negligible because of very low storativity. The change in storage in the intake area of this aquifer was calculated by multiplying the weighted average change in the water levels in the intake-area wells by the area of the intake area, and then multiplying by the average storativity of the intake area.

Leakage

Leakage between the Principal Confined Aquifer and the Shallow Aquifer was estimated by applying Eq. (10). By this method, leakage could only be determined for those periods for which all the quantities in Eq. (10), except $\underline{L}$, were known. Leakages were estimated for the four periods as shown in Table XX. These values are net leakages during these four periods, and the yearly rates determined from them are not necessarily the actual rates of leakage.

The January leakage has always been positive as shown in Table VII. The net leakages calculated with Eq. (10) have been negative since 1954. This is because the potentiometric surface during pumping seasons can be lowered much more than the water table and the direction of leakage is

TABLE XX

ESTIMATED WATER BUDGETS FOR DIFFERENT PERIODS IN THE ROSWELL BASIN IN THOUSANDS OF ACRE-FEET

		1926 - 1943		1944 - 1953		1954 - 1963		1964 - 1968	
		Total	Per year	Total	Per year	Total	Per year	Total	Per year
Principal Confined Aquifer	Recharge	4,972.0	276.2	2,108.0	210.8	1,988.0	198.8	905.0	181.0
	Change in storage in the intake area	-240.0?	-13.3?	725.0	72.5	938.0	93.8	405.0	81.0
	Pumpage	-3,360.0	-186.6	-2,758.7	-275.9	-3,105.0	-310.5	-1,343.0	-268.6
	Leakage	1,372.0	76.2	74.3	7.4	-179.0	-17.9	-33.0	-6.6
Shallow Aquifer	Recharge from local precipitation	634.1	35.2	262.0	26.2	252.6	25.3	125.0	25.0
	Replenishment from return flow	1,560.6	86.7	1,359.6	136.0	1,468.0	146.8	633.5	126.7
	Total replenishment	3,566.7	198.2	1,695.9	169.6	1,541.6	154.2	725.5	145.1
	Change in storage	533.0	29.6	1,205.0	120.5	1,355.0	135.5	652.0	130.4
	Pumpage	-1,150.3	-63.9	-1,358.0	-135.8	-1,477.0	-147.7	-696.0	-139.2
	Natural discharge	2,949.4	163.9	1,542.9	154.3	1,419.6	142.0	681.5	136.3
	Base flow	1,279.9	71.1	491.8	49.2	386.8	38.7	124.6	24.9
	Surface water*			808.8	80.9	587.7	58.8	176.1	35.2

* Difference in yearly discharges of the Pecos River at Acme and at Artesia plus surface-water diversions.

lowered much more than the water table and the direction of leakage is then reversed. The difference between yearly highs and yearly lows, as shown by hydrographs, has been gradually increasing because of the gradual increase of the yearly pumpage.

In conclusion, the leakage has been upward (positive) during January and probably during some other winter months too, and downward (negative) during the pumping season. The downward components of leakage during pumping seasons since 1954 have probably been higher, on the average, than the upward components during the winter seasons, which explains why the net leakage has been negative for the periods considered since 1954. It is, however, possible that the leakage may have been positive during some years since 1954.

Natural Discharge

Natural discharges for the four periods were estimated using Eqs. (10) and (11) and are shown in Table XX. The change in storage in the intake area for the period 1926 through 1943 is not known. Moreover, the estimates for pumpages from both aquifers for this period are not reliable. Therefore, the estimated natural discharge for the period 1926 through 1943 is uncertain. Natural discharge was slightly higher during the 1944 through 1953 period than during the subsequent two periods.

There could be some error in the estimation of any of the quantities in Table XX, especially as regards changes in aquifer storage. This is especially true for the Shallow Aquifer because of lack of control in the western part of all the water table maps.

Discussion

Figure 16 summarizes the components of the hydrologic cycle of the Roswell basin. The upper portion shows yearly recharge, pumpage, leakage, and net gain or loss in storage in the Principal Confined Aquifer. From 1926 through 1943, pumpage exceeded recharge during one year only (1935). From 1944 through 1968, pumpage exceeded recharge during all the years except during 1944, 1950, and 1968. The net yearly leakage was upward till 1953, and reversed its direction in the subsequent two periods.

The cumulative change in storage in the Principal Confined Aquifer is also shown. The storage has been gradually decreasing since 1941 because of overdraft and in 1967 it reached its lowest value in history. In 1967, metering of water wells and limited pumpage went into effect as the result of a court decree fixing duty of water at 15 acre-feet per acre per 5 years. For this reason, and also because of higher precipitation, storage increased slightly during 1968.

Total replenishment to the Shallow Aquifer is shown in the bottom part of Figure 16. The pumpage from the Shallow Aquifer has always been less than the total replenishment except during 1963 and 1964. However, the difference between pumpage and total replenishment has been less than 10,000 acre-feet during 8 years, not including 1963-64. A gradual increase in pumpage has led to a progressive decrease in the groundwater inflow to the Pecos River from the basin. This decrease in the inflow is also partly due to a gradual increase in saltcedar acreage. Saltcedars thrive on groundwater and, in addition, consume surface water.

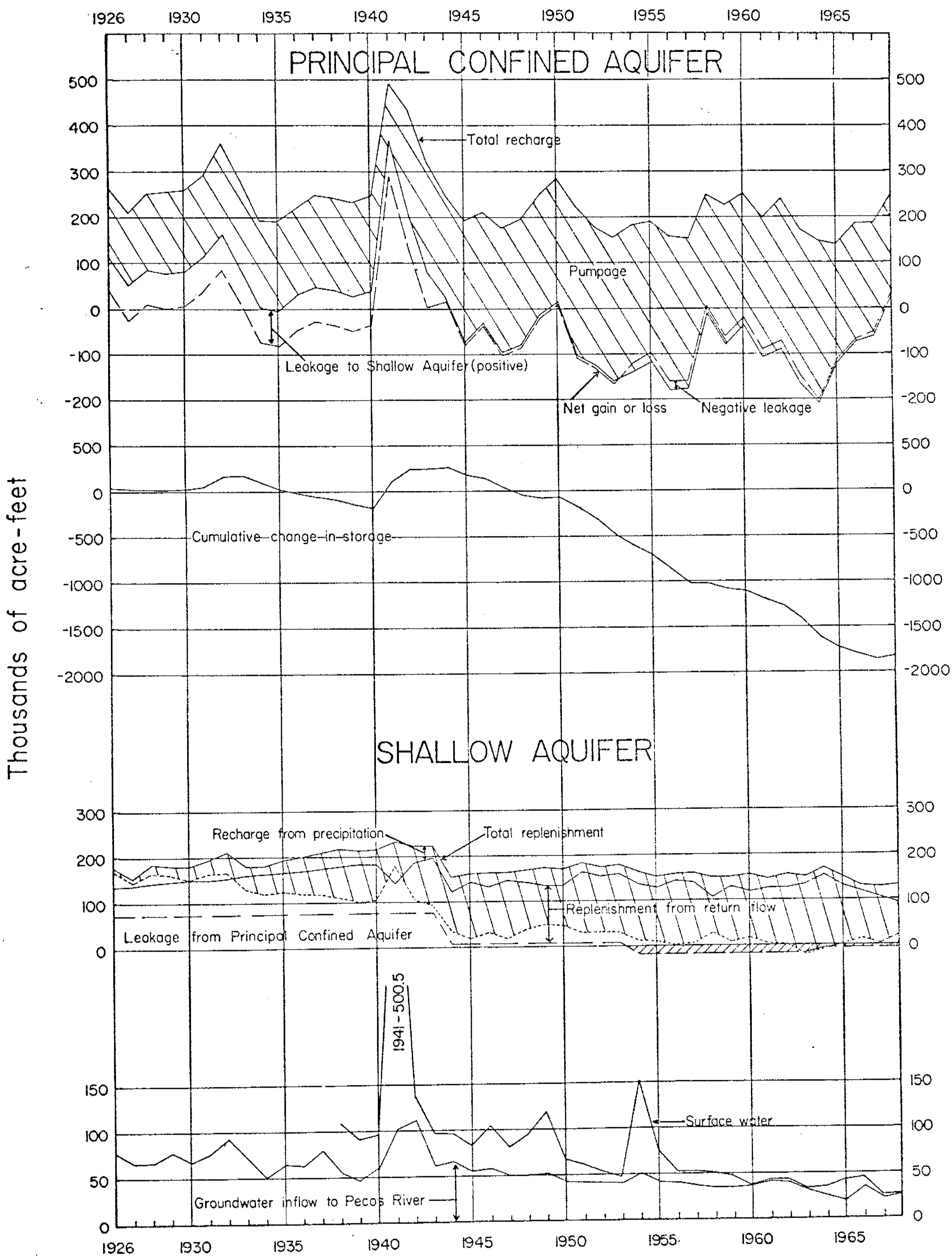

FIGURE 16

ESTIMATED TRENDS IN INFLOWS, OUTFLOWS, AND CHANGE IN AQUIFER STORAGE, ROSWELL BASIN, NEW MEXICO

This situation has been aggravated by droughts. The precipitation at Roswell has been below average since 1950, except during four years. Consequently, the amount of Pecos River water available in the basin has gradually decreased.

Saline Water Encroachment

The San Andres Limestone grades into salt beds in the northeasternmost part of the basin and beyond the basin boundary in that direction. In this part of the basin, the groundwater in the San Andres Limestone has always been saline. Since the development of the basin, the saline water has been moving from the northeast toward the southwest, or toward Roswell, in the Principal Confined Aquifer.

The chloride content of the water in the area varies from about 40 ppm to 40,000 ppm. Figures 17, 18, and 19, prepared by the office of the State Engineer, show isochlors and chloride content of selected wells tapping the Principal Confined Aquifer. The location of isochlors changes with the time of year. They are more southwest, toward the pumping centers, during the pumping season than during the shutoff period. Hood [1963], Hood et al. [1950], Spiegel [1967], and Havenor [1968] have discussed in detail the saline-water encroachment in the Roswell basin.

Summary

The Roswell basin in southeastern New Mexico is part of the Pecos River basin. It comprises two coupled leaky aquifers and a surface

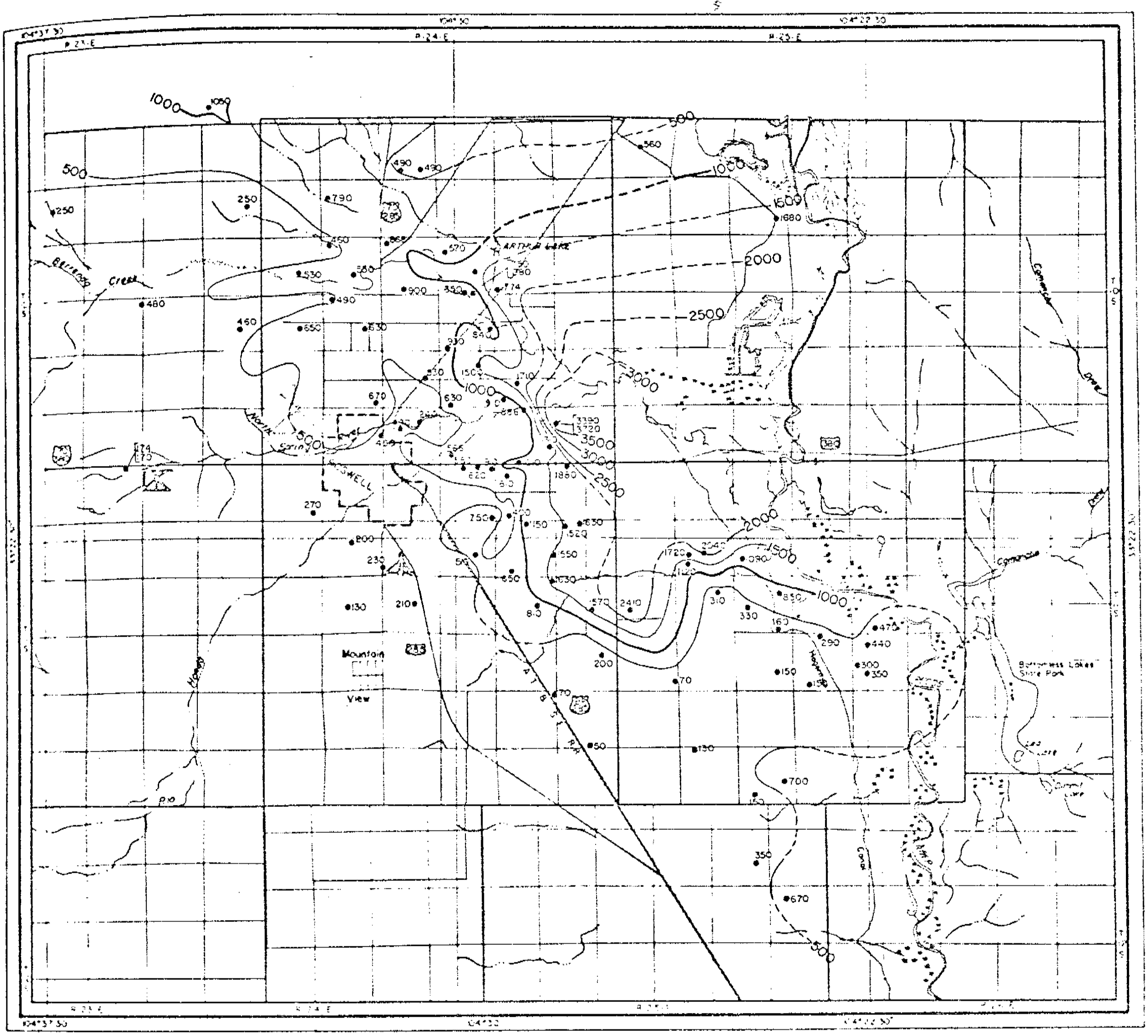

FIGURE 17

ISOCHLORS IN THE PRINCIPAL CONFINED AQUIFER NEAR ROSWELL, MARCH-APRIL 1967, NEW MEXICO

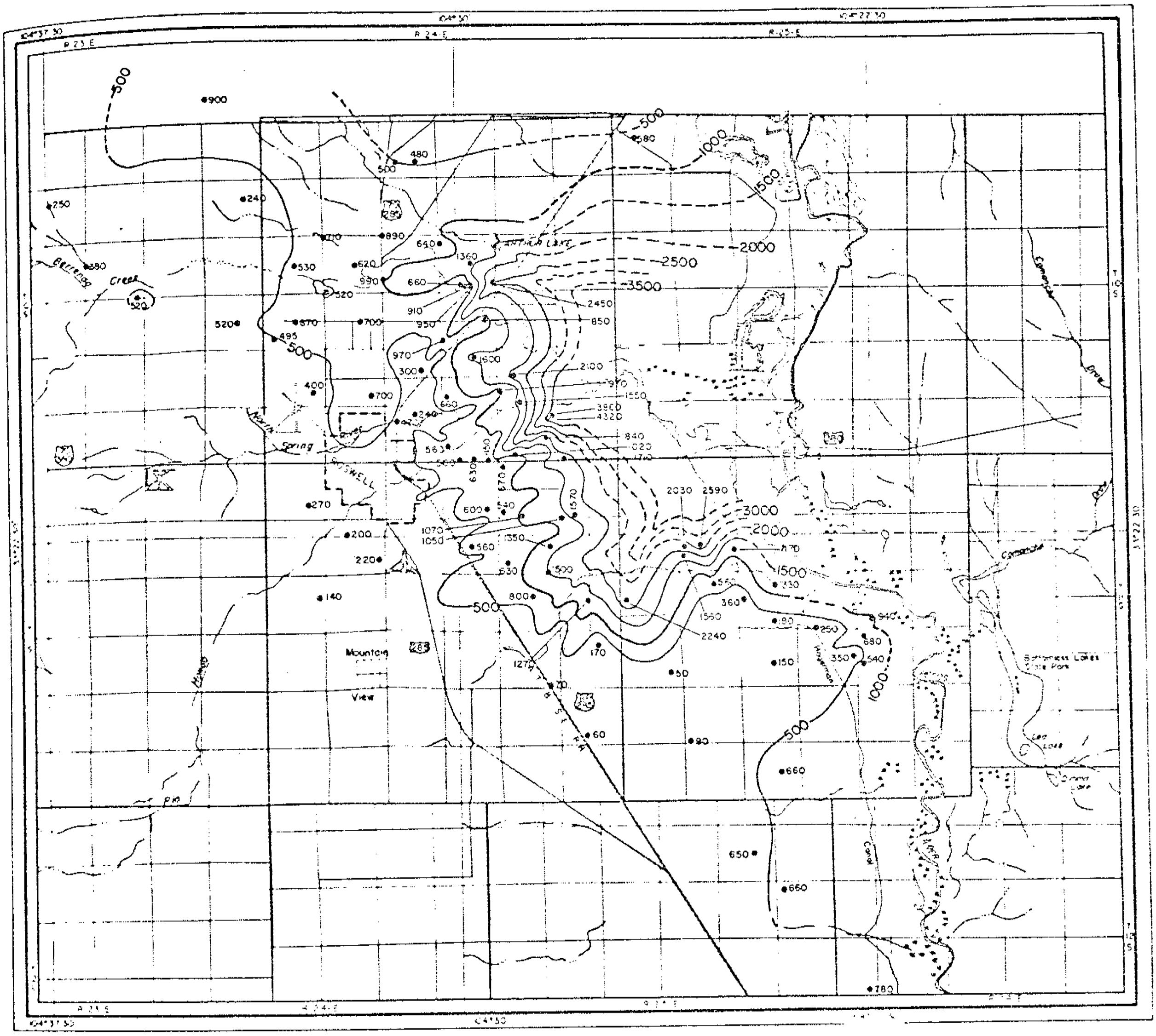

FIGURE 18

ISOCHLORS IN THE PRINCIPAL CONFINED AQUIFER NEAR ROSWELL, AUGUST-SEPTEMBER 1967, NEW MEXICO

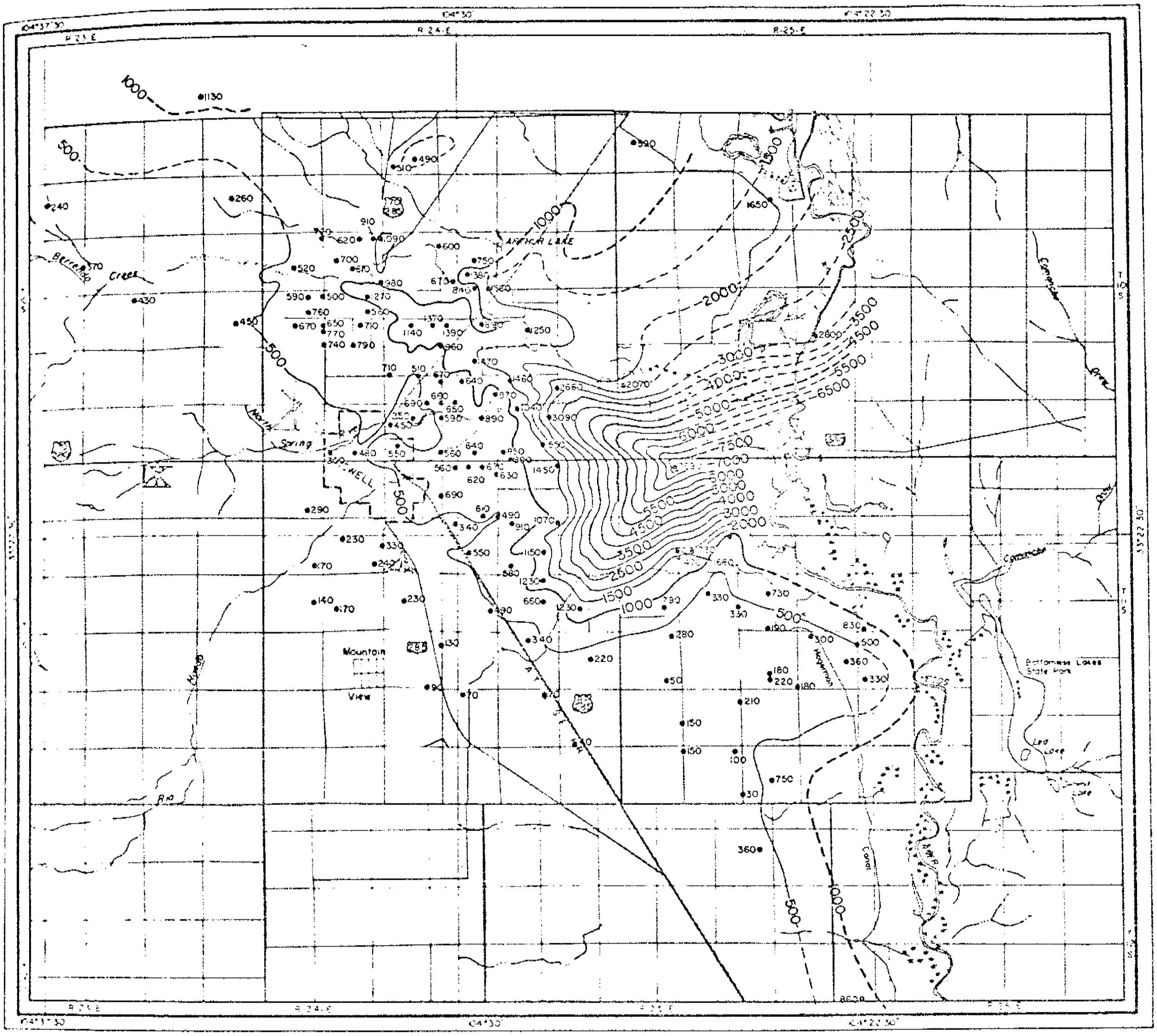

FIGURE 19

ISOCHLORS IN THE PRINCIPAL CONFINED AQUIFER NEAR ROSWELL, FEBRUARY-MARCH-APRIL 1969, NEW MEXICO water system. Groundwater occurs in unconfined as well as confined states in the basin. Groundwater is unconfined in the Shallow Aquifer and in the intake area of the Principal Confined Aquifer. It is confined in the valley part of the Principal Confined Aquifer and, in spite of the overdraft, there are still some wells in the northern half of the basin near the Pecos River which flow during winter months.

The recharge to the Principal Confined Aquifer is from precipitation in the western part of the basin and averages about 240,000 acre-feet per year. The replenishment to the Shallow Aquifer is from: (1) Gain or loss due to leakage between the Principal Confined Aquifer and the Shallow Aquifer, (2) irrigation returns and losses from the surface drainage system, and (3) deep percolation from local precipitation.

Most of the pumpage from the Principal Confined Aquifer is in the northern half of the basin, whereas the pumpage from the Shallow Aquifer is minimal in the northern part near Roswell.

Water levels and potentiometric surface have been declining everywhere since the development of the basin.

The base flow to the Pecos River from the Shallow Aquifer has been decreasing continuously since the large-scale development of the aquifer started in 1938. This is true except for a few years when, as a consequence of heavy rains in 1941, the aquifer almost recovered to its initial state.

Loss of water by saltcedars in the basin is still very large, amounting to 107,000 acre-feet in 1968. The loss has decreased from 133,000 acre-feet during 1967 because of the eradication program of the U. S. Bureau of Reclamation.

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Saline-water encroachment is still continuing but it appears that the withdrawal of saline water from the Principal Confined Aquifer just east of Roswell, by a saline water conversion plant, might retard the encroachment.

III. DYNAMIC PROGRAMMING APPROACH TO THE PROBLEM

Introduction

Many of the systems and processes in use today are large and complex. Most of the present-day water-resource systems fall into this category. The best way to analyze such systems is to approach them systematically. The Harvard Water Resources Group developed such an approach [Mass, et al., 1962] to the methodologies of design and development of water-resource systems. They applied their studies to the Indus Plain, which has one of the largest irrigation systems in the world [White House Report, 1964]. We are concerned in this report only with the optimal operation of existing water-resource systems, which is only one of the aspects of a complete system design. By optimal operation, it is meant to improve the operation of the system with optimum, or 'the best', as a goal. Methods of achieving optima come under the theory of optimization.

It seems appropriate to quote Wilde and Beightler [1967] here: "Although many phases of optimization theory have been known to mathematicians for centuries, the tedious and voluminous computations required prevented their practical application. The development of rapid, inexpensive, automatic computers in the middle twentieth century has not only made these older methods attractive, but also encouraged much new research on optimization."

An important group of optimization methods comes under the mathematical-programming techniques. The term 'programming' here should not be confused with 'setting up programs' for a digital computer.

Mathematical programming is defined by Sipple [1966] as the technique of finding an optimum value of a function of many variables when these variables are subject to restrictions in the form of equations or inequalities. The term is usually restricted to problems so complex that they require a digital computer for their solution.

According to the way a particular technique optimizes a problem, the optimization techniques can be classified in two categories, namely, simultaneous and partial optimization [Meier and Beightler, 1968]. In simultaneous optimization techniques, of which linear programming and nonlinear programming are examples, all decision variables are directed toward their optimum values simultaneously using some form of iterative technique. In partial optimization, of which dynamic programming is an example, the problem is decomposed into simpler subproblems analyzed sequentially by partially optimizing single variables or groups of variables while the effects of interactions among them are maintained.

Linear programming is suitable for problems with linear objective functions and linear constraints, whereas nonlinear programming is for problems with nonlinear objective functions and/or nonlinear constraints and is much more complex. For details, the reader is referred to Hadley [1962, 1964]. An application of nonlinear programming for the evaluation of aquifer parameters is given in the preceding chapter.

In problems that involve discrete input data, or tabular, or discontinuous objective functions, multistage optimization (dynamic programming) is often the only satisfactory method for optimization. Problems of this type are fairly common in water-resource systems.

The main limitation of the usefulness of dynamic programming is the dimensionality of a problem, i.e., the number of independent state variables involved in the problem. At the present, a two-dimensional, or even a three-dimensional problem can be handled on a medium to a large size computer, depending upon the speed and storage capacity of the computer as well as the size of the problem. However, there are methods to overcome the problem of dimensionality to a limited extent [see Bellman, 1957, and 1962].

A brief dexcription of dynamic programming and some of the terms associated with it are presented in the next section.

Dynamic Programming

A process in which a single decision is to be made is called a single-stage process and the one which involves a sequence of decisions is known as a multistage decision process. Dynamic programming is a strategy for solving optimization problems involving multistage decision processes. Some problems can be formulated into such a process by the introduction of an artificial element of time. Richard E. Bellman coined this term and is responsible for developing the theory of dynamic programming. He is also the author of several books on it [Bellman, 1957, 1961, 1962; Bellman and Kalaba, 1965]. The original principle on which Bellman based his principle of optimality was formulated by Massé [1946].

Perhaps the earliest application of dynamic programming to water-resource studies was by Little [1955]. Bear et al. [1964] has given a survey of literature related to optimization of water-resource systems.

Before the problem is formally stated, some of the terminology applied in dynamic programming are described below.

State

A state of a process is a description of one of the conditions or situations in which the process may exist. A set of all possible states in which the process might exist constitutes a state space and the set of variables defining this state of the process are called the state variables.

Decision

A decision represents one of the choices available when the process is in a particular state. A decision set for a particular state is the set of all possible choices that might be made when the process is in that state.

Policy

An operating policy or policy is an ordered collection of decisions containing one decision for each state in the state space. A policy which satisfies all the constraints on the system is known as an admissible policy and an admissible policy which maximizes the objective function for a system is called optimal policy.

Transformation

Each stage of a process transforms the state of its input into an output state dependent on the decision that is made for the operation of that stage.

Constraints

In general, both the state and decision variables are limited by constraints. Typical constraints are physical, technical, budgetary, political, and legal. Generally they have the form of inequalities and/or equalities.

Objective Function

In an optimization problem there must be some criterion according to which the problem is to be optimized. This is usually called criterion function, return function, or objective function. Generally the objective is to maximize the net benefits or to minimize the costs. It is a scalar function (or functional) of decision and sometimes also of state variables (of functions of these variables). For a discussion about an objective function, see Maas, et al. [1962] and Parker and Crutchfield [1968]. The maximized return for a given state is called optimal net return for that state.

Principal of Optimality

The first step in solving a mathematical model is to simplify it and/or to make certain changes or transformations so that it is easier to solve in the new form. In contrast to simplifications, these changes preserve the properties of the model completely but the model in the transformed form is easier to optimize. Such a transformation is accomplished for multistage-decision problems by the dynamic programming approach. A problem with N decisions can be transformed into N subproblems, each containing only one decision variable. This is accomplished through the application of Bellman's principle of optimality [Bellman, 1957]:

> An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision.

"It is really saying that if you don't do the best you can with what you happen to have got, you'll never do the best you might have done with what you should have had" [Rutherford, 1964].

Statement of the Problem

A schematic representation of two coupled leaky aquifers and an interrelated surface-water system is shown in Figure 20. The combined system includes a shallow unconfined aquifer and a deeper confined aquifer. The two aquifers are separated by a semiconfining layer which permits leakage from one aquifer to the other. The direction of leakage is locally toward the aquifer with lower head. The surface-water system is tied to the unconfined aquifer through base flow, which can be negative, i.e., the aquifer can gain water from the river.

The system is assumed to be used only for irrigation of land. Only four crops are assumed grown: alfalfa, cotton, sorghum, and small grains (e.g., barley). Areas of specific crops to be irrigated from each of the three sources (12 areas in all) are assumed known.

The Shallow Aquifer and the Confined Aquifer receive probabilistic recharges from precipitation. Besides leakage, which is assumed positive if it is from the Confined Aquifer to the Unconfined Aquifer, the latter gains water also in the form of return flows from irrigation and loses (or can gain) water in the form of natural discharge to the river. The river loses water through evaporation and the river and Shallow Aquifer lose water through consumptive waste use by saltcedars.

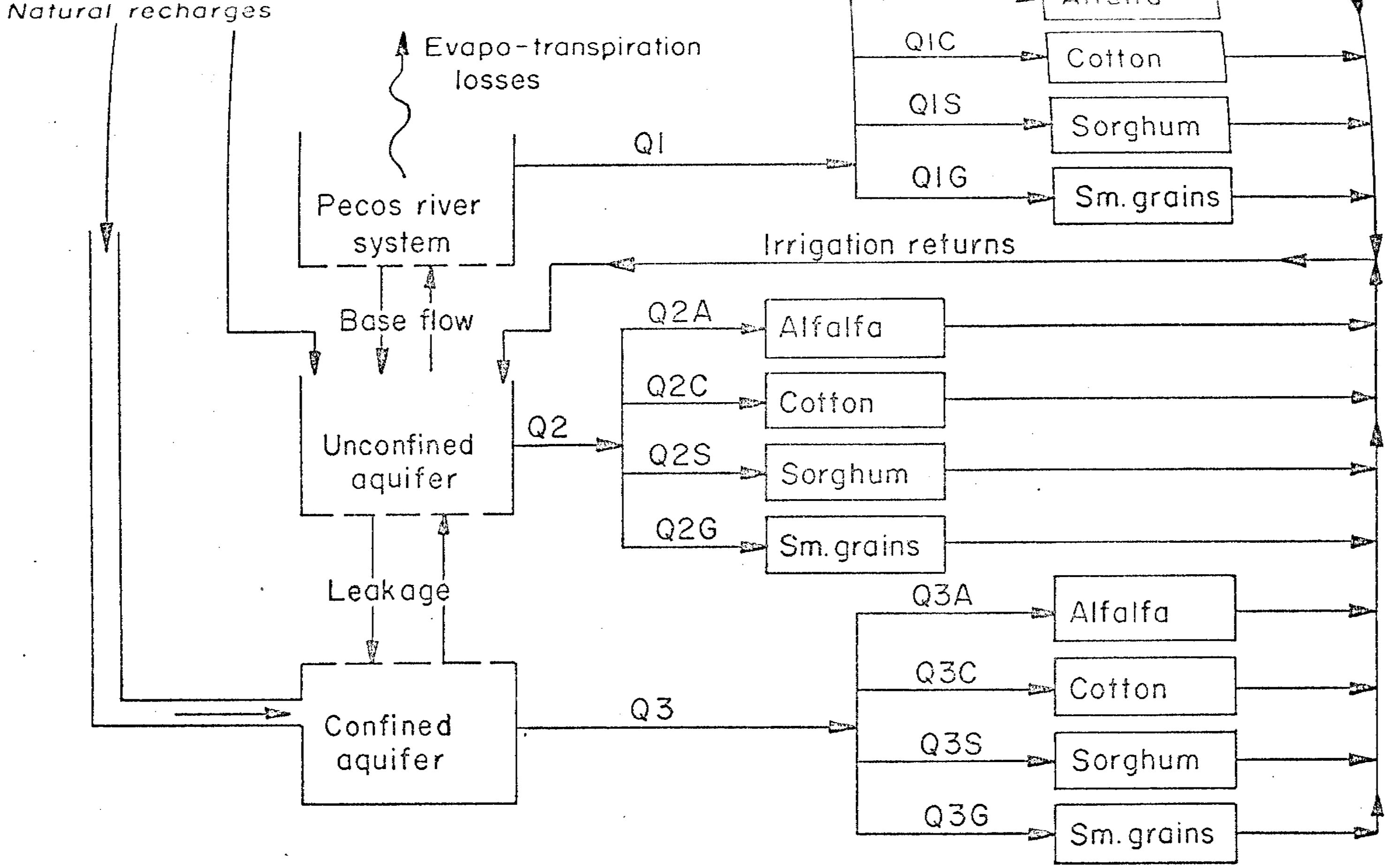

FIGURE 20

SCHEMATIC REPRESENTATION OF ROSWELL BASIN, NEW MEXICO

The system is operated by pumping water from both aquifers and by diverting surface water for irrigation. The amounts of water to be withdrawn from both aquifers and the surface water to be used, in one period, are treated as decision variables. All the decision variables have four components each, one for each of the crops. The purpose of the study is to find an optimal operating policy so that the value added to the basin is maximized over a long period of time.

Dynamic Programming Formulation

The following notations are used for the mathematical formulation of the problem:

1, 2, 3 = subscripts referring to the Surface Water System, Shallow, and Confined Aquifers, respectively.

Q_{1n}, Q_{2n}, Q_{3n} = volume of water diverted or pumped during the n^{th} period from the end of the planning horizon.

V_1, V_2, V_3 = amount of water in storage at the beginning of a period.

r_{1i}, r_{2j}, r_{3k} = probabilistic recharges to the Surface Water System to the Shallow Aquifer and to the Confined Aquifer during the n^{th} period from the end of the planning horizon.

p_{1i}, p_{2j}, p_{3k} = probabilities for r_{1i}, r_{2j}, and r_{3k}, respectively.

E_n = natural losses from the surface-water system during the n^{th} period from the end of the planning horizon.

D_n = natural discharge from the Shallow Aquifer during the n^{th} period from the end of the planning horizon.

L_n = amount of leakage during the n^{th} period from the end of the planning horizon, assumed positive when to the Shallow Aquifer.

u = discount rate to reduce future benefits to present values.

$B_n(Q_{1n}, Q_{2n}, Q_{3n}, V_1, V_2, V_3)$ = net value added to the basin during the n^{th} period from the end of the planning horizon, obtained from the use of Q_{1n}, Q_{2n}, and Q_{3n} amounts of water when the storages were V_1, V_2, and V_3, respectively, in the Surface Water System, the Shallow Aquifer, and the Confined Aquifer.

$f_n(V_1, V_2, V_3)$ = the expected value added to the basin from the n-stage process following an optimal policy starting with V_1, V_2, and V_3 as the amounts of water in the three components of the system.

For the optimization of a system, an appropriate objective function must be defined. Strictly speaking, the objective function of a system like the one under investigation is a function of, (1) physical characteristics and limitations of the system, and (2) the operating policy for the system.

The category (1), physical characteristics and limitation of the system, implies the physical dimensions of the three components (the three sources of water) of the system (i.e., the maximum capacities, range of pumping lifts, etc.) and the extent of the twelve areas to be irrigated from each of the three components of the system. B is a response surface and a function of the variables mentioned in (1) and (2). The maximum of B is to be obtained in the multidimensional space of the variables of which it is a function.

In order to obtain the maximum, we approach the problem through dynamic programming. We treat the areas which are to be irrigated as parameters of the system. The physical dimensions of the system are evaluated from hydrologic analysis. We find the optimum operating policy by operating the system for a finite number of stages.

Two distinct stages of optimization are involved, one is the optimization of the system as a function of time, i.e., to find an optimum operating policy for a finite number of stages $\underline{n}$. In order to perform optimization of the system as a function of time, one has to optimize the system in space first. The results of optimization in space are incorporated in the dynamic model so that we have total optimization within the constraints of the system. The dynamic model is formulated first.

Formulation as a Function of Time

In order to analyze the problem of two coupled leaky aquifers and a surface-water system, a set $\underline{S}$ and a set $\underline{P}$ are defined such that all admissible states and all admissible decisions are contained in $\underline{S}$ and $\underline{P}$ respectively; i.e., $(V_1, V_2, V_3) \varepsilon S$ and $(Q_1, Q_2, Q_3) \varepsilon P$.

Set $f_0(V_1, V_2, V_3) = 0$ and consider the operation of the system for one stage; one obtains the optimal one-stage return as follows:

$$f_1(V_1, V_2, V_3) = \max_{(Q_1,Q_2,Q_3)\varepsilon P} \{B_1(Q_1,Q_2,Q_3,V_1,V_2,V_3)\} \tag{12}$$

The state of the system is transformed by the transformation T, where $T = T(Q_1,Q_2,Q_3,r_1,r_2,r_3,D,E,L)$.

Employing the principle of optimality, using the expected value criterion and discounting the returns to current value, the functional equation of dynamic programming [Bellman, 1957] for the system can be written as:

$$f_n(V_1,V_2,V_3) = \max_{(Q_{1n},Q_{2n},Q_{3n})\varepsilon P} \{B_n(Q_{1n},Q_{2n},Q_{3n},V_1,V_2,V_3)$$

$$+ (1+u)^{-1} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_{n-1}(V_1+r_1-E_n+D_n-Q_{1n},V_2+r_2+c(Q_{1n}+Q_{2n}+Q_{3n})$$

$$+ L_n-D_n-Q_{2n},V_3+r_3-L_n-Q_{2n})h_1(r_1)h_2(r_2)h_3(r_3)dr_1dr_2dr_3\} \qquad (13)$$

Where $h_1(r_1)$, $h_2(r_2)$ and $h_3(r_3)$ are probability density functions for r_1, r_2, and r_3, respectively, and <u>c</u> is a constant for calculation of deep percolation from irrigation returns.

The above functional equation for an n-stage process can be interpreted as the maximization, with respect to water withdrawals during stage <u>n</u>, of immediate net value added during stage <u>n</u> plus the present value of future net value added during the (n-1) stages, following an optimal policy during the remaining (n-1) stages.

In order to solve Eq. (13), all the variables are made discrete and the equation takes the following form:

$$f_n(V_1,V_2,V_3) = \max_{(Q_{1n},Q_{2n},Q_{3n})\varepsilon P} \{B_n(Q_{1n},Q_{2n},Q_{3n},V_1,V_2,V_3)$$

$$+ (1+u)^{-1} \sum_{i=1}^{L} \sum_{j=1}^{M} \sum_{k=1}^{N} p_{1i}p_{2j}p_{3k}f_{n-1}(V_1+r_{1i}-E_n+D_n-Q_{1n},$$

$$V_2+r_{2j}+c(Q_{1n}+Q_{2n}+Q_{3n})+L_n-D_n-Q_{2n},V_3+r_{3k}-L_n-Q_{2n})\} \qquad (14)$$

where

$$p_1, p_2, p_3 \geq 0, \quad \sum_{i=1}^{L} p_{1i} = \sum_{j=1}^{M} p_{2j} = \sum_{k=1}^{N} p_{3k} = 1 \tag{15}$$

and r_{11}, r_{12}, r_{13}, . . . r_{1L} are stochastic recharges to the Surface Water System with probabilities p_{11}, p_{12}, p_{13}, . . . p_{1L}; r_{21}, r_{22}, r_{23}, . . ., r_{2M} are stochastic recharges to the Shallow Aquifer with probabilities p_{21}, p_{22}, p_{23}, . . ., p_{2M}; and r_{31}, r_{32}, r_{33}, . . ., r_{3N} are stochastic recharges to the Confined Aquifer with probabilities p_{31}, p_{32}, p_{33}, . . ., p_{3N}, respectively.

It is assumed that the decision variables and the states are non-negative and that the decision variables cannot exceed the amounts of storage in the respective components of the system, i.e.,

$$0 \leq Q_j \leq V_j \; , \qquad j = 1, 2, 3. \tag{16}$$

The discretization of the problem reduces it to a finite Markovian decision process [Howard, 1960]. The probabilities in Eq. (13) can be expressed in the form of a transition probability matrix, where the multidimensional matrix will define the probabilities of going from one state to the next.

Formulation as a Function of Space

In this section we are concerned with the optimal allocation of a given amount of water from one of the three sources to the various crops that are to be grown on given areas. This problem is an example of optimization in space.

This problem is approached in the same manner as the previous problem, which was about optimization over time. An artificial element of time is introduced and the stages of the previous section are now replaced by the four crops and the problem is formulated as a functional equation of dynamic programming and solved through sequential analysis.

For the formulation of this problem, some additional symbols are described below:

S_i = the initial state of the system, defined by the total amount of water in storage in the system component under consideration and the total amount to be withdrawn from that component for allocation to different crops. The system has three components, namely, the Surface-Water System, the Shallow Aquifer, and the Confined Aquifer.

Q_{ik} = the amount of water allocated to the k^{th} activity and is a fraction of the total amount of water Q_i to be used from the i^{th} component of the system during one period.

$G_k(Q_{ik},Q_i,V_\ell)$ = net value added to the basin resulting from the use of an amount Q_{ik} of water for the k^{th} activity with Q_i as the total amount of water to be withdrawn from one of the three components of the system, when storage in that component is V_ℓ.

S_j = the state resulting from the transformation of state S_i. The transformation is due to allocation of an amount Q_{ik} of water to the k^{th} activity.

Using the principle of optimality, as in the previous section, we derive the functional equation for the optimal allocation of water from one of the components of the system to various crops:

$$f_k(S_i) = \max_{Q_{ik} \varepsilon P_n} \{G_k(Q_{ik}, Q_i, V_\ell) + f_{k-1}(S_j)\} \qquad (17)$$

where

$$S_i = (Q_i, V_\ell) \qquad (18)$$

$$S_j = (Q_i - Q_{ik}, V_\ell - Q_{ik}) \qquad (19)$$

P_n = the set containing all the admissible decisions. There are three such sets, one for each of the components of the system.

$$f_0(S_i) = 0. \qquad (20)$$

There are three equations like (17), one for each of the three components of the system. Each equation can have a different state set, a different decision set, and a different set of G_k's.

The results obtained from the solution of (17) are incorporated into the dynamic model to obtain overall optimization.

Discussion

Two types of maximization problems are formulated in the foregoing part of this chapter. One is the maximization of net value added due to the operation of the coupled leaky aquifer-surface water system over a long period of time. The second one, which is incorporated in the first one, is the maximization of net value added due to allocation of a given amount of water from one of the components of the system to various activities with independent objective functions.

If the system is to be operated for n stages (for the Roswell basin a stage is of one year duration), there will be 3n decisions to be performed simultaneously for a system consisting of three components.

By the approach adopted in this report, the problem was reduced to a sequence of n different problems with only three decisions to be made in each problem. This approach of sequential decision making has simplified the original problem tremendously. Bellman [1957, 1962] has discussed the advantages from an analytic as well as from a computational point of view. For the problem of optimization in space, the same approach is adopted.

The main disadvantage of the dynamic programming approach is the limitation of dimension. To illustrate this, for a system with only one state variable and ten possible states, the maximization will be performed only 10 times. For a system with two state variables, each having ten possible states, the computational burden will increase 10 times, i.e., the maximization will be carried out 10^2 times. For a three-state variable, 10^3, and so on. At present, most of the large size computers can only handle problems with three state variables or, at the most, four dimensional problems of limited size.

The formulation of the problem of finding the optimal operating policy for the system into a dynamic-programming model is an example of stochastic dynamic programming (Eq.13) because the transformation is not completely known and the resultant outcome of the transformation is in the form of a probability distribution. The second problem of optimization, in space, is an example of deterministic dynamic programming (Eq. 17), because the outcome of the transformation is uniquely determined by a decision.

For the stochastic dynamic model, the expected value criterion was used. It is implied that if the system is operating for infinitely many stages, the system will yield the maximum average returns. In actual practice the computations are carried out only to a finite number of stages. This is a valid procedure because for n large the effect of all those stages which are far off in the future is negligible on the current decisions. Bellman [1957] and Howard [1960] have shown that when the objective function is invariant over the stages, the decisions converge rapidly to a steady state. Usually convergence is obtained in 7 to 15 stages. For the Roswell basin the objective function was assumed invariant over the stages and a rapid convergence was obtained.

IV. SOLUTION OF THE MODEL

Introduction

The model developed in the last chapter is applied to the Roswell basin. The model is given by Eqs. 14, 15, and 17 of the previous chapter. No general analytical solutions of these equations are available. One has to solve them on digital computers for specific cases.

Models are usually simplified so that they can be handled on computers. However, oversimplification may lead us away from the real situation. The solution of the problem for the Roswell basin was obtained on an IBM System 360 Model 44 computer. The inputs to the model, results, and limitations are discussed in this chapter.

Inputs to the Models

There are two main types of inputs to the model; economic, and hydrologic. The crop pattern used in the model is given under the heading of other inputs.

The Economic Inputs

Benefit Functions

The net returns per acre were derived for different crops for the Roswell basin by Dregne, Garnett, and Lansford [1967]. The values added per acre to the basin were computed from the net returns to land and management by D'Arge [personal communication, 1968]. The benefit functions for all the crops are nonlinear. Second degree polynomials were fitted through the values added as a function of the amount of water pumped per acre of land and are as follows:

$$v_a = - 443.89 + 181.86 - 12.26x^2 \quad (21)$$

where v_a is the value added for alfalfa in dollars per acre and x is the amount of water pumped for irrigation of one acre of land.

$$v_c = - 90.91 + 242.54y - 32.32y^2 \quad (22)$$

where v_c is the value added for cotton in dollars per acre and y is the amount of water pumped for irrigation of one acre of land. The pumping costs were then added because originally in calculating net returns they were assumed constant and were deducted. For the purpose of our analysis, we want the pumping cost to vary as a function of pumping lifts.

Pumping Costs

The cost for pumping a unit amount of water depends on the depth to water in wells and varies in general from well to well and from aquifer to aquifer in the basin.

The fuel costs for 31 different wells in the basin were collected. Only at four of the wells was natural gas used; the rest were equipped with electric motors. From this information and the information about the total amount of water pumped by each well during 1967, fuel costs per acre-foot of water were calculated. Dividing by weighted average lift, costs per acre-foot per foot of lift were calculated, and these are summarized in Table XXI. An amount of $0.002 per acre-foot per foot of lift was added for maintenance, repairs, lubrication, and labor. These costs are fairly close to those obtained by Long [1965] for the Roswell basin.

TABLE XXI

PUMPING COSTS PER ACRE-FOOT PER FOOT OF LIFT IN DOLLARS, 1967

Aquifer	Average Fuel Cost		Weighted Average Cost*
	Electricity	Natural Gas**	
Shallow	0.0386	-	0.0355
Principal Confined	0.0303	0.0170	0.0283

* Includes maintenance, repair, lubrication, and labor costs.

** Using the same ratio for the Shallow Aquifer.

The Hydrologic Inputs

Storage-Depth Relations

The relations of average depth to water to the amount of water in storage in the Shallow Aquifer and in the Principal Confined Aquifer were assumed linear on a yearly basis. It is implied that the pumpage from the aquifers is reasonably uniformly distributed.

The relation of average depth to the amount of water in storage in the Shallow Aquifer was estimated from the average east-west cross section of the basin and on the average elevations of the water table calculated from the water-table maps. A maximum permissible average depth of pumping of 145 feet and an average minimum depth of pumping of 45 feet were assumed to preclude water logging and other drainage problems. An average storativity of 0.15 was used for the Shallow Aquifer. The relation is as follows:

$$D = 145 - 2.50\ V_1 \qquad (23)$$

where

D = the average January depth to the water table in feet,

V_1 = the volume of water in storage in the permissible depth range in the Shallow Aquifer in millions of acre-feet.

A similar relationship was obtained for the Principal Confined Aquifer. The storativity in the confined part of this aquifer is negligible compared to the storativity in the intake area. The January average water levels in the intake-area wells were correlated with the January average piezometric surface as recorded by the U. S. Geological Survey recorders in the confined part of the aquifer. The following relation was derived:

$$h = 150 - 27.273\, V_2 \tag{24}$$

where

h = average January lift in the Principal Confined Aquifer in feet,

V_2 = the amount of water in storage in the permissible depth range in the Principal Confined Aquifer in millions of acre-feet.

A maximum average lift of 150 feet was allowed and average storativity of 0.03 was assumed in the intake area. The maximum storage capacities of the Shallow Aquifer and the Principal Confined Aquifer were estimated within the permissible depth ranges to be 4.0 and 5.5 million acre-feet respectively.

Drawdowns at the Wells

Previous authors [Buras, 1963; Burt, 1964] did not deduct the additional pumping costs associated with the self-drawdowns of pumping wells from the benefit function. As a well pumps water, the amount of lift increases somewhat in proportion to the amount of water pumped from the well. Drawdowns at shallow and deep wells were calculated as functions of discharges from the wells, from the average values of B, the formation-loss coefficient and of C, the well-loss coefficient. For the Shallow Aquifer logarithmic average values for B and C are 8.37 ft/cfs and 2.98 ft/$(cfs)^2$, respectively. The logarithmic average values of B and C for the Principal Confined Aquifer are 3.41 ft/cfs and 2.20 ft/$(cfs)^2$, respectively. These values were obtained as described in Chapter II and were adjusted to take into consideration the pumping time in an average irrigation cycle, average days of use of wells, and the number of wells tapping the two aquifers.

The relation for self-drawdown is

$$s = BQ + CQ^2 \tag{25}$$

Pumping costs due to additional lifts at the wells were also subtracted from the value added, in addition to the costs associated with the lifts calculated from the storage-depth relations.

Leakage

The amount of leakage through the semi-confining layer was calculated as described in Chapter II. The leakage was calculated as a function not only of difference of average heads in the two aquifers, but also the area of the semi-confining bed, through which leakage takes place, was incorporated as a variable.

Recharge to the Aquifers

The rates of recharge to the Shallow Aquifer and to the Principal Confined Aquifer were calculated as described in Chapter II and tabulated in increasing order in Tables I, VI. The probabilities were calculated by Kimball's method [1946]

$$p(r_m) = \frac{m}{n+1} \tag{26}$$

where $p(r_m)$ is the probability of recharge of magnitude r_m or less and having a rank m, when the sample size is n. For the numerical solution, the amounts of recharges and their probabilities are shown in Table XXII and were used as input to the model.

TABLE XXII

AMOUNTS OF RECHARGE IN ACRE-FEET AND PROBABILITIES, BASED ON RECORDS FOR 68 YEARS

Principal Confined Aquifer		Shallow Aquifer	
Recharge	Probability	Recharge	Probability
150,000	0.10	20,260	0.30
184,000	0.20	35,000	0.40
246,000	0.40	49,600	0.30
291,000	0.20		
361,000	0.10		

Natural Discharge

For the numerical solution of the model a total value of 130,000 acre-feet per year for the natural discharge from the Shallow Aquifer was used, which includes base flow as well as other natural losses.

Other Inputs

An interest rate of 5 percent was used to discount the future benefits to present values. The crop pattern assumed for the model is shown in Table XXIII and is based on the yearly records of crops grown in the basin.

TABLE XXIII

CROP PATTERN FOR THE DYNAMIC PROGRAMMING MODEL*

Crop	Shallow Aquifer	Principal Confined Aquifer	Total
Alfalfa	18	30	48
Cotton	14	22	36
Sorghum	4	8	12
Small grains	6	12	18
Total	42	72	114

* In thousands of acres.

Solution of the Model

It was mentioned earlier that the surface water used for irrigation is less than 4 percent of the total amount used for irrigation in the basin. Therefore surface water was not included in the dynamic programming model as an independent state and the model became simplified from a three-dimensional to a two-dimensional model. This entails considerable saving of computer time. The error introduced is very small. It was assumed that the amount of surface water used will continue to be the same as at the present time.

It was further assumed that 3.25 acre-feet and 2.25 acre-feet of water per acre of land is pumped for irrigating sorghum and small grains, respectively. These amounts give the maximum gross value added of 104.80 and 66.15 dollars per acre for sorghum and for small grains, respectively, and these were added to the benefit function. This was done to save computer time and the error introduced because of this simplification is small because the irrigated acreage of sorghum and small grains is small compared to that of the two main crops, alfalfa and cotton.

Flow charts for the numerical solution of the dynamic programming functional equation are given in several publications, such as Bellman [1962] and Nemhauser [1966].

Results

The optimal operating policy for the Shallow Aquifer and the Principal Confined Aquifer are shown in Figures 21 and 22, respectively.

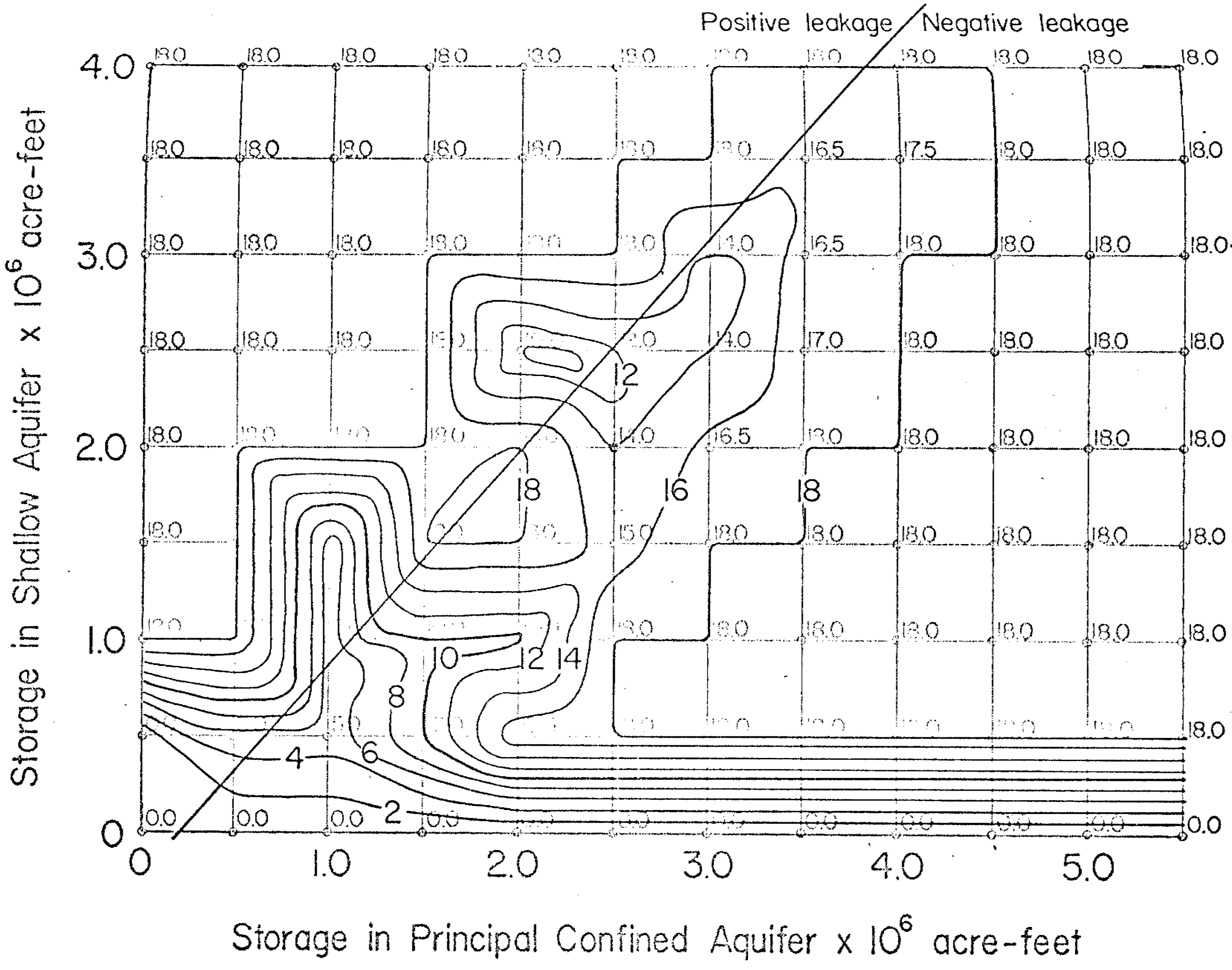

FIGURE 21

YEARLY PUMPAGES FROM THE SHALLOW AQUIFER (IN 10^4 ACRE-FEET) WHICH

MAXIMIZE THE OBJECTIVE FUNCTION FOR $N \geq 8$

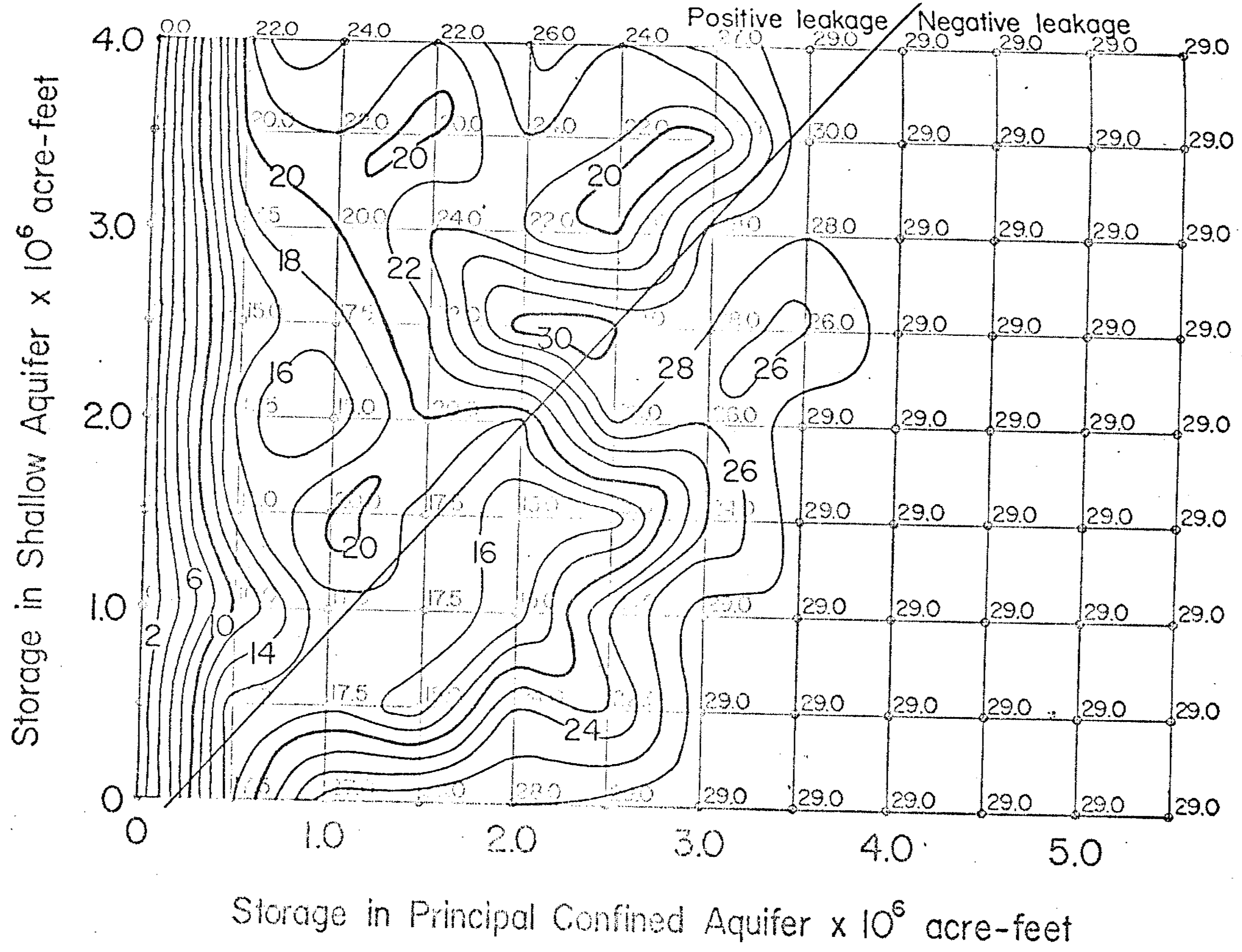

FIGURE 22

YEARLY PUMPAGES FROM THE PRINCIPAL CONFINED AQUIFER (IN 10^4 ACRE-FEET) WHICH MAXIMIZE THE OBJECTIVE FUNCTION FOR $N \geq 8$

These policies are based on the physical and hydrological characteristics of the system as described in the preceding sections. The benefit function was assumed invariant with respect to time, and the solution converged to the optimal policies on the 8th stage.

Interpretation of Results

For the purpose of interpreting the results obtained, one has to keep in mind that the policies derived are optimal within the estimated physical limitations, the assumptions made in the analysis, and the validity of the objective function.

In order to interpret the optimal operating policies shown in Figures 21 and 22, one has to understand the economic factors affecting the optimal operating policies [Burt, 1964]. The two economic factors which tend to increase the operating policy for an aquifer are the discount factor, which tends to reduce the influence of future benefits and thus increases the influence of current benefits, and the increase in marginal returns at low levels of water use per period. The two economic factors which reduce the optimal operating policy are the decrease in marginal returns when the policy is already high and the increase in expected pumping costs associated with the remainder of the planning horizon. In addition to the above four factors, there is a strong factor which influences the operating policy of a coupled leaky aquifer system. This factor is the mutual interaction of the aquifers. The amount of leakage from one aquifer to the other makes the optimal operation of one aquifer strongly dependent on the storage in the other aquifer in addition to the storage in itself. The final optimal operating rule is a function of all the five factors and is, as a matter of fact, the resultant of all these appropriately weighted positive and negative factors. This makes the interpretation of the optimal policy fairly difficult.

The results of the computer solution are shown as isoquants depicting the optimal operating policies for the Principal Confined Aquifer and for the Shallow Aquifer, in Figs. 22 and 21, respectively. A line of zero leakage is also drawn. The leakage is positive (from the Principal Confined to the Shallow Aquifer) to the right of this line, and leakage is negative to the left of the line.

The optimal operating policy for the Principal Confined Aquifer is strongly influenced by the interaquifer leakage. This is shown, in general, by the alignment of highs and lows on the opposite sides of the zero-leakage line. The two highs can be interpreted as indicating that the optimal policy is to pump more water from the Principal Confined Aquifer at these states because the aquifer is gaining water through leakage. Similarly, lows indicate that the pumpage should be less because the aquifer is losing water. The low appearing in Fig. 22, when the storage in the shallow aquifer is about 3.25 million acre-feet, is probably because of other factors affecting the optimal operating policy.

Referring to Fig. 21, the optimal operating policy for the Shallow Aquifer is uniform for all storages in the aquifers except when storage is very low in the Shallow Aquifer and except near the zero-leakage line. The optimal operating policy appears to be strongly influenced by mutual leakage of the aquifers. This is manifested by a broad low which trends parallel to the zero-leakage line. Corresponding to the two highs to the left of the zero-leakage line in Fig. 22, there are two lows in Fig. 21 This is because the Shallow Aquifer is losing water through leakage at those storages.

In general, the results obtained agree closely with those expected intuitively, i.e., the optimal operating policy for an aquifer is high when the storage in the aquifer is high. It is never higher than the amount at which the marginal value of the net output ceases to be positive. The sum of the operating policies for both aquifers at given storage values also follows this relationship, and furthermore the influence of leakage is not obvious as in the case of individual aquifers.

The operating policies shown in Figs. 21 and 22 are the amounts of water to be pumped for irrigating alfalfa and cotton only. In addition, 26,500 and 53,000 acre-feet of water must be pumped from the Shallow Aquifer and the Principal Confined Aquifer, respectively. These amounts are for growing sorghum and small grains. The acreages of these two crops are shown in Table XXII.

Procedure for Use of Results

The average depths to water level and potentiometric surface in the Shallow Aquifer and in the Principal Confined Aquifer, respectively, are first calculated from the January maps for the year for which optimal pumpages are required. Using the depth-storage relations given in Chapter IV, storage in each aquifer is calculated for the year under consideration. Knowing the storage in the two aquifers, optimal amounts of groundwater to be pumped in that year from the two aquifers are read from Figs. 21 and 22, respectively. This pumpage is for growing alfalfa and cotton only; the acreages of these crops are listed in Table XXIII. To these pumpages must be added the amounts of groundwater needed to grow sorghum and small grains.

Limitation of Results

The optimal operating policies derived in this report are based on the hydrologic, economic, and other inputs to the model. Reliability of the results depends upon the validity of the various assumptions explicitly stated or implied in the formulation and in solution of the model.

The hydrologic inputs that may introduce errors are the storage-depth relations. These relations imply maximum and minimum permissible depths of pumping, average hydraulic parameters of the aquifers, and the areal extent of aquifers. Optimal policies are strongly influenced by the objective function which in turn is made up of values added for different crops for different amounts of water applied, and the pumping costs. The discount rate also influences the optimal policies. The error of discretization, which is introduced when the model is simplified from a continuous to a discrete form, can be further reduced by making the storage and pumpage intervals smaller and by increasing the number or recharges and associated probabilities used as input to the model. In conclusion, the optimal policies derived are optimal with respect to the limitations and constraints imposed on the model rather than in an absolute sense.

Application of Results

The average depths to the water table in the Shallow Aquifer, and to the potentiometric surface in the Principal Confined Aquifer were estimated from Table XIX for January 1969. Using these values for average depths and the storage-depth relations (Eqs. 23 and 24), the storages in the Shallow Aquifer and the Principal Confined Aquifer were estimated at 1.9 million acre-feet and 3.2 million acre-feet, respectively. These storages correspond to optimal operating policies of 265,000 acre-feet and of 170,000 acre-feet, respectively, for the year 1969. To these, amounts of water to be used for growing sorghum and small grains must be added. The total groundwater optimal pumpage comes to about 470,000 acre-feet for 1969. This figure is higher than the actual pumpages for the years 1967 and 1968, but it is lower than the pumpages during 1963 and 1964.

The above optimal pumpage is based on the hydrologic, the economic, and other inputs to the model, discussed previously. Any changes in the crop pattern given in Table XXIII will change the total optimal pumpage from the two aquifers. The values added for alfalfa and for cotton used as input to the model give maximum outputs at 7.33 and 3.75 acre-feet of irrigation water pumped per acre, respectively. The current practice in the Roswell basin is to pump about 5 or 6 acre-feet of water per acre of alfalfa. Stochastic recharges from precipitation to the Principal Confined Aquifer and to the Shallow Aquifer used as inputs to the model correspond to mean recharges of 245,000 and 35,000 acre-feet per year, respectively.

V. CONCLUSION AND RECOMMENDATIONS

Conclusion

The composite problem of two coupled leaky aquifers and a surface-water system was investigated in this report from the point of view of optimal utilization of the combined system over a long period of time. In order to derive sensible solutions, one has to analyze the system hydrologically and determine all the hydrologic factors that influence the system.

The problem was approached through dynamic programming, a sequential decision-making technique. An interconnected dynamic programming model was formulated, one part for the optimization of the system as a function of time, and the other part for the optimization of the system in space. The part which optimizes as a function of time is a stochastic dynamic programming model as the recharge to both the aquifers is stochastic. As a consequence, the resultant outcome of a decision is not uniquely known but is in the form of a probability distribution. The other part is a deterministic dynamic programming model. The model was applied to a complex overdrawn basin in a semiarid irrigated area of New Mexico, namely, the Roswell Basin.

Before the model could be applied to the Roswell basin, the basin was analyzed to determine the hydrologic and other inputs to the model. The basin comprises two coupled leaky aquifers and a surface-water system. The model was simplified before application to the Roswell basin. The three-dimensional dynamic programming model, which optimizes over time, was simplified to a two-dimensional model by not incorporating the surface-water system as an independent state variable. This seems to be a fairly valid simplification because the surface water used in the Roswell basin is less than 4 percent of the total amount of water used for irrigation in the basin. Only two crops, alfalfa and cotton, which comprise about 80 percent of the total irrigated acreage in the basin were considered explicitly in the model. There is no conceptual difficulty involved in including more than two crops or more than two states in the model. It simply increases the computer time and requires more computer storage.

The optimal operating policies for the Shallow Aquifer and the Principal Confined Aquifer were derived from the solution of the above model for the Roswell basin and are shown in Figures 21 and 22. The optimal policies were derived while taking into consideration not only the mutual leakage of the aquifers, stochastic recharge to the aquifers, and natural discharge from the Shallow Aquifer, but also the physical characteristics of the system, the extent of the areas to be irrigated, and the additional pumping costs associated with the self-drawdown of wells.

The optimal operating policies are influenced by the values added to the basin by different crops as functions of amount of water pumped, by the pumping costs, by the physical characteristics of the system, by the amounts of water in storage in the two aquifers, by the discount factor, and by mutual leakage from one aquifer to the other. Some of these factors tend to increase while others tend to decrease the optimal operating policy. Leakage tends to change its effect--that is, to increase or decrease the optimal policy--depending on the storages in the aquifers. The resultant of all these factors determines the final optimal operating decision rule.

The amount of leakage from one aquifer to the other strongly influences optimal operating policies for the two aquifers. It is concluded here that the optimal operating policies derived for a coupled leaky-aquifer system, without incorporating leakage from one aquifer to the other, will not be truly optimal. The aquifers have to be utilized conjunctively.

Recommendations

The first requirement for optimal utilization of any system is the identification of the system. Identification of a system means that the system is defined, i.e., all of its dimensions are known and all the components of the system and their characteristics and mutual interactions are explicitly known. Under these conditions one should be able to predict the response of the system to any expected stresses on it.

The following measures, some of which were recommended by Hantush [1955], would be helpful in optimal management of the water resources of the Roswell basin:

1. Detailed geological investigations are needed; specifically, the relation of the geologic structures to the potentiometric surface in the southern half of the basin needs to be studied.

2. The potentiometric-surface and water-level maps lack control in the western, and especially the southwestern, parts of the basin. Since wells for water-level measurements are not available in these areas, a suitable number of wells should be drilled there.

3. Recharge to the Principal Confined Aquifer should be determined periodically by independent hydrogeologic methods. This calls for a study of the infiltration rates in the intake area and for a detailed study of the intake area itself.

4. Replenishment to the Shallow Aquifer from return flows should be measured on some typical farms in different parts of the basin.

5. Hydraulic gradients in the intake area and in the Shallow Aquifer near the Pecos River should be measured Periodically.

6. Recorders should be installed on selected wells penetrating the Shallow Aquifer in different parts of the basin.

7. Water table and potentiometric-surface maps should also be constructed for periods of low water levels immediately after the pumping season.

8. Cooperation in planning and working among all interested organizations and agencies should be increased. An independent technical expert should help in guiding, planning and coordinating activities of the various bodies concerned.

9. Digital and/or analog model studies of the basin should be carried out for the refinement and verification of the hydraulic characteristics of the aquifers and aquitard.

10. Estimates of crop yield as a function of water applied should be made in more detail and verified experimentally. Data are lacking on crop yield when excessive water is applied. Optimal withdrawals of water from the aquifers, determined by a model like the one developed in this report, depend on these relations.

11. Optimal operating policies for the Roswell basin should be derived again after a few years when more refined inputs to the model become available.

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APPENDICES

APPENDIX A

DRAWDOWN DISTRIBUTION DUE TO WELL FIELDS IN COUPLED LEAKY AQUIFER SYSTEMS

Introduction

The drawdown distribution due to several pumping wells in an area can be more conveniently calculated by assuming that the pumping of the well field is uniformly distributed over the area. Analytical expressions for the response to pumping of well fields in single aquifers for a limited number of cases are given by Hantush [1964]. Analytical expressions for the formation of ground-water mounds in flow systems due to uniform percolation can also be used for predicting the effect of operation of well fields by changing the sign of the quantities representing recharge rates. Baumann [1952], Bittinger and Trelease [1960], Glover [1961], and Hantush [1963, 1967], among others, have obtained solutions for buildup of mounds due to uniform percolation.

This paper is about the prediction of response to simultaneous pumping of well fields in two coupled leaky aquifers, one confined, and the other unconfined. Pumping from one or both of the aquifers can be negative or zero, or one aquifer can be pumped while the other is being replenished.

Analysis

A schematic representation of well fields in a coupled leaky aquifer system is shown in Figure A-1. Unless otherwise stated, the following assumptions are implied in the derivations [see Hantush, 1967]: (1) The aquifers are effectively infinite in areal extent and are homogeneous, isotropic, and resting on a horizontal impermeable bed; (2) all the wells are completely penetrating; (3) the aquifer parameters remain constant with time and in space; (4) contrasts between the hydraulic conductivities of the two aquifers and the semipervious layer are so great that the flow is essentially vertical in this layer and horizontal in the two aquifers; (5) the storativity of the semipervious layer is negligible; (6) the well fields are operated at constant rates and the distribution of pumpage from the two aquifers is uniform over the two concentric circular well field areas of radii R_1 and R_2.

Two related cases of the problem are analyzed. In the first case, the induced drawdown in the upper aquifer, due to the operation of well fields, is small relative to its saturated thickness. This actually represents the case when the two aquifers are confined. In the second case the drawdown in the upper aquifer, which is unconfined, is significant relative to its depth of saturation.

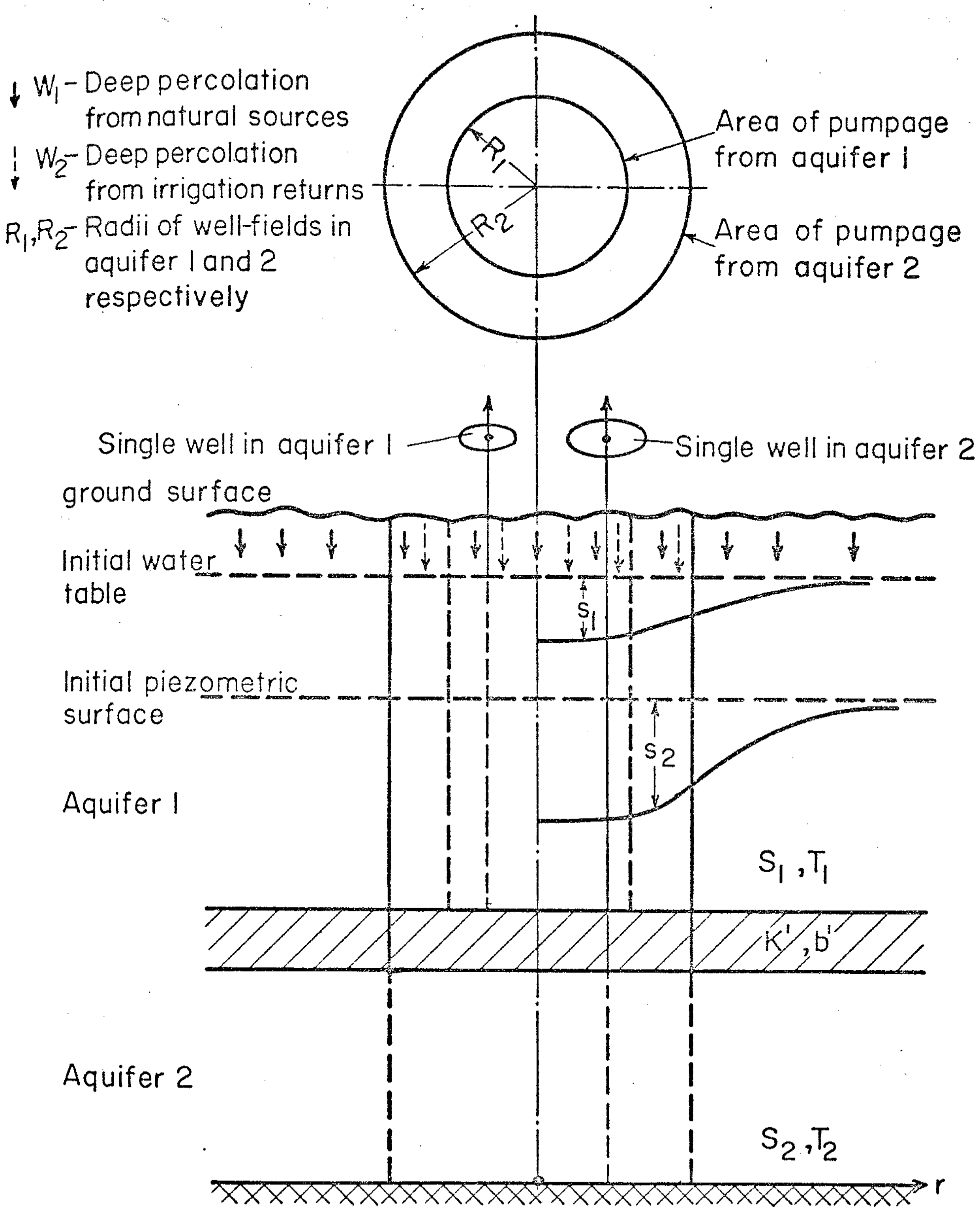

FIGURE A-1

DIAGRAMMATIC REPRESENTATION OF WELL-FIELDS IN COUPLED LEAKY AQUIFERS

CASE I, Aquifer System Infinite

The problem is to determine the distribution of drawdowns, within and outside the radii of well fields in the coupled leaky aquifer system, as induced by the operation of one or both of the well fields. In addition to pumpage, Aquifer 1 receives deep percolation from precipitation and from irrigation returns. The initial head distributions in the two aquifers can be different, that is, leakage may be taking place from one aquifer to the other. It is assumed here, in addition to the assumptions previously stated, that the induced drawdown in the unconfined aquifer is small relative to its saturated thickness. If both aquifers are confined, the upper aquifer does not receive deep percolation from precipitation and from irrigation returns.

It can be shown [see Hantush, 1967] that the flow system can be approximated by the following boundary value problem:

$$\frac{\partial^2 s_1}{\partial r^2} + \frac{1}{r}\frac{\partial s_1}{\partial r} - \frac{1}{B_1^2}(s_1 - s_2) + \frac{Q_1}{T_1} f_1(r) - \frac{W_1}{T_1} f_1(r)$$

$$- \frac{W_2}{T_1} g(r) - \frac{W_p}{T_1} f_2(r) = \frac{1}{\nu_1}\frac{\partial s_1}{\partial t} \qquad (1)$$

$$\frac{\partial^2 s_2}{\partial r^2} + \frac{1}{r}\frac{\partial s_2}{\partial r} + \frac{1}{B_2^2}(s_1 - s_2) + \frac{Q_2}{T_2} g(r) = \frac{1}{\nu_2}\frac{\partial s_2}{\partial t} \qquad (2)$$

$$s_1(r,0) = s\ (r,0) = 0 \qquad (3)$$

$$s_1(\infty,t) = s_2(\infty,t) = 0 \qquad (4)$$

$$\partial s_1(0,t)/\partial r = \partial s_2(0,t)/\partial r = 0 \qquad (5)$$

in which

$$s_1 = (h_{i1}-h_1), \quad \text{and} \quad s_2 = (h_{i2}-h_2) \qquad (6)$$

$$\nu_n = T_n/S_n, \quad B_n^2 = T_n/(K'/b'), \quad n = 1, 2 \qquad (7)$$

where subscripts 1 and 2 correspond to the aquifers 1 and 2 respectively; T, S, ν and h are, respectively, transmissivity, storativity, hydraulic diffusivity and the hydraulic head; h_{i1} and h_{i2} are the initial heads, and s_1 and s_2 are the drawdowns due to the operation of the well fields in the system; K'/b' is the leakage coefficient or leakance; Q_1 and Q_2 denote constant rates of withdrawal per unit area; W_1 and W_2 are the replenishment rates from irrigation returns from the two well fields and W_p is recharge from precipitation to Aquifer 1; R_1 and R_2 are radii of the well fields; R_e is the radius of the circular area around the well fields receiving recharge from precipitation; and r is the radial distance from the center of the well fields to any point in the flow field. The other symbols are defined below:

$$f_1(r) = \begin{cases} 1 & 0 < r < R_1 \\ 0 & r > R_1 \end{cases} \qquad (8)$$

$$f_2(r) = \begin{cases} 1 & 0 < r < R_e \\ 0 & r > R_e \end{cases} \qquad (9)$$

$$g(r) = \begin{cases} 1 & 0 < r < R_2 \\ 0 & r > R_2 \end{cases} \qquad (10)$$

Solution

Applying successively Laplace transform with respect to t and infinite zero order Hankel transform with respect to r to the boundary value problem and after simplification one obtains:

$$\bar{F}_1(\alpha,p) = \{Q_1R_1J_1(\alpha R_1) - W_1R_1J_1(\alpha R_1) - W_2R_2J_2(\alpha R_2)$$

$$- W_pR_eJ_1(\alpha R_e)\} \cdot \{\frac{\nu_1(p+a_2\nu_2)}{T_1\alpha p[(p+a)^2-\beta^2]}\} + \frac{Q_2\nu_1\nu_2R_2J_1(\alpha R_2)}{\alpha T_2B_1^2p[(p+a)^2-\beta^2]} \qquad (11)$$

$$\bar{F}_2(\alpha,p) = \frac{Q_2R_2\nu_2(a_1\nu_1+p)J_1(\alpha R_2)}{T_2\alpha p[(p+a)^2 - \beta^2]} + \{Q_1R_1J_1(\alpha R_1)$$

$$- W_1R_1J_1(\alpha R_1) - W_2R_2J_1(\alpha R_2) - W_pR_eJ_1(\alpha R_e)\}$$

$$\cdot \{ \frac{\nu_1\nu_2}{T_1\alpha B_2^2p[(p+a)^2 - \beta^2]} \} \qquad (12)$$

where $\bar{F}_1(\alpha,p)$ and $\bar{F}_2(\alpha,p)$ are the zero order Hankel transforms of the Laplace transforms of the variables $s_1(r,t)$ and $s_2(r,t)$, respectively; α and p are the parameters of the respective transformations and

$$a_1 = \alpha^2 + 1/B_1^2 , \qquad a_2 = \alpha^2 + 1/B_2^2 \qquad (13)$$

$$a = 0.5(a_1\nu_1+a_2\nu_2) = 0.5[\alpha^2(\nu_1+\nu_2) + \nu_1/B_1^2+\nu_2/B_2^2] \qquad (14)$$

$$\beta^2 = 0.25[\alpha^2(\nu_1-\nu_2) + \nu_1/B_1^2-\nu_2/B_2^2]^2 + \nu_1\nu_2/(B_1^2B_2^2) \qquad (15)$$

$$(a^2-\beta^2) = \nu_1\nu_2\alpha^2(\alpha^2+1/B_1^2+1/B_2^2) \qquad (16)$$

Applying the inverse transforms [Erdelyi, 1954] to (11) and (12), we obtain:

$$s_1(r,t) = \frac{\nu_1\nu_2}{T_1}\int_0^\infty \{(Q_1-W_1)R_1J_1(\alpha R_1) - W_2R_2J_1(\alpha R_2) - W_pR_eJ_1(\alpha R_e)\}$$

$$\cdot \{\frac{\alpha a_2}{(a^2-\beta^2)} [1-e^{-at}(\cosh\beta t + \frac{aa_2\nu_2-a^2+\beta^2}{a_2\nu_2\beta} \sinh\beta t)]\}J_0(\alpha r)d\alpha$$

$$+ \frac{Q_2\nu_1\nu_2R_2}{T_2B_1^2}\int_0^\infty \frac{\alpha}{(a^2-\beta^2)} \{1-e^{-at}(\cosh\beta t + \frac{a}{\beta} \sinh\beta t)\}J_1(\alpha R_2)J_0(\alpha r)d\alpha \quad (17)$$

$$s_2(r,t) = \frac{Q_2R_2\nu_1\nu_2}{T_2}\int_0^\infty \frac{\alpha a_1}{(a^2-\beta^2)}\{1-e^{-at}(\cosh\beta t + \frac{aa_1\nu_1-a^2+\beta^2}{a_1\nu_1\beta} \sinh\beta t)\}$$

$$\cdot J_1(\alpha R_2)J_0(\alpha r)d\alpha + \int_0^\infty \{(Q_1-W_1)R_1J_1(\alpha R_1) - W_2R_2J_1(\alpha R_2) - W_pR_eJ_1(\alpha R_e)\}$$

$$\cdot \{\frac{\alpha\nu_1\nu_2}{T_1B_2^2(a^2-\beta^2)} [1-e^{-at}(\cosh\beta t + \frac{a}{\beta} \sinh\beta t)]\}J_0(\alpha r)d\alpha \quad (18)$$

where J_0 and J_1 are the zero and first order Bessel functions of the first kind, respectively.

CASE II, Aquifer System Infinite.

An Unconfined Aquifer and a Confined Aquifer

The problem analyzed in this section is essentially the same as the problem of the last section except that in the upper, unconfined, aquifer the induced drawdown is significant relative to its depth of saturation. All the assumptions applied to the last case are also implied here. The drawdown distribution for the system is given by Eqs. 1 through 5 except that Eqs. 1 and 2, the differential equations governing the flow in the two aquifers, are now different.

The differential equation governing the flow in an unconfined aquifer coupled to a confined aquifer can be approximated from continuity considerations as follows [see Jacob, 1950, and Hantush, 1963]:

$$\nabla^2 h_1^2 - \frac{2\,K'}{b'K_1}(h_1 - h_2) = \frac{2\theta}{K_1}\frac{\partial h_1}{\partial t} \qquad (19)$$

where

$$\nabla^2 h_1^2 = \frac{\partial^2 h_1^2}{\partial r^2} + \frac{1}{r}\frac{\partial h_1^2}{\partial r} \qquad (20)$$

and θ and K_1 are specific yield and hydraulic conductivity of the unconfined aquifer respectively; h_1 and h_2 are hydraulic heads in the unconfined and the confined aquifer, respectively. Other symbols were defined earlier.

Eq. 19 is nonlinear in h and is difficult to solve. By replacing $(h_{i1}+h_1)/2$ with D, a weighted mean depth of the flow profile, one derives the following differential equations from Eq. 19, for the case when the upper aquifer is unconfined:

$$\frac{\partial^2 s_1}{\partial r^2} + \frac{1}{r}\frac{\partial s_1}{\partial r} - \frac{1}{\beta_1^2}\left(\frac{s_1}{2D} - s_2\right) + \frac{2(Q_1-W_1)}{K_1} F_1(r)$$

$$- \frac{2W_2}{K_1} g(r) - \frac{2W_p}{K_1} F_1(r) = \frac{1}{\nu_1}\frac{\partial s_1}{\partial t} \tag{21}$$

$$\frac{\partial^2 s_2}{\partial r^2} + \frac{1}{r}\frac{\partial s_2}{\partial r} + \frac{1}{B_2^2}\left(\frac{s_1}{2D} - s_2\right) + \frac{Q_2}{T_2} g(r) = \frac{1}{\nu_2}\frac{\partial s_2}{\partial t} \tag{22}$$

in which

$$s_1 = (h_{i1}^2 - h_1^2), \quad \text{and} \quad s_2 = (h_{i2} - h_2) \tag{23}$$

$$\beta_1^2 = K_1/2(K'/b'), \quad \nu_1 = K_1 D/\theta \; . \tag{24}$$

Solution

The flow problem represented by Eqs. 21 and 22 and Eqs. 3 through 5 is solved exactly like the previous problem.

$$s_1(r,t) = \frac{2\nu_1\nu_2}{K_1}\int_0^\infty \{(Q_1-W_1)R_1J_1(\alpha R_1) - W_2R_2J_1(\alpha R_2) - W_pR_eJ_1(\alpha R_e)\}$$

$$\cdot \left\{ \frac{\alpha a_2}{(a^2-\beta^2)} \left[1-e^{-at}\left(\cosh\beta t + \frac{a a_2\nu_2 - a^2+\beta^2}{a_2\nu_2\beta}\sinh\beta t\right)\right]\right\} J\ (\alpha r)\, d\alpha$$

$$+ \frac{Q_2\nu_1\nu_2R_2}{T_2\beta_1^2}\int_0^\infty \frac{\alpha}{(a^2-\beta^2)}\{1-e^{-at}(\cosh\beta t + \frac{a}{\beta}\sinh\beta t)\}J_1(\alpha R_2)J_0(\alpha r)\, d\alpha \tag{25}$$

$$s_2(r,t) = \int_0^\infty \{(Q_1-W_1)R_1J_1(\alpha R_1) - W_2R_2J_1(\alpha R_2) - W_pR_eJ_1(\alpha R_e)\}$$

$$\cdot \{ \frac{\alpha\nu_1\nu_2}{B_2^2K_1D(a^2-\beta^2)} [1-e^{-at}(\cosh\beta t + \frac{a}{\beta}\sinh\beta t)]\}J_0(\alpha r)\,d\alpha$$

$$+ \frac{Q_2\nu_1\nu_2R_2}{T_2}\int_0^\infty \frac{\alpha a_1}{(a^2-\beta^2)} \{1-e^{-at}(\cosh\beta t + \frac{aa_1\nu_1-a^2+\beta^2}{a_1\nu_1\beta}\sinh\beta t)\}J_1(\alpha R_2)J_0(\alpha r)\,d\alpha \qquad (26)$$

Eqs. 25 and 26 are quite similar to Eqs. 17 and 18 except that now

$$\nu_1 = KD/\theta; \quad B_1^2 = K_1D/(K'/b'); \quad \beta_1^2 = K_1/2(K'/b') \qquad (27)$$

$$a_1 = \alpha^2 + \frac{1}{K_1D/(K'/b')} \qquad (28)$$

Eqs. 15 and 16 are to be re-defined in view of Eqs. 27 and 28; s_1 and s_2 are defined by Eq. 23.

Special Solutions

The solutions for special cases can be derived from the solutions derived for the two cases described previously.

One well field operating. If only one of the well fields is operating, say for example the well field in Aquifer 1, the expressions for drawdowns in the two aquifers for cases I and II are obtained by substituting $Q_2 = 0$, in the respective solutions. The fractions of total drawdowns which are due to pumpage Q_2 from Aquifer 2 will vanish. It should be pointed out that the drawdown in the aquifer which is not being operated is not zero. There will be some induced drawdown because of pumpage from the other aquifer. This is because the two aquifers are coupled through the semipervious layer.

Well field in a single aquifer. In the case of a single isolated aquifer, the drawdown due to the operation of a well field is obtained by letting $1/B_1^2$, $1/B_2^2$, and Q_2 approach zero and by putting $\nu_1 = \nu_2 = \nu$ in the appropriate solutions. For example, from the solution for Case II, by making the above substitutions in Eqs. 25 and 26, we get

$$s\,(r,t) = \frac{2}{K}\int_0^\infty \{(Q_1-W_1)RJ_1(\alpha R) - W_pR_eJ_1(\alpha R_e)\}\cdot(1-e^{-\alpha^2\nu t})\,\frac{J_0(\alpha r)}{\alpha^2}\,d\alpha \qquad (29)$$

Eq. 27 gives the drawdown due to the operation of a well field of radius R in an unconfined aquifer of hydraulic conductivity K. The aquifer receives deep percolation from precipitation and from irrigation returns. If, instead of pumping, the aquifer is receiving recharge at the rate V, Eq. 27 becomes

$$h^2-h_1^2 = \frac{2V}{\pi K}\int_0^\infty (1-e^{-qr^2})J_1(r)J_0(\rho r)\,\frac{dr}{r^2} = (2V/\pi K)f(q,\rho) \qquad (30)$$

in which

$$V = \pi R^2 W, \qquad q = \nu t/R^2, \qquad \rho = r/R.$$

Eq. 30 is the same as derived by Hantush [1967] for a single aquifer.

Maximum drawdown. The maximum drawdown due to the operation of well fields occurs at the center of well fields. The expressions for maximum drawdowns for the various cases can be derived by putting $r = 0$ in the appropriate solution. When $r = 0$, $J_0(0) = 1$ and so $J_0(\alpha r)$ is replaced with unity in the solutions.

Effect of boundaries. If there are hydraulic boundaries near the well fields, the solutions can be derived by the method of images [Jacob, 1950; Carslaw and Jaeger, 1959] from the above solutions.

Well Fields in Closed Circular Aquifers

The coupled aquifers analyzed here are finite and have zero flux across their circular boundaries. The flow problem for both Case I and Case II are then described by Equations 1 through 5, and 21 through 24 except that Equation 4 is replaced with the following boundary condition:

$$\partial s_1(r_e,t)/\partial r = \partial s_2(r_e,t)/\partial r = 0 \tag{31}$$

where r_e is the radius of the aquifer system.

Solution of the Problem

In order to solve the flow problem, the zero-ordered Hankel transform of a function f(r) is modified and defined as

$$H_0[f(r)] = V(\alpha_n) = \frac{\sqrt{2}}{r_e}\int_0^{r_e} rf(r)\,\frac{J_0(\alpha_n r/r_e)}{J_0(\alpha_n)}\,dr \tag{32}$$

where n are positive roots of $J_0'(\alpha) = 0$. By expanding a function in a Fourier-Bessel series, one can show that the inversion formula for the transformation represented by Eq. 32 is

$$f(r) = \frac{\sqrt{2}}{r_e}\sum_{m=1}^{\infty}\frac{V(\alpha_n)J_0(\alpha_n r/r_e)}{J_0(\alpha_n)} \tag{33}$$

where $V(\alpha_n)$ is the transform of the function f(r) defined by Eq. 32 and J_0 is the zero-order Bessel function of the first kind.

Applying 32 to $\nabla^2\bar{s}$ and on integration by parts, one obtains

$$H_0[\nabla^2\bar{s}] = H_0[\frac{1}{r}\frac{d}{dr}(r\frac{d\bar{s}}{dr})] = [r\frac{d\bar{s}}{dr}\cdot\frac{J_0(\alpha_n r/r_e)}{J_0(\alpha_n)}]_{r=0}^{r=r_e}$$

$$-\int_0^{r_e} r\frac{d\bar{s}}{dr}\cdot\frac{\alpha_n}{r_e}\frac{J_0(\alpha_n r/r_e)}{J_0(\alpha_n)}\,dr \qquad (34)$$

The first term on the right hand side vanishes if $(d\bar{s}/dr)_{r=r_e} = 0$ or

$$H_0[\frac{1}{r}\frac{d}{dr}(r\frac{d\bar{s}}{dr})] = -[\bar{s}\,r\frac{\alpha_n}{r_e}\frac{J_0(\alpha_n r/r_e)}{J_0(\alpha_n)}]_{r=0}^{r=r_e}$$

$$+\frac{\alpha_n}{r_e}\int_0^{r_e}\frac{\bar{s}}{J_0(\alpha_n)}[J_0(\alpha_n r/r_e) + \frac{\alpha_n}{r_e}J_0''(\alpha_n r/r_e)]dr \qquad (35)$$

Again the first term on the right side vanishes because $J_1(\alpha_n) = 0$ and using the fact that $J_0(\alpha_n r/r_e)$ satisfies the differential equation

$$J_0''(\alpha_n r/r_e) + \frac{r_e}{\alpha_n r}J_0'(\alpha_n r/r_e) + J_0(\alpha_n r/r_e) = 0 \qquad (36)$$

Equation 35 becomes

$$H_0[\frac{1}{r}\frac{d}{dr}(r\frac{d\bar{s}}{dr})] = -\frac{\alpha_n^2}{r_e^2}\bar{F}(\alpha_n) \qquad (37)$$

in which $\bar{F}(\alpha_n)$ is the integral transform, defined by Eq. 32, of $\bar{s}(r)$.

Case I, Aquifer System Finite

Applying the Laplace transform and then the Bessel transform, defined by Eq. 32, to the flow problem defined by Eqs. 1 through 7, with Eq. 4 replaced by Eq. 31, and simplifying, one obtains

$$\bar{F}_1(\alpha_n,p) = \{(Q_1-W_1)R_1J_1(\alpha_nR_1/r_e) - W_2R_2J_1(\alpha_nR_2/r_e) - W_pr_eJ_1(\alpha_n)\}$$

$$\cdot \{ \frac{\sqrt{2}\ \nu_1\ (p+d_2\nu_2)}{T_1\alpha_nJ_0(\alpha_n)p[(p+d)^2-\beta^2]} \} + \frac{Q_2\ \sqrt{2}\ R_2J_1(\alpha_nR_2/r_e)\nu_1\nu_2}{T_2\alpha_nJ_0(\alpha_n)B_1^2p[(p+d)^2-\beta^2]} \qquad (38)$$

$$\bar{F}_2(\alpha_n,p) = \{(Q_1-W_1)R_1J_1(\alpha_nR_1/r_e) - W_2R_2J_1(\alpha R_2/r_e) - W_pr_eJ_1(\alpha_n)\}$$

$$\cdot \{ \frac{\sqrt{2}\ \nu_1\nu_2}{B_2^2\alpha_nT_1J_0(\alpha_n)p[(p+d)^2-\beta^2]} \} + \frac{\sqrt{2}Q_2R_2\nu_2J_1(\alpha_nR_2/re)(p+d_1\nu_1)}{T_2\alpha_nJ_0(\alpha_n)p[(p+d)^2-\beta^2]} \qquad (39)$$

where $F_1(\alpha_n,p)$ and $F_2(\alpha_n,p)$ are the Bessel transforms defined by Eq. 32, of the Laplace transforms of the variables $s_1(r,t)$ and $s_2(r,t)$ respectively; α_n and p are the parameters of respective transformations and

$$d_1 = \alpha_n^2/r_e^2 + 1/B_1^2, \qquad d_2 = \alpha_n^2/r_e^2 + 1/B_2^2 \qquad (40)$$

$$d = 0.5\ (d_1\nu_1 + d_2\nu_2) \qquad (41)$$

$$\mu^2 = 0.25[\alpha_n^2(\nu_1-\nu_2)/r_e^2 + \nu_1/B_1^2 - \nu_2/B_2^2]^2 + \nu_1\nu_2/(B_1^2B_2^2) \qquad (42)$$

where α_n are positive roots of $J_1(\alpha) = 0$.

Applying the inverse Laplace transform and the inverse Bessel transform, defined in Eq. 33, to Eqs. 38 and 39, we obtain:

$$s_1(r,t) = \frac{2}{r_e}\sum_{n=1}^{\infty}\{(Q_1-W_1)R_1J_1(\alpha_nR_1/r_e) - W_2R_2J_1(\alpha_nR_2/r_e) - W_pr_eJ_1(\alpha_n)\}$$

$$\cdot\ \{\frac{d_2\nu_1\nu_2}{T_1\alpha_n(d^2-\mu^2)}[1-e^{-dt}(\cosh\mu t + \frac{dd_2\nu_2-d^2+\mu^2}{d_2\nu_2\mu}\sinh\mu t)]\}$$

$$\frac{J_0(\alpha_nr/r_e)}{J_0^2(\alpha_n)} + \frac{2}{r_e}\sum_{n=1}^{\infty}\frac{Q_2R_2\nu_1\nu_2J_1(\alpha_nR_2/r_e)}{T_2B_1^2\alpha_n(d^2-\mu^2)}$$

$$[1-e^{-dt}(\cosh\mu t + \frac{d}{\mu}\sinh\mu t)]\frac{J_0(\alpha_nr/r_e)}{J_0^2(\ n)} \tag{43}$$

$$s_2(r,t) = \frac{2}{r_e}\sum_{n=1}^{\infty}\{(Q_1-W_1)R_1J_1(\alpha_nR_1/r_e) - W_2R_2J_1(\alpha_nR_2/r_e)-W_pr_eJ_1(\alpha_n)\}$$

$$\cdot\ \{\frac{\nu_1\nu_2}{B_2^2T_1\alpha_n(d^2-\mu^2)}[1-e^{-dt}(\cosh\mu t + \frac{d}{\mu}\sinh\mu t)]\}$$

$$\cdot\ \frac{J_0(\alpha_nr/r_e)}{J_0^2(\alpha_n)} + \frac{2}{r_e}\sum_{n=1}^{\infty}\frac{Q_2R_2\nu_1\nu_2d_1J_1(\alpha_nR_2/r_e)}{T_2\alpha_n(d^2-\mu^2)}$$

$$[1-e^{-dt}(\cosh\mu t + \frac{dd_1\nu_1-d^2+\mu^2}{d_1\nu_1\mu}\cdot\sinh\mu t)]\frac{J_0(\alpha_nr/r_e)}{J_0^2(\alpha_n)}\ . \tag{44}$$

Case II, Aquifer System Finite

The flow problem is described by Eqs. 21 through 24 and Eqs. 3 through 5, with Eq. 4 replaced by Eq. 31. Approaching the problem exactly like the problem of Case I for the aquifer system finite, we obtain:

$$s_1(r,t) = \frac{2}{r_e} \sum_{n=1}^{\infty} \{(Q_1-W_1)R_1J_1(\alpha_n R_1/r_e) - W_2R_2J_1(\alpha_n R_2/r\ )W_p r_e J_1(\alpha_n)\}$$

$$\cdot \{ \frac{2\nu_1\nu_2 d_2}{K_1\alpha_n(d^2-\mu^2)} [1-e^{-dt}(\cosh\mu t + \frac{dd_2\nu_2-d^2+\mu^2}{d_2\nu_2\mu} \sinh\mu t)]\}$$

$$\frac{J_0(\alpha_n r/r_e)}{J_0^2(\alpha_n)} + \frac{2}{r_e} \sum_{n=1}^{\infty} \frac{Q_2R_2\nu_1\nu_2J_1(\alpha_n R_2/r_e)}{T_2\beta_1^2\alpha_n(d^2-\mu^2)}$$

$$[1-e^{-dt}(\cosh\mu t + \frac{d}{\mu} \sinh\mu t)] \frac{J_0(\alpha_n r/r_e)}{J_0^2(\alpha_n)} . \qquad (45)$$

$$s_2(r,t) = \frac{2}{r_e} \sum_{n=1}^{\infty} \{(Q_1-W_1)R_1J_1(\alpha_n R_1/r_e)-W_2R_2J_1(\alpha_n R_2/r_e)-W_p r_e J_1(\alpha_n)\}$$

$$\cdot \{ \frac{\nu_1\nu_2}{B_2^2K_1D\alpha_n(d^2-\mu^2)} [1-e^{-dt}(\cosh\mu + \frac{d}{\mu} \sinh\mu t)]\}$$

$$\frac{J_0(\alpha_n r/r_e)}{J_0^2(\alpha_n)} + \frac{2}{r_e} \sum_{n=1}^{\infty} \frac{Q_2\nu_1\nu_2R_2d_1J_1(\alpha_n R_2/r_e)}{T_2\alpha_n(d^2-\mu^2)}$$

$$[1-e^{-dt}(\cosh\mu t + \frac{dd_1\nu_1-d^2+\mu^2}{d_1\nu_1\mu} \sinh\mu t)] \cdot \frac{J_0(\alpha_n r/r_e)}{J_0^2(\alpha_n)} \qquad (46)$$

where d, d_1, d_2 and μ are defined by Eqs. 40 through 42.

Concluding Remarks

The drawdown distribution in any one member of a coupled leaky aquifer system is affected by the withdrawal of groundwater from either of the aquifers. The magnitude of the drawdown induced in one of the aquifers while pumping from another depends on the discharge, and on the hydraulic characteristics of aquifers and aquitards.

Solutions derived for the drawdown distribution due to discharge from either one or from both well fields in a coupled system of two aquifers and an aquitard can be numerically evaluated on a digital computer. It is not practical to tabulate the integrals which occur in the solutions because several parameters are involved.

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APPENDIX B

TIME OF TRAVEL FOR AN IMPULSE DUE TO AN INSTANTANEOUS LINE SOURCE IN LEAKY AND NONLEAKY AQUIFERS

Introduction

The idea of an instantaneous source comes from the theory of heat flow and it was very successfully used by Thomson (Lord Kelvin) [1833]. When a finite amount of heat is instantaneously released in each unit of area of a plane surface in a body, this surface becomes an instantaneous source of heat. In this paper we use the idea of an instantaneous source of water and calculate the time taken by an impulse due to such a source to propagate through a leaky aquifer and a nonleaky aquifer.

Analysis

Consider a coupled leaky aquifer system comprised of two aquifers separated by an aquitard. Unless otherwise stated, the following assumptions are implied in the derivations: (1) The aquifers are effectively infinite in area and are homogeneous, isotropic, and resting on a horizontal impermeable bed; (2) the aquifer parameters remain constant with time and in space; (3) contrasts between the hydraulic conductivities of the two aquifers and the semipervious layer are so great that the flow is essentially vertical in this layer and horizontal in the two aquifers; (4) the storativity of the semipervious layer is negligible; and (5) effects of withdrawal of groundwater from the aquifers are not considered.

The geohydrologic diffusion equation governing the flow of groundwater in an aquifer is (e.g., Hantush, 1964):

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{1}{\nu}\frac{\partial h}{\partial t} \tag{1}$$

where h is the hydraulic head and ν is the hydraulic diffusivity and is equal to T/S, transmissivity over storativity. The solution of the diffusion equation for an instantaneous point source of heat is given by Carslaw and Jaeger (1959). They have also derived the solution for an instantaneous line source by integrating the point sources along a line. By analogy, the head in an infinite aquifer due to an instantaneous line source is

$$h = \frac{V}{4\pi Tt} \exp\left(-\frac{a^2}{4\nu t}\right) \tag{2}$$

where a is the distance from the line source, V is the amount of water released, and t is the time since the release of water. Following the procedure of Carslaw and Jaeger (1959), it can be shown that the head due to an instantaneous line source in a leaky aquifer is given by

$$h = \frac{V}{4\pi Tt} \exp\left[-\left(u + \frac{a^2}{4B^2 u}\right)\right] \tag{3}$$

where $u = \frac{a^2}{4\nu t}$ and $B^2 = T/(K'/b')$, B is the leakage factor, (K'/b') is the leakage coefficient or leakance, and K' and b' are the hydraulic conductivity and the thickness of the aquitard, respectively.

The time taken by the head due to an instantaneous line source to reach its maximum value at a distance a from the line source is calculated from Eq. (3) by equating to zero the first derivative of the head with respect to time:

$$\frac{\nu}{B^2} t^2 + t - \frac{a^2}{4\nu} = 0 \qquad (4)$$

Solving Eq. (4) for t and choosing the positive solution,

$$t = \frac{B^2}{2\nu} \left[\sqrt{1 + \frac{a^2}{B^2}} - 1 \right] \qquad (5)$$

The time t for a nonleaky aquifer is derived from Eq. (4) by letting 1/B approach zero.

$$t = a^2/4\nu \qquad (6)$$

Application of Results to the Roswell Basin

The results derived in the last section were applied to the Roswell basin. Using Eq. (5), travel times of an impulse due to an instantaneous line source in the Shallow Aquifer and in the Principal Confined Aquifer were calculated for different areas of the basin and are shown in Tables B-1 and B-2, respectively. The hydraulic characteristics of the two aquifers and of the aquitard for different areas of the basin are summarized by Hantush [1955].

The travel time in the Shallow Aquifer varies from 3.2 years to about 4.5 years for a distance of 6 miles and the time varies from 4.2 years to 7.5 years for a distance of 8 miles. Impulses travel fastest in the Roswell area and slowest in the Dexter Area. The impulse travels

TABLE B-1

TIME OF TRAVEL OF AN IMPULSE DUE TO AN INSTANTANEOUS LINE SOURCE IN THE SHALLOW AQUIFER OF THE ROSWELL BASIN, NEW MEXICO

Area	Distance a (miles)	Leakage factor B*	Hydraulic ** diffusivity ν	Time t Days	Years
Roswell	6	9.5×10^3	133.7×10^3	1,180	3.2
	8	9.5×10^3	133.7×10^3	1,540	4.2
Dexter	6	40.0×10^3	133.7×10^3	1,650	4.5
	8	40.0×10^3	133.7×10^3	2,720	7.5
Artesia	6	20.0×10^3	133.7×10^3	1,310	3.6
	8	20.0×10^3	133.7×10^3	2,000	5.5
Lakewood	6	36.0×10^3	133.7×10^3	1,610	4.4
	8	36.0×10^3	133.7×10^3	2,630	7.2

* In feet

** In ft^2/day.

TABLE B-2

TIME OF TRAVEL OF AN IMPULSE DUE TO AN INSTANTANEOUS LINE SOURCE IN THE PRINCIPAL CONFINED AQUIFER OF THE ROSWELL BASIN, NEW MEXICO

Area	Distance $\underline{a}$ (miles)	Leakage factor $\underline{B}$*	Hydraulic diffusivity $\underline{\nu}$ **	Time $\underline{t}$ in Days	Time $\underline{t}$ in Years
Roswell	6	9.5	1.87×10^{10}	0.0060	1.6×10^{-5}
	8	9.5	1.87×10^{10}	0.0086	2.4×10^{-5}
Dexter	6	40.0	2.01×10^{8}	1.10	3.0×10^{-3}
	8	40.0	2.01×10^{8}	1.81	5.0×10^{-3}
Artesia	6	20.0	4.01×10^{8}	0.44	1.2×10^{-3}
	8	20.0	4.01×10^{8}	0.67	1.8×10^{-3}
Lakewood	6	36.0	8.82×10^{7}	2.44	6.7×10^{-3}
	8	36.0	8.82×10^{7}	3.98	1.1×10^{-2}

* In thousands of feet.

** In ft^2/day.

at a much faster rate in the Principal Confined Aquifer than in the Shallow Aquifer. The travel time in the Principal Confined Aquifer varies from about 10 minutes to aboue a day for a distance of 6 miles.

The travel time in the intake area of the Principal Confined Aquifer was calculated using Eq. (6). The time varies from about 2 years to 3.7 years for a distance of 6 miles for hydraulic diffusivities of 334,000 and 187,000 ft^2 per day, respectively. The travel time in the intake area is of importance because it governs the recharge to the Principal Confined Aquifer.

Discussion

The time of travel derived using Eq. (5) or Eq. (6) is the time for the head due to an instantaneous line source to reach its maximum at a given distance. Travel times derived for the two aquifers in the Roswell basin are based on the hydraulic characteristics derived by Hantush [1955] from pumping tests. Pumping tests were carried out in the developed part of the basin. Travel time increases with increase in the leakage factor and decreases as the hydraulic diffusivity increases.

The hydraulic diffusivity of the Principal Confined Aquifer is expected to decrease as we move away from the developed part of the basin. The travel time per unit distance would increase as we move toward the intake area of this aquifer.

CONCLUSIONS

Eqs. (5) and (6) can be used to calculate times of travel of an impulse due to an instantaneous line source in leaky and nonleaky aquifers, respectively. For leaky aquifers, time of travel increases with increase in leakage factor and decreases as diffusivity increases. Time of travel is directly proportional to the square of the distance and inversely proportional to the hydraulic diffusivity for nonleaky aquifers.

The time of travel of an impulse due to a line source is about a day in the Principal Confined Aquifer of the Roswell basin and is about 3 to 7 years in the Shallow Aquifer. Times of travel for both aquifers are the shortest in the Roswell area and largest in the Dexter area. The time of travel in the intake area of the Roswell basin is about 2 to 3.7 years for a distance of six miles. The width of the area, from the confined-unconfined boundary of the Principal Confined Aquifer to the western limit of water in this aquifer is about 8 to 10 miles, just west of the developed areas. Therefore, the use of three-year effective precipitation for the calculation of recharge to the Principal Confined Aquifer of the Roswell basin seems reasonable. This is supported by the study of hydrographs of the recorder wells in the Principal Confined Aquifer.

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APPENDIX C

SALT WATER ENCROACHMENT IN A CONFINED LEAKY AQUIFER DUE TO A STEADILY OPERATING WELL FIELD

Introduction

Salt water encroachment due to withdrawal of fresh water from aquifers is a problem occurring in several regions of the world. The movement of the interface between fresh water and salt water has been investigated extensively. Bear and Dagan [1964] and Hantush [1968] have made literature surveys in addition to their own studies about the different aspects of the interface. The present paper discusses an approximate approach to the lateral encroachment of salt water due to operation of a well field in a confined leaky aquifer. This procedure was discussed by Hantush in one of his classes for a single well in a nonleaky aquifer.

Analysis

Consider a coupled leaky aquifer system comprised of two aquifers separated by an aquitard. Unless otherwise stated, the following assumptions are implied in the derivations: (1) The aquifers are effectively infinite in areal extent and are homogeneous, isotropic, and resting on a horizontal impermeable bed; (2) contrasts between the hydraulic conductivities of the two aquifers and the semipervious layer are so great that the flow is essentially vertical in this layer and horizontal in the two aquifers; (3) the aquifer parameters remain constant with time and in space; (4) the storativity of the semipervious layer is negligible; (5) a well field is an area in which several pumping wells are located and where pumping is uniformly distributed over the area; (6) the induced drawdown in the aquifer which is not being pumped is negligible; and (7) the interface between fresh water and salt water is sharp.

Let $\underline{R}$ be radius of the well field (Fig. C-1) that is being pumped steadily at a rate $\underline{V}$. Rate of movement of a particle of water is given by

$$\frac{dr}{dt} = \frac{K}{n}\frac{\partial h}{\partial r} \tag{1}$$

where $\underline{n}$ is the porosity of the aquifer, $\underline{K}$ is the hydraulic conductivity, and $\underline{h}$ is the hydraulic head in the aquifer above the base of the aquifer. The drawdown $\underline{s}$ in a leaky aquifer during steady operation of the well field is given by Hantush [1964], for $r > R$:

$$s(r,t) = \frac{VB}{\pi RT} I_1 \ (R/B) K_0 (r/B) \tag{2}$$

where $s(r,t) = h_0 - h(r,t)$, and $\underline{h_0}$ is the initial head, $\underline{h}$ is the head at any time $\underline{t}$ at a distance $\underline{r}$, $\underline{B}$ is the leakage factor and is equal to $\sqrt{T/(K'/b')}$, K'/b' is the leakance or leakage coefficient, K' and b' are the vertical hydraulic conductivity and thickness of the aquitard, respectively, $\underline{T}$ is the transmissivity and is equal to Kb, $\underline{b}$ is the thickness of the aquifer, I_1 is the modified Bessel function of first kind and first order, and $\underline{K_0}$ is the modified Bessel function of second kind and zero order.

From Eqs. (1) and (2)

$$\frac{dr}{dt} = \frac{V}{\pi Rnb} I_1 (R/B) K_1 (r/B) \tag{3}$$

where K_1 is the modified Bessel function of second kind and first order.

Integrating Eq. (3) with respect to time as time goes from zero to t and as r goes from r to r:

$$\int_0^t dt = \frac{\pi Rnb}{VI_1(R/B)} \int_{r_0}^{r} \frac{dr}{K_1(r/B)} \quad (4)$$

where r_0 is the initial position of the interface when t = 0 (Fig. C-1). After simplification, Eq. (4) becomes

$$t = - \frac{\pi RnbB}{VI_1(R/B)} \left[\int_0^{r_0/B} \frac{d\alpha}{K_1(\alpha)} - \int_0^{r/B} \frac{d\alpha}{K_1(\alpha)} \right], \text{ for } r > R. \quad (5)$$

Eq. (5) gives the time taken by the interface to travel from r_0 to r. The negative sign indicates that, as the distance from the center of the well field to the interface decreases, the time increases.

In order to determine the motion of the interface in a particular time, Eq. (4) is solved inversely for r using the values of the integral given in Table C-1. The distance r is calculated for several points on each of the salinity contours and plotted, thus giving the new position of the interface.

Discussion

The procedure described is useful for predicting the encroachment of a salt water front in an aquifer and can be used for other flow systems for which analytical drawdown expressions are available. The

TABLE C-1. $I(x) = \int_0 \frac{d\eta}{K_1(\eta)}$.

X	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.01	0.000050	0.000061	0.000072	0.000085	0.000098	0.000113	0.000128	0.000145	0.000162	0.000181
0.02	0.000200	0.000221	0.000242	0.000265	0.000288	0.000313	0.000338	0.000365	0.000392	0.000421
0.03	0.000450	0.000481	0.000513	0.000545	0.000579	0.000613	0.000649	0.000685	0.000723	0.000762
0.04	0.000801	0.000842	0.000884	0.000926	0.000970	0.001015	0.001060	0.001107	0.001155	0.001203
0.05	0.001253	0.001304	0.001356	0.001408	0.001462	0.001517	0.001573	0.001629	0.001687	0.001746
0.06	0.001806	0.001867	0.001929	0.001992	0.002056	0.002121	0.002187	0.002254	0.002322	0.002391
0.07	0.002461	0.002532	0.002604	0.002677	0.002751	0.002826	0.002902	0.002980	0.003058	0.003137
0.08	0.003217	0.003299	0.003381	0.003465	0.003549	0.003634	0.003721	0.003808	0.003897	0.003986
0.09	0.004077	0.004169	0.004261	0.004355	0.004450	0.004546	0.004642	0.004740	0.004839	0.004939

X	0.0	0.010	0.020	0.030	0.040	0.050	0.060	0.070	0.080	0.090
0.10	0.005040	0.006107	0.007279	0.008555	0.009939	0.011429	0.013026	0.014733	0.016549	0.018475
0.20	0.020513	0.022663	0.024927	0.027305	0.029798	0.032408	0.035136	0.037983	0.040950	0.044038
0.30	0.047248	0.050583	0.054042	0.057628	0.061341	0.065184	0.069157	0.073262	0.077500	0.081873
0.40	0.086383	0.091030	0.095816	0.100744	0.105614	0.111028	0.116388	0.121895	0.127551	0.133359
0.50	0.139319	0.145434	0.151704	0.158133	0.164722	0.171473	0.178387	0.185467	0.192715	0.200132
0.60	0.207721	0.215484	0.223422	0.231539	0.239835	0.248314	0.256978	0.265827	0.274866	0.284096
0.70	0.293520	0.303140	0.312958	0.322976	0.333198	0.343625	0.354260	0.365107	0.376166	0.387441
0.80	0.398935	0.410650	0.422588	0.434754	0.447148	0.459776	0.472638	0.485737	0.499078	0.512663
0.90	0.526495	0.540576	0.554911	0.569501	0.584351	0.599463	0.614841	0.630487	0.646406	0.662600

X	0.0	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900
1.00	0.6791	0.8599	1.0727	1.3216	1.6112	1.9468	2.3343	2.7803	3.2922	3.8783
2.00	4.5481	5.3119	6.1816	7.1701	8.2923	9.5647	11.0054	12.6354	14.4774	16.5573
3.00	18.9038	21.5490	24.5289	27.8835	31.6575	35.9013	40.6699	46.0264	52.0396	58.7875
4.00	66.3558	74.8419	84.3521	95.0077	106.9413	120.3010	135.2548	151.9851	170.7004	191.6272
5.00	215.0246	241.1759	270.3948	303.0396	339.4976	380.2131	425.6658	476.4041	533.0237	596.2068
6.00	666.6943	745.3103	832.9922	930.7549	1039.7583	1161.2588	1296.6882	1447.6143	1615.7681	1803.1262
7.00	2011.8267	2244.3010	2503.1860	2791.5051	3112.5061	3469.9224	3867.7993	4310.6328	4803.5625	5352.0391
8.00	5962.5312	6641.6758	7397.3711	8238.0781	9173.0859	10213.2539	11370.1797	12656.8125	14087.2461	15678.2578
9.00	17447.1758	19413.8828	21600.2852	24030.1953	26731.9297	29734.6875	33072.1406	36780.4805	40902.0352	45482.4102

X	0.0	1.000	2.000	3.000	4.000	5.000	6.000	7.000	8.000	9.000
10.00	0.5057E 05	0.1455E 06	0.4163E 06	0.1185E 07	0.3362E 07	0.9502E 07	0.2678E 08	0.7531E 08	0.2113E 09	0.5917E 09
20.00	0.1654E 10	0.4618E 10	0.1287E 11	0.3584E 11	0.9969E 11	0.2770E 12	0.7689E 12	0.2133E 13	0.5911E 13	0.1637E 14
30.00	0.4531E 14	0.1253E 15	0.3464E 15	0.9570E 15	0.2643E 16	0.7294E 16	0.2012E 17	0.5549E 17	0.1530E 18	0.4215E 18
40.00	0.1161E 19	0.3197E 19	0.8799E 19	0.2421E 20	0.6661E 20	0.1832E 21	0.5037E 21	0.1384E 22	0.3805E 22	0.1045E 23
50.00	0.2871E 23	0.7886E 23	0.2165E 24	0.5944E 24	0.1631E 25	0.4477E 25	0.1228E 26	0.3369E 26	0.9241E 26	0.2534E 27
60.00	0.6949E 27	0.1904E 28	0.5219E 28	0.1430E 29	0.3920E 29	0.1074E 30	0.2942E 30	0.8060E 30	0.2208E 31	0.6046E 31
70.00	0.1656E 32	0.4533E 32	0.1241E 33	0.3398E 33	0.9300E 33	0.2546E 34	0.6967E 34	0.1906E 35	0.5216E 35	0.1427E 36
80.00	0.3904E 36	0.1068E 37	0.2921E 37	0.7990E 37	0.2185E 38	0.5976E 38	0.1634E 39	0.4469E 39	0.1222E 40	0.3340E 40
90.00	0.9132E 40	0.2496E 41	0.6824E 41	0.1865E 42	0.5097E 42	0.1393E 43	0.3807E 43	0.1040E 44	0.2843E 44	0.7767E 44
100.00	0.2122E 45	0.5798E 45	0.1584E 46	0.4327E 46	0.1182E 47	0.3229E 47	0.8819E 47	0.2409E 48	0.6579E 48	0.1797E 49

procedures are approximate in nature because some of the assumptions made are not quite true in nature. The interface between salt water and fresh water is usually not sharp. For some flow systems, it may be difficult to simplify the final expression for time to a form like Eq. (5) which can readily be evaluated.

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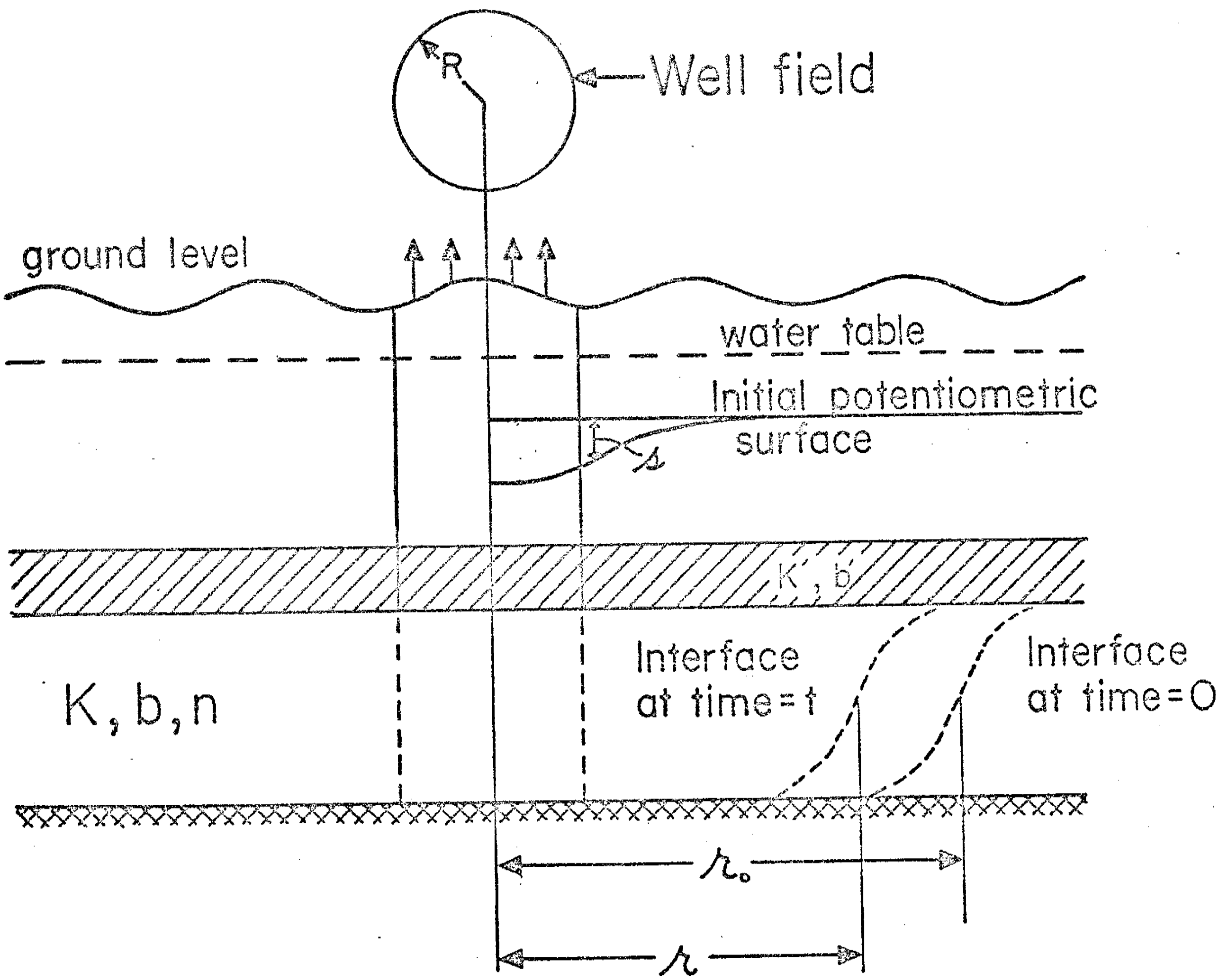


FIGURE C-1

ENCROACHMENT OF THE INTERFACE BETWEEN FRESH WATER AND SALT WATER DUE TO THE OPERATION OF A WELL FIELD IN A LEAKY AQUIFER

APPENDIX D

DATA TABLES AND MAPS

TABLE D-I

MONTHLY PRECIPITATION AT ROSWELL*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	0.55	2.62	2.95	1.87	0.01	1.78	0.97	0.01	0.64	0.37	2.40	1.06	19.23
19 6	0.53	0.47	0.24	2.70	0.46	0.42	2.30	1.83	0.48	0.73	4.06	0.99	15.21
19 7	0.36	0.0	0.0	0.64	1.15	2.03	1.74	2.06	0.96	2.98	1.36	0.15	13.43
19 8	0.26	0.28	0.01	1.29	0.07	0.68	2.16	2.87	1.29	0.0	0.70	0.01	9.62
19 9	0.02	0.02	0.97	0.0	0.05	1.05	1.94	2.01	0.40	0.63	0.29	0.31	7.69
1910	0.10	0.11	0.05	0.08	0.15	0.75	0.57	2.03	0.44	0.36	0.22	0.01	4.87
1911	0.14	1.92	0.29	2.16	3.38	0.45	2.93	1.23	1.71	1.14	0.46	0.56	16.37
1912	0.03	1.32	0.04	0.15	0.34	1.21	1.94	2.80	2.67	0.87	0.43	1.10	12.90
1913	0.60	0.55	0.74	1.21	0.03	4.17	0.82	0.28	2.67	0.85	0.97	0.88	13.77
1914	0.04	0.11	0.14	1.14	3.77	1.45	1.97	1.33	0.05	3.37	0.30	1.78	15.45
1915	0.39	0.95	1.85	6.04	1.18	0.14	0.45	1.77	2.29	0.12	0.0	0.99	16.16
1916	0.44	0.0	0.58	1.11	0.17	0.44	1.04	9.56	0.37	2.31	0.44	0.36	16.82
1917	0.19	0.26	0.29	0.0	0.97	0.0	0.07	3.25	1.11	0.01	0.06	0.0	6.21
1918	0.73	0.02	0.0	0.07	0.59	0.29	1.47	1.40	1.16	0.79	1.70	0.96	9.18
1919	0.02	0.15	5.19	3.70	1.00	4.02	0.15	0.72	6.33	0.62	0.55	0.24	22.69
1920	1.38	0.66	0.12	0.0	1.74	2.19	0.81	2.07	2.57	0.89	0.15	0.0	12.58
1921	0.17	0.47	0.74	0.01	1.49	5.58	2.18	0.77	0.26	0.0	0.0	0.0	11.67
1922	0.04	0.16	0.72	1.37	1.50	1.69	0.17	0.15	0.13	0.10	0.53	0.01	6.57
1923	0.44	1.93	0.24	0.96	0.10	1.18	2.59	0.78	5.74	3.14	1.05	1.89	20.04
1924	0.25	0.76	0.36	0.53	0.15	0.0	2.76	0.12	0.0	0.41	0.12	0.31	5.77
1925	0.48	0.0	0.0	0.0	0.54	0.16	4.02	1.58	3.73	0.95	0.0	0.07	11.53
1926	0.88	0.0	1.59	0.86	2.03	1.01	1.44	0.40	3.85	1.50	0.14	1.09	14.79
1927	0.02	0.14	0.10	0.01	0.04	2.00	1.13	0.54	0.17	0.33	0.0	0.35	4.83
1928	0.0	0.84	0.0	0.72	1.92	1.53	0.95	4.36	0.43	3.34	0.31	0.64	15.04
1929	0.03	0.46	0.80	0.0	2.30	1.15	4.70	0.85	0.42	0.58	1.09	0.0	12.39
1930	0.26	0.0	0.96	0.53	0.48	1.72	0.60	1.92	0.55	2.76	0.43	0.26	10.47
1931	0.42	1.19	0.38	4.54	0.70	0.93	0.98	2.71	0.02	0.37	0.38	1.80	14.42
1932	0.65	0.65	1.38	0.51	1.87	1.33	2.06	4.52	4.98	0.57	0.0	0.31	18.83
1933	0.15	0.39	0.0	0.16	0.50	0.63	0.79	3.28	1.67	0.09	1.13	0.0	8.79
1934	0.04	0.04	1.12	0.14	0.89	0.80	0.13	1.48	0.0	0.47	1.80	0.05	6.96
1935	0.06	0.53	0.57	0.39	2.38	0.95	0.41	1.33	2.99	0.05	0.75	0.13	10.54
1936	0.98	0.04	0.09	0.04	2.21	0.94	1.42	0.22	5.15	0.29	0.28	0.16	11.82
1937	0.11	0.21	1.43	1.25	3.88	0.91	0.94	0.33	3.51	0.62	0.08	0.17	13.45
1938	1.15	0.93	0.38	0.12	0.03	1.76	1.56	0.48	1.45	0.96	0.02	0.24	9.08
1939	0.77	0.10	1.15	0.57	0.88	0.66	5.32	1.38	0.65	0.25	0.38	0.70	12.81
1940	0.11	0.77	0.0	1.23	2.71	4.20	1.64	0.79	0.57	0.97	1.02	0.08	14.09
1941	0.49	0.84	2.82	3.95	6.42	0.85	3.83	1.96	7.80	3.51	0.11	0.34	32.92
1942	0.15	0.21	0.17	2.41	0.01	0.56	1.96	3.63	2.50	1.39	0.0	1.78	14.77
1943	0.05	0.0	0.0	0.23	1.17	2.39	0.68	0.22	0.79	0.01	0.58	2.66	8.78
1944	0.90	0.58	0.11	0.07	0.14	1.98	1.52	3.83	0.86	0.89	0.26	0.21	11.35
1945	0.03	0.0	0.19	0.15	0.02	0.33	1.45	1.79	0.79	1.39	0.0	0.74	6.88
1946	1.15	0.07	0.53	0.34	0.28	1.67	1.26	0.94	2.93	1.31	0.36	0.78	11.62
1947	0.81	0.0	0.35	0.48	1.71	0.56	0.13	1.55	0.39	0.52	0.93	0.83	8.26
1948	0.68	1.22	0.64	0.28	0.92	1.57	1.89	1.03	0.21	0.71	0.0	0.15	9.30
1949	1.70	0.42	0.0	0.50	0.75	2.84	3.25	1.33	1.87	1.10	0.01	0.81	14.58
1950	0.0	0.03	0.0	0.14	1.78	2.17	4.69	0.74	5.64	1.82	0.0	0.01	17.02
1951	0.09	0.35	0.33	0.44	0.87	0.39	1.59	1.76	0.02	0.29	0.15	0.61	6.89
1952	0.21	0.21	0.13	1.02	0.30	0.14	2.11	3.17	0.76	0.0	0.55	0.04	8.64
1953	0.24	0.49	0.25	0.72	0.70	0.48	2.48	2.11	0.0	0.30	0.26	0.21	8.24
1954	0.21	0.0	0.0	0.11	2.56	0.09	0.33	1.61	0.47	4.44	0.0	0.27	10.18
1955	0.29	0.0	0.10	0.19	0.41	0.15	2.25	0.61	2.95	1.71	0.05	0.0	8.71
1956	0.02	1.42	0.03	0.03	0.40	0.04	0.54	1.13	0.16	0.54	0.0	0.04	4.35
1957	0.09	0.64	0.80	0.31	0.43	0.06	0.87	1.23	1.18	2.91	0.80	0.0	9.32
1958	1.57	0.84	1.93	0.84	0.77	0.20	0.66	1.27	3.56	0.98	0.19	0.25	13.06
1959	0.02	0.10	0.03	0.59	1.44	0.82	2.98	1.87	0.16	0.52	0.24	0.75	9.52
1960	1.26	0.43	0.04	0.0	1.03	1.24	3.31	0.16	0.45	3.53	0.0	2.12	13.57
1961	0.68	0.04	0.81	0.02	0.44	0.62	1.08	1.37	0.44	0.44	1.62	0.29	7.85
1962	0.38	0.51	0.12	0.09	0.21	0.97	3.44	1.31	3.51	0.50	0.62	0.15	11.81
1963	0.44	0.77	0.0	0.16	0.88	0.60	0.21	2.26	0.62	0.15	0.05	0.16	6.30
1964	0.80	1.25	0.15	0.02	0.30	1.10	0.17	0.57	2.05	0.0	0.33	0.24	6.98
1965	0.12	0.84	0.21	0.38	0.35	1.09	1.50	0.83	0.76	0.05	0.08	0.47	6.68
1966	0.53	0.03	0.25	1.97	0.54	2.35	0.15	2.89	0.97	0.0	0.0	0.0	9.68
1967	0.0	0.20	0.07	0.0	0.11	3.55	0.97	4.00	0.85	0.02	0.22	1.07	11.06
1968	1.50	1.17	1.93	0.06	0.57	0.60	5.50	2.67	0.10	0.41	1.11	0.22	15.84

* Inches.

MONTHLY PRECIPITATION AT ARTESIA*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	0.74	2.31	3.17	1.97	0.28	1.92	6.31	0.29	3.52	0.89	1.31	0.80	23.51
19 6	0.35	0.62	0.66	2.62	0.23	0.0	3.40	0.36	0.0	1.13	2.82	0.85	13.04
19 7	0.14	0.0	0.12	0.34	0.74	1.74	1.72	2.44	0.48	5.53	1.29	0.10	14.64
19 8	0.26	0.28	0.01	1.29	0.07	0.68	2.16	2.87	1.29	0.0	0.70	0.01	9.62
19 9	0.02	0.02	0.97	0.0	0.05	1.05	1.94	2.01	0.40	0.63	0.29	0.31	7.69
1910	0.08	0.0	0.01	0.21	0.27	0.32	0.03	2.04	1.34	0.46	0.66	0.04	5.46
1911	0.60	1.72	0.56	2.30	0.62	1.02	7.76	1.99	0.87	0.92	0.47	0.57	19.40
1912	0.0	0.42	0.03	0.09	0.15	1.17	1.97	0.58	2.77	0.79	0.70	0.85	9.52
1913	0.09	0.42	0.18	1.75	0.93	1.84	0.10	0.48	3.58	0.94	0.88	0.79	11.98
1914	0.04	0.23	0.13	1.04	1.96	1.46	3.70	0.98	0.60	2.99	0.70	1.44	15.27
1915	0.33	0.79	1.44	5.78	0.0	0.49	1.75	0.21	2.20	0.10	0.0	0.48	13.57
1916	0.20	0.0	0.22	1.14	0.07	0.34	2.00	5.95	0.85	2.38	0.48	0.30	13.93
1917	0.15	0.0	0.18	0.0	0.27	0.0	0.0	1.35	1.74	0.0	0.28	0.0	3.97
1918	0.87	0.0	0.0	0.0	0.78	0.52	0.48	1.42	0.29	1.48	1.22	0.45	7.51
1919	0.15	0.02	4.57	1.01	0.62	1.65	1.41	0.37	6.44	1.00	0.58	0.30	18.15
1920	0.81	0.31	0.0	0.0	1.08	3.19	1.82	2.09	1.08	3.60	0.66	0.0	14.64
1921	0.31	1.14	0.0	0.04	1.03	4.89	5.12	1.01	0.96	0.33	0.10	0.01	14.94
1922	0.09	0.04	0.08	2.35	1.67	0.93	0.17	0.41	0.31	0.18	0.77	0.0	7.00
1923	0.38	2.04	0.56	1.20	0.0	3.37	0.77	0.09	0.57	1.88	1.03	2.11	14.00
1924	0.0	0.55	0.43	0.05	0.40	0.0	2.69	0.15	0.23	0.64	0.0	0.35	5.49
1925	0.20	0.0	0.0	0.05	1.36	0.40	2.23	2.98	0.77	1.05	0.0	0.0	9.04
1926	0.92	0.0	1.47	1.68	2.50	0.32	2.83	1.54	3.94	1.14	0.20	1.01	17.55
1927	0.38	0.41	0.03	0.0	0.0	2.35	1.60	0.12	0.24	0.04	0.0	1.42	6.59
1928	0.0	1.23	0.0	0.68	1.74	0.21	3.00	4.86	0.80	1.53	0.54	0.54	15.13
1929	0.0	0.68	0.24	0.01	4.14	2.20	1.51	0.73	1.14	0.72	0.99	0.12	12.48
1930	0.18	0.0	0.12	1.08	2.78	1.85	0.61	1.29	0.06	4.28	0.07	0.19	12.51
1931	0.75	0.98	1.22	4.85	1.02	0.40	0.86	4.13	0.0	0.48	0.72	2.41	17.82
1932	0.63	1.32	1.00	0.50	4.15	0.50	0.20	2.65	7.81	1.42	0.0	0.75	20.93
1933	0.11	0.54	0.0	0.25	0.13	0.73	2.29	0.61	1.29	0.49	0.0	0.0	6.44
1934	0.0	0.0	1.24	0.18	1.52	0.33	0.10	1.74	0.0	0.93	0.13	0.10	6.27
1935	0.0	0.62	0.32	0.63	1.95	0.82	1.58	1.33	2.40	0.0	0.87	0.08	10.60
1936	0.56	0.0	0.18	0.10	3.14	0.10	1.61	0.34	3.59	0.92	0.64	0.08	11.26
1937	0.0	0.35	1.60	0.0	5.05	0.0	1.25	1.05	0.57	1.05	0.10	0.10	11.13
1938	1.01	0.20	0.23	0.18	0.25	3.68	3.21	0.05	1.80	1.19	0.40	0.35	12.55
1939	0.79	0.10	1.08	0.33	1.25	0.15	1.16	1.86	0.30	0.88	0.61	0.60	9.11
1940	0.10	0.75	0.0	0.96	2.19	2.89	1.07	1.30	0.05	0.56	0.96	0.06	10.89
1941	1.67	0.72	2.56	0.85	9.99	0.66	3.88	3.51	9.23	2.05	0.18	0.70	36.31
1942	0.35	0.30	0.22	2.13	0.12	1.32	1.85	2.14	1.18	1.35	0.0	1.90	12.85
1943	0.45	0.02	0.05	0.02	0.64	3.65	1.73	0.95	0.14	0.58	0.55	1.55	10.33
1944	0.64	0.35	0.0	0.05	0.0	1.80	3.30	2.90	3.95	0.25	0.35	0.15	13.75
1945	0.70	0.0	0.0	0.0	0.05	0.0	0.40	2.00	1.15	1.65	0.0	0.45	6.40
1946	0.45	0.0	0.45	0.0	1.80	1.05	3.14	1.36	0.66	1.70	0.53	0.15	11.49
1947	0.68	0.0	0.32	0.25	1.10	0.10	0.15	1.09	0.35	0.32	0.50	0.20	5.06
1948	0.60	1.40	0.10	0.30	0.12	5.94	1.35	0.17	0.04	0.64	0.0	0.44	11.10
1949	1.40	0.05	0.03	0.33	0.22	4.46	1.33	1.82	3.64	0.96	0.0	0.35	14.59
1950	0.0	0.07	0.0	0.06	0.02	2.63	3.36	1.01	2.64	1.01	0.0	0.0	10.80
1951	0.07	0.20	0.45	0.05	0.85	0.05	4.35	0.24	0.0	0.95	0.0	0.15	7.36
1952	0.05	0.30	0.58	0.65	0.85	0.97	1.42	0.58	0.81	0.0	0.53	0.0	6.74
1953	0.14	0.05	0.23	0.68	1.30	0.20	1.70	0.86	0.32	0.66	0.0	0.29	6.43
1954	0.03	0.0	0.0	0.83	0.85	0.29	0.14	3.57	0.05	3.43	0.0	0.12	9.31
1955	0.44	0.0	0.0	0.15	0.63	0.34	3.95	0.45	1.34	1.85	0.24	0.0	9.39
1956	0.05	0.45	0.0	0.04	0.91	2.08	0.81	1.68	0.12	0.87	0.0	0.0	7.01
1957	0.15	0.28	0.26	0.06	0.88	0.07	0.60	0.47	0.07	2.48	0.64	0.0	5.96
1958	1.44	1.14	2.67	1.19	0.14	2.97	1.34	2.06	4.76	1.79	0.70	0.01	20.21
1959	0.0	0.13	0.01	0.19	2.48	0.31	2.15	0.29	0.0	0.23	0.04	0.28	6.11
1960	0.82	0.18	0.14	0.29	0.16	1.18	3.74	0.74	0.20	3.26	0.11	1.69	12.51
1961	0.71	0.16	0.45	0.0	0.48	0.99	0.99	1.10	0.27	0.14	1.41	0.30	7.00
1962	0.45	0.41	0.11	0.67	0.66	0.92	3.31	0.21	2.31	1.39	0.25	0.62	11.31
1963	0.08	0.68	0.0	0.11	0.92	1.59	0.18	2.11	0.10	0.17	0.16	0.05	5.95
1964	0.0	0.23	0.32	0.02	0.81	1.71	0.10	0.80	0.71	0.0	0.17	0.28	5.15
1965	0.02	0.36	0.06	0.05	0.82	0.84	1.64	2.05	0.67	0.11	0.05	1.03	7.70
1966	0.50	0.03	0.58	1.23	0.39	1.07	0.40	6.67	0.59	0.0	0.0	0.0	11.46
1967	0.0	0.15	0.09	0.0	0.16	0.46	0.67	2.06	0.68	0.0	0.65	0.49	5.41
1968	1.73	0.81	0.81	0.27	1.11	0.01	3.94	2.37	0.03	1.05	1.41	0.26	13.80

* Inches.

TABLE D-III

AVERAGE OF MONTHLY PRECIPITATIONS AT ROSWELL AND AT ARTESIA*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	0.64	2.46	3.06	1.92	0.14	1.85	3.64	0.15	2.08	0.63	1.85	0.93	21.37
19 6	0.44	0.54	0.45	2.66	0.34	0.21	2.85	1.09	0.24	0.93	3.44	0.92	14.12
19 7	0.25	0.0	0.06	0.49	0.94	1.88	1.73	2.25	0.72	4.25	1.32	0.12	14.03
19 8	0.26	0.28	0.01	1.29	0.07	0.68	2.16	2.87	1.29	0.0	0.70	0.01	9.62
19 9	0.02	0.02	0.97	0.0	0.05	1.05	1.94	2.01	0.40	0.63	0.29	0.31	7.69
1910	0.09	0.05	0.03	0.14	0.21	0.53	0.30	2.03	0.89	0.41	0.44	0.02	5.16
1911	0.37	1.82	0.42	2.23	2.00	0.73	5.34	1.61	1.29	1.03	0.46	0.56	17.88
1912	0.01	0.87	0.03	0.12	0.24	1.19	1.95	1.69	2.72	0.83	0.56	0.97	11.21
1913	0.34	0.48	0.46	1.48	0.48	3.00	0.46	0.38	3.12	0.89	0.92	0.83	12.87
1914	0.04	0.17	0.13	1.09	2.86	1.45	2.83	1.15	0.32	3.18	0.50	1.61	15.36
1915	0.36	0.87	1.64	5.91	0.59	0.31	1.10	0.99	2.24	0.11	0.0	0.73	14.86
1916	0.32	0.0	0.40	1.12	0.12	0.39	1.52	7.75	0.61	2.34	0.46	0.33	15.37
1917	0.17	0.13	0.23	0.0	0.62	0.0	0.03	2.30	1.42	0.00	0.17	0.0	5.09
1918	0.80	0.01	0.0	0.03	0.68	0.40	0.97	1.41	0.72	1.13	1.46	0.70	8.34
1919	0.08	0.08	4.88	2.35	0.81	2.85	0.78	0.54	6.38	0.81	0.56	0.27	20.42
1920	1.09	0.48	0.06	0.0	1.41	2.69	1.31	2.08	1.82	2.24	0.40	0.0	13.61
1921	0.24	0.80	0.37	0.02	1.26	5.23	3.65	0.89	0.61	0.16	0.05	0.00	13.30
1922	0.06	0.10	0.40	1.86	1.58	1.31	0.17	0.28	0.22	0.14	0.65	0.00	6.78
1923	0.41	1.98	0.40	1.08	0.05	2.27	1.68	0.43	3.15	2.51	1.04	2.00	17.02
1924	0.13	0.65	0.39	0.29	0.27	0.0	2.72	0.13	0.11	0.52	0.06	0.33	5.63
1925	0.34	0.0	0.0	0.02	0.95	0.28	3.12	2.28	2.25	1.00	0.0	0.03	10.28
1926	0.90	0.0	1.53	1.27	2.26	0.66	2.13	0.97	3.89	1.32	0.17	1.05	16.17
1927	0.20	0.27	0.06	0.00	0.02	2.17	1.36	0.33	0.20	0.18	0.0	0.88	5.71
1928	0.0	1.03	0.0	0.70	1.83	0.87	1.97	4.61	0.61	2.43	0.42	0.59	15.08
1929	0.01	0.57	0.52	0.00	3.22	1.67	3.10	0.79	0.78	0.65	1.04	0.06	12.43
1930	0.22	0.0	0.54	0.80	1.63	1.78	0.60	1.60	0.30	3.52	0.25	0.22	11.49
1931	0.58	1.08	0.80	4.69	0.86	0.66	0.92	3.42	0.01	0.42	0.55	2.10	16.12
1932	0.64	0.98	1.19	0.50	3.01	0.91	1.13	3.58	6.39	0.99	0.0	0.53	19.88
1933	0.13	0.46	0.0	0.20	0.31	0.68	1.54	1.94	1.48	0.29	0.56	0.0	7.61
1934	0.02	0.02	1.18	0.16	1.20	0.56	0.11	1.61	0.0	0.70	0.96	0.07	6.61
1935	0.03	0.57	0.44	0.51	2.16	0.88	0.99	1.33	2.69	0.02	0.81	0.10	10.57
1936	0.77	0.02	0.13	0.07	2.67	0.52	1.51	0.28	4.37	0.60	0.46	0.12	11.54
1937	0.05	0.28	1.51	0.63	4.47	0.45	1.09	0.69	2.04	0.83	0.09	0.13	12.29
1938	1.08	0.56	0.30	0.15	0.14	2.72	2.38	0.26	1.62	1.07	0.21	0.29	10.81
1939	0.78	0.10	1.11	0.45	1.06	0.40	3.24	1.62	0.47	0.56	0.49	0.65	10.96
1940	0.10	0.76	0.0	1.09	2.45	3.54	1.35	1.04	0.31	0.76	0.99	0.07	12.49
1941	1.08	0.78	2.69	2.40	8.20	0.75	3.85	2.73	8.51	2.78	0.14	0.52	34.61
1942	0.25	0.25	0.19	2.27	0.06	0.94	1.90	2.88	1.84	1.37	0.0	1.84	13.81
1943	0.25	0.01	0.02	0.12	0.90	3.02	1.20	0.58	0.46	0.29	0.56	2.10	9.55
1944	0.77	0.46	0.05	0.06	0.07	1.89	2.41	3.36	2.40	0.57	0.30	0.18	12.55
1945	0.36	0.0	0.09	0.07	0.03	0.16	0.92	1.89	0.97	1.52	0.0	0.59	6.64
1946	0.80	0.03	0.49	0.17	1.04	1.36	2.20	1.15	1.89	1.50	0.44	0.46	11.55
1947	0.74	0.0	0.33	0.36	1.40	0.33	0.14	1.32	0.37	0.42	0.71	0.51	6.66
1948	0.64	1.31	0.37	0.29	0.52	3.75	1.62	0.60	0.12	0.67	0.0	0.29	10.20
1949	1.55	0.23	0.01	0.41	0.48	3.65	2.29	1.57	2.75	1.03	0.00	0.58	14.58
1950	0.0	0.05	0.0	0.10	0.90	2.40	4.02	0.87	4.14	1.41	0.0	0.00	13.91
1951	0.08	0.27	0.39	0.24	0.86	0.22	2.97	1.00	0.01	0.62	0.07	0.38	7.12
1952	0.13	0.25	0.35	0.83	0.57	0.55	1.76	1.87	0.78	0.0	0.54	0.02	7.69
1953	0.19	0.27	0.24	0.70	1.00	0.34	2.09	1.48	0.16	0.48	0.13	0.25	7.33
1954	0.12	0.0	0.0	0.47	1.70	0.19	0.23	2.59	0.26	3.93	0.0	0.19	9.74
1955	0.36	0.0	0.05	0.17	0.52	0.24	3.10	0.53	2.14	1.78	0.14	0.0	9.05
1956	0.03	0.93	0.01	0.03	0.65	1.06	0.67	1.40	0.14	0.70	0.0	0.02	5.68
1957	0.12	0.46	0.53	0.18	0.65	0.06	0.73	0.85	0.62	2.69	0.72	0.0	7.64
1958	1.50	0.99	2.30	1.01	0.45	1.58	1.00	1.66	4.16	1.38	0.44	0.13	16.63
1959	0.01	0.11	0.02	0.39	1.96	0.56	2.56	1.08	0.08	0.37	0.14	0.51	7.81
1960	1.04	0.30	0.09	0.14	0.59	1.21	3.52	0.45	0.32	3.39	0.05	1.90	13.04
1961	0.69	0.10	0.63	0.01	0.46	0.80	1.03	1.23	0.35	0.29	1.51	0.29	7.42
1962	0.41	0.46	0.11	0.38	0.43	0.94	3.37	0.76	2.91	0.94	0.43	0.38	11.56
1963	0.26	0.72	0.0	0.13	0.90	0.99	0.19	2.18	0.36	0.16	0.10	0.10	6.12
1964	0.40	0.74	0.23	0.02	0.55	1.40	0.13	0.68	1.38	0.0	0.25	0.26	6.06
1965	0.07	0.60	0.13	0.21	0.58	0.96	1.57	1.44	0.71	0.08	0.06	0.75	7.19
1966	0.51	0.03	0.41	1.60	0.46	1.71	0.27	4.78	0.78	0.0	0.0	0.0	10.57
1967	0.0	0.17	0.08	0.0	0.13	2.00	0.82	3.03	0.76	0.01	0.43	0.78	8.23
1968	1.61	0.99	1.37	0.16	0.84	0.30	4.72	2.52	0.06	0.73	1.26	0.24	14.82

* Inches.

TABLE D-IV

MONTHLY EFFECTIVE PRECIPITATION AT ROSWELL*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	0.53	2.39	2.64	1.76	0.01	1.68	0.93	0.01	0.61	0.35	2.21	1.01	14.12
19 6	0.51	0.45	0.23	2.45	0.44	0.40	2.13	1.72	0.46	0.70	3.34	0.95	13.77
19 7	0.34	0.0	0.0	0.61	1.10	1.90	1.64	1.92	0.92	2.66	1.29	0.14	12.53
19 8	0.25	0.27	0.01	1.23	0.07	0.65	2.01	2.58	1.23	0.0	0.67	0.01	8.97
19 9	0.02	0.02	0.93	0.0	0.05	1.00	1.82	1.88	0.38	0.60	0.28	0.30	7.27
1910	0.09	0.10	0.05	0.08	0.14	0.72	0.54	1.90	0.42	0.34	0.21	0.01	4.61
1911	0.13	1.80	0.28	2.01	2.94	0.43	2.62	1.17	1.62	1.09	0.44	0.54	15.06
1912	0.03	1.26	0.04	0.14	0.32	1.15	1.82	2.52	2.42	0.83	0.41	1.05	12.01
1913	0.57	0.53	0.71	1.15	0.03	3.40	0.78	0.27	2.42	0.81	0.93	0.84	12.45
1914	0.04	0.10	0.13	1.09	3.18	1.38	1.85	1.27	0.05	2.93	0.29	1.68	13.98
1915	0.37	0.91	1.74	4.03	1.13	0.13	0.43	1.67	2.12	0.11	0.0	0.95	13.58
1916	0.42	0.0	0.55	1.06	0.16	0.42	0.99	4.01	0.35	2.14	0.42	0.34	10.87
1917	0.18	0.25	0.28	0.0	0.93	0.0	0.07	2.85	1.06	0.01	0.06	0.0	5.67
1918	0.70	0.02	0.0	0.07	0.56	0.28	1.40	1.33	1.11	0.76	1.61	0.92	8.74
1919	0.02	0.14	3.82	3.14	0.96	3.32	0.14	0.69	4.07	0.59	0.53	0.23	17.65
1920	1.31	0.63	0.11	0.0	1.64	2.03	0.78	1.93	2.35	0.85	0.14	0.0	11.78
1921	0.16	0.45	0.71	0.01	1.42	3.93	2.03	0.74	0.25	0.0	0.0	0.0	9.69
1922	0.04	0.15	0.69	1.30	1.42	1.60	0.16	0.14	0.12	0.09	0.51	0.01	6.24
1923	0.42	1.81	0.23	0.92	0.09	1.13	2.36	0.75	3.97	2.77	1.00	1.78	17.23
1924	0.24	0.73	0.34	0.51	0.14	0.0	2.49	0.11	0.0	0.39	0.11	0.30	5.37
1925	0.46	0.0	0.0	0.0	0.52	0.15	3.32	1.50	3.16	0.91	0.0	0.07	10.08
1926	0.84	0.0	1.51	0.82	1.90	0.97	1.37	0.38	3.23	1.42	0.13	1.04	13.61
1927	0.02	0.13	0.09	0.01	0.04	1.87	1.08	0.52	0.16	0.31	0.0	0.33	4.57
1928	0.0	0.80	0.0	0.69	1.80	1.45	0.91	3.49	0.41	2.91	0.30	0.61	13.38
1929	0.03	0.44	0.77	0.0	2.13	1.10	3.65	0.81	0.40	0.55	1.04	0.0	10.91
1930	0.25	0.0	0.92	0.51	0.46	1.62	0.57	1.80	0.53	2.49	0.41	0.25	9.81
1931	0.40	1.14	0.36	3.58	0.67	0.89	0.94	2.46	0.02	0.35	0.36	1.70	12.86
1932	0.62	0.62	1.31	0.49	1.76	1.27	1.92	3.57	3.75	0.54	0.0	0.30	16.15
1933	0.14	0.37	0.0	0.15	0.48	0.60	0.76	2.87	1.58	0.09	1.08	0.0	8.12
1934	0.04	0.04	1.07	0.13	0.85	0.77	0.12	1.41	0.0	0.45	1.70	0.05	6.62
1935	0.06	0.51	0.54	0.37	2.19	0.91	0.39	1.27	2.67	0.05	0.72	0.12	9.79
1936	0.94	0.04	0.09	0.04	2.05	0.90	1.35	0.21	3.81	0.28	0.27	0.15	10.11
1937	0.10	0.20	1.36	1.19	3.24	0.87	0.90	0.31	3.02	0.59	0.08	0.16	12.04
1938	1.10	0.89	0.36	0.11	0.03	1.66	1.48	0.46	1.38	0.92	0.02	0.23	8.63
1939	0.74	0.09	1.10	0.54	0.84	0.63	3.86	1.31	0.62	0.24	0.36	0.67	11.02
1940	0.10	0.74	0.0	1.17	2.46	3.42	1.55	0.76	0.54	0.93	0.98	0.08	12.72
1941	0.47	0.80	2.54	3.28	4.08	0.81	3.22	1.84	4.10	3.02	0.10	0.32	24.59
1942	0.14	0.20	0.16	2.22	0.01	0.54	1.84	3.10	2.29	1.32	0.0	1.68	13.49
1943	0.05	0.0	0.0	0.22	1.12	2.20	0.65	0.21	0.76	0.01	0.55	2.42	8.18
1944	0.86	0.55	0.10	0.07	0.13	1.85	1.44	3.22	0.82	0.85	0.25	0.20	10.35
1945	0.03	0.0	0.18	0.14	0.02	0.31	1.38	1.69	0.76	1.32	0.0	0.71	6.54
1946	1.10	0.07	0.51	0.32	0.27	1.58	1.20	0.90	2.62	1.25	0.34	0.75	10.90
1947	0.78	0.0	0.33	0.46	1.62	0.54	0.12	1.47	0.37	0.50	0.89	0.79	7.86
1948	0.65	1.16	0.61	0.27	0.88	1.49	1.78	0.98	0.20	0.68	0.0	0.14	8.84
1949	1.61	0.40	0.0	0.48	0.72	2.56	2.85	1.27	1.76	1.05	0.01	0.78	13.47
1950	0.0	0.03	0.0	0.13	1.68	2.02	3.64	0.71	3.95	1.71	0.0	0.01	13.88
1951	0.09	0.33	0.31	0.42	0.83	0.37	1.51	1.66	0.02	0.28	0.14	0.58	6.55
1952	0.20	0.20	0.12	0.98	0.29	0.13	1.97	2.79	0.73	0.0	0.53	0.04	7.97
1953	0.23	0.47	0.24	0.69	0.67	0.46	2.27	1.97	0.0	0.29	0.25	0.20	7.73
1954	0.20	0.0	0.0	0.10	2.34	0.09	0.31	1.52	0.45	3.53	0.0	0.26	8.80
1955	0.28	0.0	0.09	0.18	0.39	0.14	2.09	0.58	2.64	1.62	0.05	0.0	8.05
1956	0.02	1.35	0.03	0.03	0.38	0.04	0.52	1.08	0.15	0.52	0.0	0.04	4.15
1957	0.09	0.61	0.77	0.30	0.41	0.06	0.83	1.17	1.13	2.61	0.77	0.0	8.73
1958	1.49	0.80	1.81	0.80	0.74	0.19	0.63	1.21	3.05	0.94	0.18	0.24	12.08
1959	0.02	0.09	0.03	0.56	1.37	0.78	2.66	1.76	0.15	0.50	0.23	0.72	8.87
1960	1.20	0.41	0.04	0.0	0.98	1.18	2.89	0.15	0.43	3.03	0.0	1.98	12.30
1961	0.65	0.04	0.78	0.02	0.42	0.59	1.03	1.30	0.42	0.42	1.53	0.28	7.48
1962	0.36	0.49	0.11	0.09	0.20	0.93	2.98	1.25	3.02	0.48	0.59	0.14	10.63
1963	0.42	0.74	0.0	0.15	0.84	0.57	0.20	2.09	0.59	0.14	0.05	0.15	5.95
1964	0.77	1.19	0.14	0.02	0.29	1.05	0.16	0.54	1.92	0.0	0.31	0.23	6.62
1965	0.11	0.80	0.20	0.36	0.33	1.04	1.42	0.79	0.73	0.05	0.08	0.45	6.37
1966	0.51	0.03	0.24	1.85	0.52	2.17	0.14	2.59	0.93	0.0	0.0	0.0	8.97
1967	0.0	0.19	0.07	0.0	0.10	3.05	0.93	3.31	0.81	0.02	0.21	1.02	9.71
1968	1.42	1.12	1.81	0.06	0.54	0.57	3.91	2.42	0.09	0.39	1.06	0.21	13.62

* Inches.

TABLE D-V

MONTHLY PRECIPITATION AT ARTESIA*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	0.71	2.14	2.79	1.85	0.27	1.80	4.06	0.28	3.03	0.85	1.25	0.77	19.79
19 6	0.33	0.59	0.63	2.39	0.22	0.0	2.95	0.34	0.0	1.08	2.54	0.81	11.89
19 7	0.13	0.0	0.11	0.32	0.71	1.64	1.62	2.24	0.46	3.92	1.23	0.09	12.49
19 8	0.25	0.27	0.01	1.23	0.07	0.65	2.01	2.58	1.23	0.0	0.67	0.01	8.97
19 9	0.02	0.02	0.93	0.0	0.05	1.00	1.82	1.88	0.38	0.60	0.28	0.30	7.27
1910	0.08	0.0	0.01	0.20	0.26	0.30	0.03	1.91	1.28	0.44	0.63	0.04	5.17
1911	0.57	1.62	0.54	2.13	0.59	0.98	4.11	1.86	0.83	0.88	0.45	0.54	15.10
1912	0.0	0.40	0.03	0.09	0.14	1.12	1.85	0.55	2.50	0.76	0.67	0.81	8.92
1913	0.09	0.40	0.17	1.65	0.89	1.73	0.09	0.46	3.07	0.90	0.84	0.76	11.04
1914	0.04	0.22	0.12	0.99	1.84	1.39	3.14	0.94	0.57	2.67	0.67	1.37	13.95
1915	0.31	0.76	1.37	3.98	0.0	0.47	1.65	0.20	2.04	0.09	0.0	0.46	11.33
1916	0.19	0.0	0.21	1.09	0.07	0.32	1.87	4.01	0.81	2.19	0.46	0.29	11.51
1917	0.14	0.0	0.17	0.0	0.26	0.0	0.0	1.29	1.64	0.0	0.27	0.0	3.77
1918	0.83	0.0	0.0	0.0	0.75	0.50	0.46	1.35	0.28	1.41	1.16	0.43	7.16
1919	0.14	0.02	3.59	0.97	0.59	1.59	1.34	0.35	4.08	0.96	0.55	0.29	14.47
1920	0.78	0.30	0.0	0.0	1.03	2.81	1.71	1.95	1.03	3.08	0.63	0.0	13.31
1921	0.30	1.09	0.0	0.04	0.98	3.72	3.80	0.97	0.92	0.31	0.09	0.01	12.23
1922	0.09	0.04	0.08	2.17	1.58	0.89	0.16	0.39	0.30	0.17	0.74	0.0	6.59
1923	0.36	1.91	0.54	1.15	0.0	2.93	0.74	0.09	0.54	1.77	0.98	1.97	12.96
1924	0.0	0.53	0.41	0.05	0.38	0.0	2.44	0.14	0.22	0.61	0.0	0.33	5.11
1925	0.19	0.0	0.0	0.05	1.29	0.38	2.07	2.66	0.74	1.00	0.0	0.0	8.38
1926	0.88	0.0	1.40	1.59	2.29	0.30	2.55	1.46	3.28	1.09	0.19	0.97	15.99
1927	0.36	0.39	0.03	0.0	0.0	2.17	1.52	0.11	0.23	0.04	0.0	1.35	6.20
1928	0.0	1.17	0.0	0.65	1.64	0.20	2.67	3.71	0.77	1.45	0.52	0.52	13.30
1929	0.0	0.65	0.23	0.01	3.39	2.04	1.43	0.70	1.09	0.69	0.95	0.11	11.29
1930	0.17	0.0	0.11	1.03	2.51	1.74	0.58	1.23	0.06	3.46	0.07	0.18	11.14
1931	0.72	0.94	1.16	3.70	0.98	0.38	0.82	3.38	0.0	0.46	0.69	2.22	15.45
1932	0.60	1.26	0.96	0.48	3.39	0.48	0.19	2.41	4.10	1.35	0.0	0.72	15.93
1933	0.10	0.52	0.0	0.24	0.12	0.70	2.12	0.58	1.23	0.47	0.0	0.0	6.08
1934	0.0	0.0	1.18	0.17	1.44	0.31	0.09	1.64	0.0	0.89	0.12	0.09	5.96
1935	0.0	0.59	0.30	0.60	1.83	0.78	1.50	1.27	2.21	0.0	0.83	0.08	10.00
1936	0.54	0.0	0.17	0.09	2.77	0.09	1.52	0.32	3.07	0.88	0.61	0.08	10.16
1937	0.0	0.33	1.52	0.0	3.78	0.0	1.19	1.00	0.54	1.00	0.09	0.09	9.56
1938	0.97	0.19	0.22	0.17	0.24	3.13	2.82	0.05	1.70	1.14	0.38	0.33	11.33
1939	0.76	0.09	1.03	0.31	1.19	0.14	1.11	1.75	0.29	0.84	0.58	0.57	8.67
1940	0.09	0.72	0.0	0.92	2.03	2.59	1.02	1.24	0.05	0.54	0.92	0.06	10.18
1941	1.58	0.69	2.34	0.81	4.02	0.63	3.24	3.02	4.02	1.92	0.17	0.67	23.11
1942	0.33	0.29	0.21	1.98	0.11	1.26	1.74	1.99	1.13	1.29	0.0	1.78	12.11
1943	0.43	0.02	0.05	0.02	0.61	3.11	1.63	0.91	0.13	0.55	0.53	1.47	9.46
1944	0.61	0.33	0.0	0.05	0.0	1.70	2.88	2.60	3.28	0.24	0.33	0.14	12.17
1945	0.67	0.0	0.0	0.0	0.05	0.0	0.38	1.87	1.10	1.56	0.0	0.43	6.06
1946	0.43	0.0	0.43	0.0	1.70	1.00	2.77	1.29	0.82	1.61	0.51	0.14	10.70
1947	0.65	0.0	0.30	0.24	1.05	0.09	0.14	1.04	0.33	0.30	0.48	0.19	4.83
1948	0.57	1.33	0.09	0.29	0.11	4.01	1.29	0.16	0.04	0.61	0.0	0.42	8.93
1949	1.33	0.05	0.03	0.31	0.21	3.54	1.27	1.71	3.10	0.92	0.0	0.33	12.81
1950	0.0	0.07	0.0	0.06	0.02	2.39	2.92	0.97	2.40	0.97	0.0	0.0	9.79
1951	0.07	0.19	0.43	0.05	0.81	0.05	3.49	0.23	0.0	0.91	0.0	0.14	6.36
1952	0.05	0.29	0.55	0.62	0.81	0.93	1.35	0.55	0.78	0.0	0.51	0.0	6.44
1953	0.13	0.05	0.22	0.65	1.24	0.19	1.61	0.82	0.30	0.63	0.0	0.28	6.12
1954	0.03	0.0	0.0	0.79	0.81	0.28	0.13	3.06	0.05	2.97	0.0	0.11	8.23
1955	0.42	0.0	0.0	0.14	0.60	0.32	3.28	0.43	1.28	1.74	0.23	0.0	8.45
1956	0.05	0.43	0.0	0.04	0.87	1.94	0.78	1.59	0.11	0.83	0.0	0.0	6.64
1957	0.14	0.27	0.25	0.06	0.84	0.07	0.57	0.45	0.07	2.27	0.61	0.0	5.60
1958	1.37	1.09	2.42	1.14	0.13	2.65	1.28	1.92	3.67	1.69	0.67	0.01	18.04
1959	0.0	0.12	0.01	0.18	2.27	0.30	2.00	0.28	0.0	0.22	0.04	0.27	5.68
1960	0.78	0.17	0.13	0.28	0.15	1.13	3.16	0.71	0.19	2.86	0.10	1.60	11.26
1961	0.68	0.15	0.43	0.0	0.46	0.95	0.95	1.05	0.26	0.13	1.34	0.29	6.68
1962	0.43	0.39	0.10	0.64	0.63	0.88	2.89	0.20	2.14	1.32	0.24	0.59	10.46
1963	0.08	0.65	0.0	0.10	0.88	1.32	0.17	1.97	0.09	0.16	0.15	0.05	5.63
1964	0.0	0.22	0.30	0.02	0.78	1.62	0.09	0.77	0.68	0.0	0.16	0.27	4.90
1965	0.02	0.34	0.06	0.05	0.78	0.80	1.55	1.92	0.64	0.10	0.05	0.98	7.30
1966	0.48	0.03	0.55	1.17	0.37	1.02	0.38	4.10	0.56	0.0	0.0	0.0	8.67
1967	0.0	0.14	0.09	0.0	0.15	0.44	0.64	1.92	0.65	0.0	0.62	0.47	5.12
1968	1.63	0.78	0.78	0.26	1.06	0.01	3.28	2.18	0.03	1.00	1.34	0.25	12.59

* Inches.

MONTHLY AVERAGE TEMPERATURE AT ROSWELL, °F

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	38.6	30.7	53.0	56.2	67.2	76.2	75.0	77.6	71.4	56.4	48.4	34.0	57.1
19 6	39.2	43.4	50.4	58.0	68.0	77.0	75.2	74.7	70.8	55.2	42.4	44.9	58.3
19 7	40.8	49.6	58.4	58.4	62.8	73.6	77.9	78.0	70.4	59.0	44.4	42.6	59.7
19 8	40.8	43.4	57.0	58.9	66.1	75.4	75.1	75.2	67.8	56.8	45.3	41.6	58.6
19 9	44.4	44.9	47.4	58.9	65.4	76.0	79.0	76.2	68.3	57.5	52.0	34.2	58.7
1910	42.4	41.6	57.2	59.6	67.6	77.2	80.6	77.7	72.5	57.4	50.0	41.8	64.8
1911	47.8	42.7	55.0	60.5	67.5	76.0	77.5	76.7	73.6	57.2	43.6	35.2	59.4
1912	39.0	40.5	47.6	56.4	67.7	73.2	78.9	77.0	66.4	57.0	45.2	34.3	56.9
1913	34.8	40.6	47.8	58.0	68.6	72.4	78.4	77.6	65.7	57.0	50.8	37.0	57.4
1914	47.0	42.8	49.1	58.4	66.9	75.8	77.4	76.8	71.2	58.4	50.2	33.1	58.9
1915	36.2	43.8	41.6	58.0	64.8	74.9	77.6	74.0	69.5	60.0	50.1	42.1	57.7
1916	42.1	48.4	56.6	57.2	68.4	78.2	77.8	74.0	68.2	57.6	44.5	39.3	59.4
1917	39.0	44.0	48.6	57.3	62.2	74.8	80.4	76.6	70.6	58.1	51.4	42.2	58.8
1918	32.8	46.2	54.6	57.0	67.8	77.0	79.0	76.6	67.6	60.8	43.9	33.2	58.0
1919	34.5	44.0	49.3	59.3	66.3	70.3	76.2	77.9	70.0	59.5	46.4	40.0	57.8
1920	37.4	46.0	49.2	55.1	67.2	72.9	78.1	74.0	71.6	59.5	45.9	40.6	58.1
1921	43.2	44.9	54.4	57.6	68.4	72.0	76.3	77.6	74.2	62.6	51.6	46.1	60.7
1922	37.1	43.2	49.3	58.4	68.3	74.8	79.6	79.6	72.7	59.6	47.0	44.4	59.5
1923	46.5	41.4	47.0	59.6	68.8	77.4	78.5	77.0	70.3	56.6	46.6	33.0	58.6
1924	36.8	43.2	46.8	57.0	65.1	79.7	78.0	79.2	70.0	60.2	51.2	36.0	58.6
1925	36.2	49.0	54.6	63.9	68.9	78.2	79.6	74.4	70.2	57.0	47.3	37.0	59.7
1926	35.2	48.6	46.5	55.6	65.6	75.4	76.4	77.2	71.8	61.1	48.6	39.2	59.3
1927	43.6	49.2	51.0	61.7	72.6	75.0	79.0	78.2	71.1	61.4	54.6	36.0	61.1
1928	42.8	41.2	53.8	57.2	67.7	77.5	79.0	74.4	68.8	62.6	46.3	40.4	59.3
1929	39.7	37.4	49.8	60.6	65.2	76.2	78.0	77.0	70.9	60.2	40.6	40.9	58.0
1930	33.2	49.9	47.4	63.6	66.0	76.6	79.4	78.9	73.3	60.4	47.2	38.2	59.5
1931	40.0	45.4	47.5	56.7	65.0	77.4	79.0	75.5	76.2	63.3	48.7	37.5	59.4
1932	38.8	50.0	45.8	60.3	67.0	76.2	80.0	77.6	67.6	56.6	47.2	34.7	58.5
1933	41.2	37.4	53.0	56.0	66.9	77.4	80.6	77.8	75.0	63.7	50.8	46.8	60.6
1934	41.1	46.6	51.7	62.4	71.4	79.7	82.6	80.4	71.8	65.9	52.2	43.6	62.4
1935	45.0	44.4	55.2	61.2	63.8	75.9	78.2	78.8	66.7	62.1	48.5	40.7	60.0
1936	39.0	44.8	53.9	60.4	68.5	78.2	78.6	78.3	69.8	57.9	45.8	42.6	59.8
1937	36.7	44.4	46.8	60.8	69.2	77.0	80.0	79.8	72.8	62.1	47.8	40.2	59.8
1938	41.2	47.7	54.6	59.4	68.4	77.0	77.4	78.6	71.6	62.2	45.0	41.9	60.4
1939	42.7	39.2	53.0	61.0	69.7	79.1	78.9	76.4	73.2	60.4	46.0	45.1	60.4
1940	36.2	44.4	52.6	59.0	68.4	74.2	79.8	76.8	72.8	62.2	46.6	46.2	59.9
1941	42.0	46.4	47.6	57.6	67.0	72.8	76.8	76.8	69.7	60.8	49.8	43.0	59.2
1942	40.1	41.4	49.0	58.6	67.6	77.0	79.0	76.6	69.0	59.9	52.9	45.2	59.7
1943	42.2	48.2	51.0	64.4	68.3	78.0	78.8	82.0	71.1	59.6	47.4	37.2	60.7
1944	38.8	45.5	51.0	57.6	68.4	77.8	79.8	79.0	69.0	61.2	48.7	38.4	59.6
1945	42.8	47.6	53.0	56.4	71.1	76.2	78.2	79.2	71.8	59.8	52.0	41.0	60.8
1946	38.4	45.0	54.2	64.9	67.6	77.9	79.8	79.9	72.4	62.5	47.0	44.7	61.2
1947	38.6	42.0	50.4	58.2	69.3	77.1	80.0	77.8	72.2	63.6	43.8	38.6	59.3
1948	33.8	41.3	45.8	62.9	69.1	78.1	79.2	78.6	70.9	59.0	44.6	44.0	58.9
1949	28.5	43.2	53.4	57.7	69.7	76.6	79.8	76.6	70.9	57.3	52.5	39.0	58.8
1950	45.1	48.3	51.5	60.1	69.2	79.1	77.9	78.0	70.8	65.4	48.8	43.4	61.5
1951	38.3	43.2	49.7	58.0	69.4	77.7	83.0	80.4	72.6	62.9	45.6	41.9	60.2
1952	45.6	45.0	48.3	59.2	68.3	80.9	79.0	81.6	70.8	58.8	44.2	39.9	60.1
1953	47.4	42.8	55.4	59.6	66.6	81.5	82.0	79.1	72.0	59.9	48.7	35.8	60.9
1954	42.3	50.3	51.4	64.8	68.3	78.9	82.7	79.2	74.4	61.7	50.1	41.0	62.1
1955	38.8	41.1	51.3	61.0	68.6	75.7	78.2	78.7	73.0	61.2	48.1	42.5	59.9
1956	42.1	37.4	52.5	57.7	71.5	81.1	80.5	78.3	73.5	63.1	44.6	41.7	60.3
1957	41.6	52.3	51.5	57.0	66.6	77.9	82.6	79.4	70.4	58.1	44.8	43.7	60.5
1958	39.5	45.0	46.3	58.3	70.3	81.3	83.1	80.5	71.3	58.6	49.1	40.5	60.3
1959	39.2	43.6	49.7	59.9	70.0	78.8	79.3	80.8	73.1	59.0	45.0	42.4	60.1
1960	37.5	40.0	51.1	62.4	69.0	80.0	78.9	78.9	71.2	59.8	47.8	29.3	58.8
1961	34.3	42.4	49.9	58.0	69.3	76.4	78.1	76.8	69.6	59.1	40.4	40.0	57.9
1962	33.7	48.8	47.4	60.2	70.5	75.4	78.2	77.4	69.9	58.4	46.0	42.2	58.8
1963	31.9	43.0	50.3	61.3	69.6	76.7	81.9	78.5	72.4	63.2	47.9	35.1	59.3
1964	34.7	35.3	48.6	58.2	69.8	76.7	81.7	80.4	72.1	60.9	48.1	39.7	58.9
1965	44.2	40.1	45.3	62.0	69.0	77.0	80.9	76.7	70.7	59.0	52.5	42.0	60.0
1966	30.8	38.5	51.6	59.8	70.0	76.6	84.3	76.5	70.9	56.8	50.6	39.5	58.8
1967	41.2	44.3	57.2	65.5	68.5	75.3	80.0	75.0	68.8	59.3	47.5	35.3	59.8
1968	39.1	41.9	44.7	52.0	62.2	72.6	72.8	71.0	64.9	58.1	42.2	38.2	57.6

MONTHLY AVERAGE TEMPERATURE AT ARTESIA, °F

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	38.6	30.7	53.0	56.2	67.2	76.2	75.0	77.6	71.4	56.4	48.4	34.0	57.1
19 6	40.0	44.4	52.0	58.8	68.5	76.6	75.2	75.3	71.2	56.6	45.8	46.6	59.2
19 7	40.8	49.6	58.4	58.4	62.8	73.6	77.9	78.0	70.4	59.0	44.4	42.6	59.7
19 8	40.8	43.4	57.0	58.9	66.1	75.4	75.1	75.2	67.8	56.8	45.3	41.6	58.6
19 9	44.4	44.9	47.4	58.9	65.4	76.0	79.0	76.2	68.3	57.5	52.0	34.2	58.7
1910	46.6	44.7	59.0	61.5	69.4	79.1	82.2	80.4	74.1	59.8	53.3	43.6	62.8
1911	50.2	46.0	57.0	62.6	69.8	77.2	76.4	76.0	74.2	60.6	47.8	38.4	61.4
1912	42.4	43.9	51.2	58.3	69.6	74.6	80.2	79.8	98.9	59.7	47.7	38.7	59.6
1913	38.8	43.4	49.8	59.6	70.6	74.0	79.2	79.0	67.3	59.4	52.9	38.4	59.4
1914	49.2	45.5	51.7	61.2	69.2	77.9	79.8	80.2	74.4	61.2	52.5	37.4	61.7
1915	40.0	46.6	46.8	61.8	68.6	78.2	80.2	77.5	72.6	62.2	52.1	45.4	61.0
1916	47.4	50.8	59.4	60.3	71.3	81.2	80.8	76.8	70.5	61.4	46.4	42.7	62.4
1917	43.2	47.2	52.0	60.8	66.0	77.6	83.0	79.8	73.3	60.7	52.4	43.5	61.6
1918	36.5	50.4	57.2	60.4	69.9	80.2	83.1	80.0	71.6	63.2	46.5	38.2	61.4
1919	37.2	46.4	52.3	63.2	70.1	74.6	80.6	82.0	73.1	63.3	50.0	43.7	61.4
1920	40.4	49.8	52.4	59.3	70.6	74.8	80.9	76.1	74.3	61.5	48.0	41.3	60.8
1921	44.8	47.8	56.4	58.5	65.8	73.2	76.4	78.4	75.8	63.2	52.6	48.0	61.7
1922	38.4	47.0	51.1	59.9	69.6	74.4	81.1	80.4	73.6	60.8	48.2	45.4	60.8
1923	47.0	43.2	49.4	60.7	69.7	77.9	79.7	78.2	71.6	59.2	47.6	36.0	60.0
1924	37.4	45.9	48.0	59.0	70.2	80.4	78.8	80.2	71.0	62.0	52.0	39.0	60.3
1925	36.7	49.7	56.2	64.8	70.1	78.6	80.8	75.0	72.2	59.6	47.4	37.7	60.7
1926	37.4	49.4	48.0	57.4	65.8	75.1	76.6	77.1	72.6	62.8	48.6	39.0	59.2
1927	44.4	50.6	51.6	62.4	72.1	76.0	79.5	78.2	70.1	61.0	54.4	36.4	61.4
1928	40.8	40.9	57.0	59.6	69.4	80.2	81.7	75.9	69.4	64.2	47.8	41.8	60.7
1929	42.0	41.0	51.4	63.4	67.9	77.2	78.9	78.7	70.4	62.4	43.4	41.8	59.9
1930	34.6	50.9	49.2	64.8	66.2	77.0	81.0	79.0	74.2	61.9	48.6	38.6	60.5
1931	41.2	46.9	50.0	57.0	66.9	78.4	80.0	75.8	76.1	63.1	49.5	38.9	60.3
1932	42.3	49.6	48.7	57.1	63.6	73.4	77.8	79.7	71.4	59.8	47.0	32.4	58.6
1933	39.0	36.9	53.3	56.2	63.8	76.8	80.8	77.6	75.6	65.2	52.2	47.0	60.4
1934	40.6	47.1	52.6	63.4	73.2	80.2	81.2	80.6	73.0	65.4	50.8	42.4	62.5
1935	44.7	44.5	54.2	62.4	65.8	76.7	78.6	80.0	68.0	62.5	48.8	40.2	60.5
1936	39.0	42.6	55.4	60.2	69.2	78.1	79.2	76.6	71.4	57.4	45.8	40.8	59.7
1937	34.9	43.0	46.0	61.4	70.2	77.1	78.8	79.6	73.2	61.4	47.9	40.9	59.6
1938	40.8	47.4	55.0	60.9	69.0	76.8	77.8	78.2	70.9	62.0	44.8	39.8	60.3
1939	41.2	38.2	52.2	60.8	69.6	79.3	79.4	76.1	72.0	59.6	44.2	43.7	59.6
1940	34.6	43.1	53.0	61.3	70.3	75.0	80.1	77.5	73.4	62.1	46.7	45.1	60.2
1941	41.4	46.9	48.1	58.7	67.2	72.7	77.0	77.2	69.8	62.2	49.8	42.2	59.4
1942	39.2	40.4	47.6	60.3	68.6	75.4	77.2	75.8	67.0	57.4	50.4	42.6	58.5
1943	40.8	46.0	48.6	63.0	67.4	78.2	79.2	81.8	71.0	58.3	46.0	36.7	59.8
1944	38.0	44.4	50.0	57.7	68.6	78.6	79.2	78.2	68.4	60.0	46.8	36.3	58.8
1945	40.7	45.6	51.4	57.4	71.7	76.6	78.1	80.0	72.0	60.2	51.8	41.2	60.6
1946	38.9	47.2	56.2	65.7	68.4	79.4	80.4	80.6	74.2	63.5	47.1	44.1	62.1
1947	38.4	41.7	50.4	59.8	71.5	79.8	81.6	78.9	73.4	66.5	46.4	40.8	60.8
1948	36.1	44.2	48.8	66.7	72.0	80.0	81.5	81.7	73.2	62.3	46.3	47.7	61.7
1949	32.8	46.5	55.6	59.1	71.3	77.7	81.2	76.6	72.1	59.7	54.4	41.8	60.7
1950	47.0	50.5	53.8	63.4	70.3	80.0	78.2	78.9	72.2	66.7	51.0	44.7	63.1
1951	41.3	43.9	52.1	59.9	70.8	79.3	83.0	81.2	74.9	65.4	48.4	45.3	62.1
1952	47.7	45.8	50.5	60.7	69.5	81.5	78.7	82.9	72.4	61.0	46.2	40.5	61.4
1953	49.1	43.4	56.3	61.7	68.1	82.0	82.6	79.1	72.0	64.1	53.4	37.8	62.5
1954	46.0	51.4	52.5	65.8	68.5	78.5	83.5	81.5	77.3	65.5	53.5	44.1	64.0
1955	40.2	43.1	54.5	63.2	70.6	77.2	78.6	79.8	74.9	63.0	51.3	45.7	61.8
1956	43.8	40.4	54.3	59.9	73.2	81.6	81.7	78.6	74.5	65.8	44.6	41.7	61.7
1957	44.2	53.5	53.8	59.4	67.9	79.4	83.6	81.4	72.1	59.9	46.3	45.4	62.2
1958	39.7	45.6	46.6	59.2	71.7	81.6	83.1	80.9	72.7	59.1	50.4	42.1	61.1
1959	40.5	44.3	51.7	60.7	71.7	79.5	79.9	82.1	76.4	61.9	46.8	43.6	61.6
1960	39.8	42.9	51.9	64.8	70.4	81.7	79.3	80.0	75.0	63.0	51.9	35.4	61.3
1961	38.5	47.3	53.3	61.4	71.6	78.9	81.0	80.1	73.1	63.8	45.1	44.4	61.5
1962	37.7	52.7	50.0	63.5	73.7	78.4	81.0	82.4	74.4	64.2	52.4	43.4	62.8
1963	35.9	47.1	53.9	65.8	72.4	78.8	84.3	80.8	75.3	66.9	52.4	39.2	62.7
1964	39.8	39.6	52.2	61.8	72.9	78.2	83.9	82.2	73.8	63.8	51.9	43.7	62.0
1965	45.8	43.2	47.3	64.5	70.8	78.6	82.9	78.7	72.9	61.9	56.0	44.4	62.3
1966	35.8	40.7	53.6	61.2	69.5	76.5	84.3	77.0	72.9	59.7	50.6	39.5	59.3
1967	41.2	44.3	57.2	64.8	67.3	76.5	80.8	76.9	70.7	62.4	52.0	39.7	60.4
1968	43.3	47.0	51.7	57.9	67.9	77.2	76.1	75.2	66.2	60.3	47.4	39.1	59.1

TABLE D-VIII

MONTHLY CONSUMPTIVE-USE FACTORS FOR ROSWELL

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	2.75	2.12	4.40	4.93	6.49	7.36	7.37	7.31	5.95	4.46	3.41	2.36	58.92
19 6	2.79	3.00	4.18	5.09	6.57	7.44	7.39	7.04	5.90	4.36	2.98	3.12	59.87
19 7	2.90	3.43	4.85	5.12	6.07	7.11	7.66	7.35	5.87	4.66	3.13	2.96	61.11
19 8	2.90	3.10	4.74	5.15	6.37	7.26	7.37	7.06	5.64	4.48	3.18	2.88	60.14
19 9	3.16	3.11	3.93	5.17	6.32	7.34	7.77	7.18	5.70	4.54	3.66	2.38	60.25
1910	3.02	2.88	4.75	5.23	6.53	7.46	7.92	7.32	6.05	4.53	3.52	2.91	62.11
1911	3.40	2.95	4.56	5.31	6.52	7.34	7.62	7.23	6.14	4.52	3.07	2.45	61.11
1912	2.77	2.90	3.96	4.93	6.53	7.05	7.74	7.23	5.52	4.49	3.17	2.38	58.67
1913	2.48	2.81	3.97	5.09	6.63	6.99	7.71	7.31	5.48	4.50	3.58	2.57	59.11
1914	3.35	2.96	4.08	5.12	6.46	7.32	7.61	7.23	5.94	4.61	3.53	2.30	60.52
1915	2.58	3.03	3.45	5.09	6.26	7.24	7.63	6.97	5.80	4.74	3.53	2.93	59.23
1916	2.99	3.46	4.71	5.00	6.59	7.53	7.63	6.95	5.67	4.54	3.12	2.72	60.93
1917	2.78	3.04	4.03	5.03	6.01	7.23	7.90	7.22	5.89	4.59	3.62	2.93	60.26
1918	2.34	3.20	4.53	5.00	6.55	7.44	7.77	7.22	5.64	4.80	3.09	2.31	59.87
1919	2.46	3.04	4.09	5.20	6.40	6.79	7.49	7.34	5.84	4.70	3.27	2.78	59.40
1920	2.66	3.29	4.09	4.82	6.48	7.02	7.66	6.95	5.96	4.69	3.22	2.81	59.65
1921	3.08	3.11	4.52	5.05	6.61	6.96	7.50	7.31	6.19	4.95	3.63	3.20	62.09
1922	2.64	2.99	4.09	5.12	6.60	7.23	7.82	7.50	6.06	4.71	3.31	3.09	61.16
1923	3.31	2.86	3.90	5.23	6.65	7.48	7.72	7.25	5.86	4.47	3.28	2.29	60.30
1924	2.61	3.09	3.89	4.99	6.28	7.68	7.65	7.44	5.82	4.74	3.59	2.49	60.28
1925	2.58	3.39	4.53	5.60	6.66	7.55	7.82	7.01	5.85	4.50	3.33	2.57	61.41
1926	2.51	3.36	3.86	4.88	6.34	7.28	7.51	7.27	5.99	4.83	3.42	2.72	59.97
1927	3.10	3.40	4.23	5.41	7.01	7.24	7.77	7.37	5.93	4.85	3.84	2.50	62.67
1928	3.04	2.95	4.48	5.00	6.53	7.46	7.75	6.99	5.72	4.93	3.25	2.80	60.90
1929	2.83	2.59	4.13	5.31	6.30	7.36	7.67	7.25	5.91	4.76	2.86	2.84	59.81
1930	2.36	3.45	3.93	5.58	6.38	7.40	7.81	7.43	6.11	4.77	3.32	2.65	61.20
1931	2.85	3.14	3.94	4.97	6.28	7.48	7.77	7.11	6.36	5.00	3.43	2.61	60.93
1932	2.75	3.57	3.81	5.28	6.46	7.34	7.85	7.29	5.62	4.46	3.31	2.40	60.15
1933	2.93	2.59	4.40	4.91	6.46	7.48	7.92	7.33	6.25	5.03	3.58	3.25	62.14
1934	2.93	3.22	4.29	5.47	6.90	7.70	8.12	7.57	5.99	5.21	3.67	3.03	64.10
1935	3.20	3.07	4.58	5.37	6.16	7.33	7.69	7.42	5.56	4.91	3.41	2.83	61.54
1936	2.77	3.20	4.48	5.28	6.60	7.53	7.71	7.35	5.81	4.56	3.22	2.95	61.48
1937	2.61	3.07	3.88	5.33	6.68	7.44	7.86	7.52	6.07	4.91	3.37	2.79	61.54
1938	2.93	3.30	4.53	5.21	6.61	7.44	7.61	7.40	5.97	4.91	3.17	2.91	62.00
1939	3.04	2.71	4.40	5.35	6.73	7.64	7.76	7.20	6.10	4.77	3.24	3.13	62.08
1940	2.57	3.17	4.38	5.16	6.59	7.15	7.83	7.21	6.06	4.90	3.27	3.20	61.49
1941	2.99	3.21	3.95	5.05	6.47	7.03	7.55	7.23	5.81	4.80	3.51	2.99	60.60
1942	2.86	2.86	4.07	5.14	6.53	7.44	7.77	7.22	5.75	4.73	3.72	3.14	61.23
1943	3.00	3.34	4.23	5.65	6.60	7.53	7.75	7.72	5.93	4.71	3.34	2.59	62.38
1944	2.75	3.25	4.24	5.04	6.59	7.49	7.83	7.42	5.74	4.82	3.42	2.66	61.27
1945	3.05	3.29	4.40	4.95	6.87	7.36	7.69	7.46	5.99	4.72	3.66	2.85	62.29
1946	2.73	3.11	4.50	5.69	6.53	7.53	7.84	7.53	6.04	4.94	3.31	3.11	62.86
1947	2.75	2.91	4.18	5.10	6.69	7.45	7.86	7.33	6.02	5.02	3.08	2.68	61.09
1948	2.40	2.95	3.81	5.50	6.66	7.52	7.77	7.38	5.90	4.65	3.13	3.05	60.73
1949	2.03	2.99	4.43	5.06	6.73	7.40	7.84	7.22	5.91	4.53	3.70	2.71	60.55
1950	3.21	3.34	4.27	5.27	6.68	7.64	7.66	7.35	5.90	5.17	3.44	3.02	62.95
1951	2.73	2.99	4.13	5.09	6.70	7.51	8.16	7.57	6.05	4.97	3.21	2.91	62.02
1952	3.24	3.22	4.02	5.18	6.58	7.79	7.75	7.66	5.89	4.63	3.10	2.77	61.83
1953	3.37	2.96	4.60	5.23	6.43	7.87	8.06	7.45	6.00	4.73	3.43	2.49	62.63
1954	3.01	3.48	4.27	5.68	6.60	7.62	8.13	7.46	6.20	4.87	3.53	2.85	63.71
1955	2.76	2.84	4.26	5.35	6.63	7.31	7.69	7.41	6.09	4.83	3.39	2.95	61.52
1956	2.99	2.67	4.37	5.05	6.89	7.81	7.90	7.35	6.12	4.97	3.13	2.89	62.14
1957	2.96	3.62	4.27	5.00	6.43	7.53	8.12	7.48	5.87	4.59	3.15	3.04	62.06
1958	2.81	3.11	3.84	5.11	6.79	7.85	8.17	7.58	5.95	4.63	3.46	2.81	62.13
1959	2.79	3.02	4.13	5.25	6.76	7.61	7.80	7.61	6.10	4.66	3.17	2.95	61.84
1960	2.66	2.86	4.25	5.46	6.65	7.70	7.74	7.41	5.92	4.71	3.36	2.03	60.76
1961	2.44	2.93	4.14	5.09	6.69	7.38	7.68	7.23	5.80	4.67	2.84	2.78	59.69
1962	2.40	3.38	3.93	5.28	6.81	7.28	7.69	7.29	5.83	4.61	3.24	2.93	60.68
1963	2.27	2.98	4.17	5.38	6.72	7.41	8.05	7.39	6.04	4.99	3.37	2.44	61.22
1964	2.46	2.52	4.04	5.09	6.73	7.39	8.01	7.55	6.00	4.80	3.38	2.75	60.73
1965	3.15	2.77	3.76	5.44	6.67	7.44	7.95	7.23	5.90	4.66	3.70	2.92	61.57
1966	2.19	2.66	4.28	5.24	6.76	7.40	8.29	7.21	5.91	4.49	3.56	2.75	60.75
1967	2.93	3.07	4.75	5.74	6.62	7.27	7.86	7.06	5.74	4.68	3.34	2.45	61.53
1968	2.78	3.00	3.72	4.55	6.00	6.99	7.14	6.67	5.40	4.58	2.96	2.65	56.42

TABLE D-IX

MONTHLY CONSUMPTIVE-USE FACTORS FOR ARTESIA

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
19 5	2.68	2.14	4.42	5.01	6.52	7.38	7.39	7.25	5.80	4.48	3.43	2.38	58.89
19 6	2.78	3.09	4.34	5.24	6.64	7.41	7.41	7.03	5.79	4.50	3.25	3.27	60.76
19 7	2.84	3.45	4.87	5.21	6.09	7.12	7.68	7.29	5.72	4.69	3.15	2.99	61.10
19 8	2.83	3.12	4.74	5.24	6.40	7.28	7.39	7.01	5.50	4.50	3.21	2.91	60.14
19 9	3.09	3.13	3.95	5.25	6.34	7.36	7.79	7.12	5.55	4.57	3.69	2.40	60.23
1910	3.24	3.11	4.92	5.49	6.73	7.66	8.10	7.51	6.02	4.75	3.78	3.06	64.37
1911	3.49	3.20	4.75	5.58	6.77	7.47	7.53	7.10	6.03	4.82	3.39	2.69	62.83
1912	2.94	3.16	4.26	5.19	6.74	7.21	7.89	7.44	8.02	4.73	3.38	2.71	63.66
1913	2.70	3.02	4.15	5.32	6.85	7.16	7.81	7.38	5.47	4.72	3.75	2.69	61.02
1914	3.42	3.17	4.31	5.46	6.71	7.54	7.87	7.49	6.05	4.87	3.72	2.62	63.23
1915	2.78	3.24	3.90	5.51	6.65	7.57	7.91	7.24	5.90	4.94	3.69	3.18	62.53
1916	3.28	3.66	4.94	5.37	6.90	7.84	7.95	7.16	5.72	4.87	3.29	2.98	63.96
1917	3.00	3.29	4.34	5.42	6.40	7.51	8.18	7.45	5.96	4.83	3.72	3.05	63.15
1918	2.54	3.51	4.77	5.39	6.78	7.76	8.19	7.47	5.82	5.02	3.30	2.68	63.23
1919	2.59	3.23	4.36	5.64	6.80	7.22	7.95	7.66	5.94	5.03	3.54	3.06	63.02
1920	2.80	3.59	4.36	5.28	6.83	7.23	7.96	7.09	6.03	4.88	3.40	2.89	62.32
1921	3.11	3.33	4.70	5.22	6.38	7.09	7.53	7.32	6.16	5.02	3.73	3.36	62.97
1922	2.67	3.27	4.26	5.34	6.75	7.20	8.00	7.51	5.98	4.83	3.42	3.18	62.42
1923	3.27	3.01	4.12	5.41	6.76	7.54	7.86	7.30	5.82	4.71	3.37	2.52	61.70
1924	2.59	3.30	3.99	5.25	6.80	7.77	7.75	7.47	5.76	4.92	3.68	2.73	62.01
1925	2.55	3.46	4.69	5.78	6.80	7.61	7.97	7.00	5.87	4.74	3.36	2.64	62.47
1926	2.60	3.44	4.00	5.12	6.38	7.27	7.55	7.20	5.90	4.99	3.45	2.73	60.64
1927	3.09	3.52	4.30	5.57	6.99	7.36	7.84	7.30	5.70	4.85	3.86	2.55	62.93
1928	2.83	2.94	4.74	5.30	6.72	7.75	8.04	7.07	5.63	5.09	3.38	2.92	62.42
1929	2.92	2.85	4.29	5.66	6.59	7.47	7.78	7.35	5.72	4.96	3.08	2.93	61.60
1930	2.40	3.54	4.10	5.78	6.42	7.45	7.99	7.38	6.03	4.92	3.45	2.71	62.18
1931	2.86	3.26	4.17	5.08	6.49	7.59	7.89	7.08	6.19	5.02	3.51	2.73	61.87
1932	2.93	3.57	4.05	5.08	6.16	7.09	7.66	7.43	5.79	4.74	3.33	2.26	60.09
1933	2.71	2.57	4.45	5.01	6.19	7.43	7.97	7.25	6.15	5.18	3.70	3.29	61.90
1934	2.82	3.28	4.39	5.66	7.10	7.76	8.01	7.53	5.93	5.20	3.60	2.97	64.25
1935	3.11	3.10	4.52	5.57	6.38	7.42	7.75	7.47	5.53	4.97	3.46	2.82	62.09
1936	2.70	3.07	4.61	5.36	6.70	7.54	7.79	7.14	5.79	4.55	3.24	2.85	61.35
1937	2.43	2.99	3.84	5.48	6.81	7.46	7.77	7.43	5.95	4.88	3.40	2.87	61.30
1938	2.84	3.30	4.59	5.43	6.69	7.43	7.67	7.30	5.76	4.93	3.18	2.79	61.92
1939	2.86	2.66	4.35	5.42	6.75	7.68	7.83	7.11	5.85	4.74	3.13	3.06	61.45
1940	2.40	3.10	4.41	5.46	6.81	7.24	7.88	7.22	5.95	4.92	3.31	3.15	61.86
1941	2.88	3.26	4.01	5.24	6.52	7.04	7.59	7.21	5.67	4.94	3.53	2.96	60.86
1942	2.72	2.81	3.97	5.38	6.65	7.30	7.61	7.08	5.45	4.56	3.57	2.99	60.10
1943	2.84	3.20	4.05	5.62	6.54	7.57	7.81	7.64	5.77	4.63	3.26	2.57	61.51
1944	2.63	3.20	4.16	5.14	6.64	7.59	7.79	7.29	5.55	4.76	3.31	2.54	60.60
1945	2.83	3.17	4.29	5.12	6.95	7.41	7.70	7.47	5.85	4.79	3.67	2.89	62.15
1946	2.70	3.29	4.69	5.86	6.63	7.69	7.93	7.53	6.03	5.05	3.34	3.09	63.82
1947	2.67	2.90	4.20	5.33	6.94	7.72	8.05	7.37	5.97	5.29	3.29	2.86	62.59
1948	2.50	3.18	4.06	5.94	6.97	7.73	8.02	7.61	5.94	4.94	3.28	3.33	63.50
1949	2.28	3.24	4.64	5.27	6.92	7.52	8.01	7.15	5.86	4.75	3.86	2.93	62.42
1950	3.27	3.51	4.49	5.66	6.82	7.74	7.71	7.37	5.87	5.30	3.62	3.13	64.49
1951	2.87	3.06	4.35	5.34	6.87	7.68	8.18	7.58	6.09	5.20	3.43	3.18	63.82
1952	3.31	3.30	4.20	5.40	6.73	7.87	7.74	7.73	5.87	4.84	3.27	2.83	63.09
1953	3.41	3.02	4.70	5.50	6.61	7.94	8.14	7.39	5.85	5.10	3.79	2.65	64.09
1954	3.20	3.58	4.38	5.87	6.64	7.60	8.23	7.61	6.28	5.21	3.79	3.09	65.49
1955	2.79	3.00	4.55	5.64	6.85	7.47	7.75	7.45	6.09	5.01	3.64	3.20	63.44
1956	3.04	2.91	4.52	5.33	7.09	7.88	8.04	7.33	6.04	5.22	3.16	2.91	63.46
1957	3.07	3.72	4.49	5.30	6.59	7.69	8.24	7.60	5.86	4.76	3.28	3.18	63.79
1958	2.76	3.17	3.89	5.28	6.95	7.90	8.19	7.56	5.91	4.70	3.57	2.95	62.84
1959	2.81	3.08	4.31	5.41	6.95	7.70	7.88	7.67	6.21	4.92	3.32	3.06	63.33
1960	2.76	3.09	4.32	5.77	6.81	7.89	7.80	7.46	6.08	5.00	3.67	2.47	63.13
1961	2.68	3.29	4.45	5.48	6.95	7.64	7.99	7.48	5.94	5.07	3.20	3.11	63.27
1962	2.62	3.67	4.17	5.66	7.15	7.59	7.99	7.70	6.05	5.10	3.72	3.04	64.45
1963	2.50	3.28	4.50	5.87	7.02	7.63	8.31	7.55	6.12	5.32	3.72	2.75	64.55
1964	2.76	2.85	4.34	5.50	7.06	7.55	8.26	7.66	5.99	5.06	3.67	3.05	63.75
1965	3.18	3.01	3.94	5.75	6.87	7.61	8.17	7.35	5.93	4.92	3.97	3.11	63.82
1966	2.49	2.83	4.47	5.46	6.74	7.41	8.31	7.19	5.93	4.75	3.59	2.77	61.93
1967	2.86	3.08	4.77	5.78	6.53	7.41	7.97	7.18	5.75	4.96	3.69	2.78	62.76
1968	3.00	3.38	4.30	5.15	6.57	7.46	7.49	7.01	5.37	4.78	3.36	2.73	60.61

TABLE D-X

MONTHLY CONSUMPTIVE USE MINUS EFFECTIVE PRECIPITATION FOR ALFALFA NEAR ROSWELL*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	
19 5	-0.53	-2.39	-1.27	1.54	5.18	4.95	6.44	7.30	4.15	2.54	-1.90	-1.01	25.01	2.08
19 6	-0.51	-0.45	1.07	0.96	4.82	6.29	5.27	5.31	4.27	2.14	-3.07	-0.95	25.14	2.10
19 7	-0.34	0.0	1.50	2.82	3.75	4.50	6.02	5.42	3.78	0.37	-1.01	-0.14	26.67	2.22
19 8	-0.25	-0.27	1.46	2.22	5.03	5.88	5.36	4.48	3.28	2.91	-0.38	-0.01	29.73	2.48
19 9	-0.02	-0.02	0.29	3.46	5.01	5.60	5.95	5.30	4.18	2.35	0.05	-0.30	31.85	2.65
1910	-0.09	-0.10	1.42	3.43	5.08	5.99	7.38	5.42	4.42	2.60	0.11	-0.01	35.65	2.97
1911	-0.13	-1.80	1.14	1.55	2.28	6.18	5.00	6.05	3.30	1.85	-0.16	-0.54	24.70	2.06
1912	-0.03	-1.26	1.19	3.16	4.90	5.19	5.92	4.71	1.99	2.09	-0.12	-1.05	26.69	2.22
1913	-0.57	-0.53	0.52	2.25	5.27	2.89	6.92	7.04	1.96	2.11	-0.61	-0.84	26.43	2.20
1914	-0.04	-0.10	1.13	2.34	1.99	5.21	5.76	5.97	4.70	0.07	0.03	-1.68	25.39	2.12
1915	-0.37	-0.91	-0.67	-0.62	3.88	6.38	7.20	5.30	2.52	2.97	0.32	-0.95	25.05	2.09
1916	-0.42	0.0	0.91	2.29	5.11	6.36	6.64	2.94	4.19	0.81	-0.14	-0.34	28.34	2.36
1917	-0.18	-0.25	0.97	3.37	3.88	6.50	7.84	4.37	3.65	2.97	0.27	0.0	33.39	2.78
1918	-0.70	-0.02	1.40	3.28	4.68	6.42	6.37	5.88	3.40	2.37	-1.33	-0.92	30.84	2.57
1919	-0.02	-0.14	-2.55	0.35	4.17	2.79	7.35	6.65	0.60	2.46	-0.23	-0.23	21.19	1.77
1920	-1.31	-0.63	1.16	3.23	3.54	4.28	6.89	5.02	2.42	2.20	0.15	0.0	26.93	2.24
1921	-0.16	-0.45	0.69	3.38	3.87	2.33	5.47	6.57	4.70	3.21	0.33	0.0	29.95	2.50
1922	-0.04	-0.15	0.58	2.13	3.85	4.91	7.66	7.36	4.73	2.97	-0.21	-0.01	33.77	2.81
1923	-0.42	-1.81	0.98	2.58	5.22	5.60	5.35	6.51	0.72	0.13	-0.71	-1.78	22.39	1.87
1924	-0.24	-0.73	0.86	2.84	4.88	6.91	5.16	7.32	4.66	2.69	0.21	-0.30	34.27	2.86
1925	-0.46	0.0	1.40	3.75	4.81	6.65	4.50	5.51	1.53	2.02	0.30	-0.07	29.95	2.50
1926	-0.84	0.0	-0.31	2.44	3.17	5.59	6.14	6.89	1.56	1.71	0.18	-1.04	25.50	2.12
1927	-0.02	-0.13	1.22	3.62	5.57	4.65	6.69	6.85	4.58	2.84	0.35	-0.33	35.87	2.99
1928	0.0	-0.80	1.39	2.66	3.42	5.27	6.84	3.49	4.17	0.30	-0.00	-0.61	26.12	2.18
1929	-0.03	-0.44	0.52	3.56	2.91	5.53	4.02	6.44	4.33	2.54	-0.78	0.0	28.59	2.38
1930	-0.25	0.0	0.30	3.23	4.64	5.04	7.23	5.63	4.36	0.61	-0.11	-0.25	30.44	2.54
1931	-0.40	-1.14	0.86	-0.25	4.35	5.84	6.83	4.66	5.07	2.90	-0.05	-1.70	26.97	2.25
1932	-0.62	-0.62	-0.13	3.05	3.41	5.34	5.92	3.72	0.75	2.35	0.30	-0.30	23.17	1.93
1933	-0.14	-0.37	1.36	3.14	4.69	6.13	7.17	4.46	3.42	3.19	-0.76	0.0	32.29	2.69
1934	-0.04	-0.04	0.26	3.53	4.67	6.16	8.00	6.17	4.79	2.94	-1.37	-0.05	35.03	2.92
1935	-0.06	-0.51	0.88	3.22	2.74	5.69	7.30	6.16	1.78	3.14	-0.41	-0.12	29.81	2.48
1936	-0.94	-0.04	1.30	3.50	3.23	5.88	6.36	7.14	0.84	2.69	0.02	-0.15	29.84	2.49
1937	-0.10	-0.20	-0.16	2.38	2.10	5.82	6.96	7.20	1.84	2.60	0.23	-0.16	28.51	2.38
1938	-1.10	-0.89	1.04	3.38	5.26	5.03	6.13	6.95	3.40	2.28	0.27	-0.23	31.51	2.63
1939	-0.74	-0.09	0.27	3.04	4.54	6.25	3.89	5.88	4.26	2.86	-0.07	-0.67	29.43	2.45
1940	-0.10	-0.74	1.36	2.29	2.82	3.02	6.28	6.46	4.30	2.26	-0.68	-0.08	27.17	2.26
1941	-0.47	-0.80	-1.32	0.10	1.10	5.52	4.33	5.40	0.55	0.10	0.21	-0.32	14.40	1.20
1942	-0.14	-0.20	1.10	1.23	5.21	6.16	5.93	4.12	2.31	1.75	0.34	-1.68	26.13	2.18
1943	-0.05	0.0	1.31	3.57	4.16	4.58	7.10	7.52	3.99	3.05	-0.25	-2.42	32.55	2.71
1944	-0.86	-0.55	1.21	3.31	5.14	4.89	6.39	4.20	3.77	2.28	0.06	-0.20	29.64	2.47
1945	-0.03	0.0	1.18	3.17	5.48	6.31	6.31	5.77	4.03	1.75	0.33	-0.71	33.60	2.80
1946	-1.10	-0.07	0.89	3.49	4.96	5.19	6.64	6.63	2.21	1.96	-0.05	-0.75	30.01	2.50
1947	-0.78	0.0	0.96	2.96	3.74	6.17	7.74	5.86	4.45	2.77	-0.61	-0.79	32.46	2.71
1948	-0.65	-1.16	0.57	3.42	4.45	5.28	5.99	6.40	4.52	2.34	0.28	-0.14	31.30	2.61
1949	-1.61	-0.40	1.37	2.91	4.67	4.10	5.00	5.95	2.97	1.89	0.32	-0.78	26.41	2.20
1950	0.0	-0.03	1.33	3.40	3.67	4.86	4.02	6.64	0.78	1.64	0.31	-0.01	26.60	2.22
1951	-0.09	-0.33	0.96	2.99	4.53	6.38	6.65	5.91	4.82	2.95	0.15	-0.58	34.35	2.86
1952	-0.20	-0.20	1.12	2.50	4.98	6.88	5.78	4.87	3.99	3.01	-0.25	-0.04	32.44	2.70
1953	-0.23	-0.47	1.19	2.81	4.48	6.63	5.79	5.48	4.80	2.79	0.06	-0.20	33.13	2.76
1954	-0.20	0.0	1.32	3.70	2.94	6.77	7.81	5.94	4.52	-0.36	0.32	-0.26	32.50	2.71
1955	-0.28	0.0	1.23	3.40	4.91	6.44	5.60	6.83	2.23	1.53	0.26	0.0	32.15	2.68
1956	-0.02	-1.35	1.33	3.35	5.13	6.99	7.38	6.27	4.74	2.72	0.28	-0.04	36.79	3.07
1957	-0.09	-0.61	0.56	3.05	4.74	6.72	7.29	6.31	3.57	0.38	-0.48	0.0	31.43	2.62
1958	-1.49	-0.80	-0.62	2.62	4.70	6.88	7.54	6.37	1.70	2.07	0.13	-0.24	28.86	2.41
1959	-0.02	-0.09	1.25	2.96	4.04	6.07	5.14	5.85	4.73	2.53	0.06	-0.72	31.79	2.65
1960	-1.20	-0.41	1.28	3.66	4.34	5.75	4.85	7.26	4.31	0.03	0.30	-1.98	28.19	2.35
1961	-0.65	-0.04	0.51	3.39	4.94	6.05	6.65	5.93	4.22	2.61	-1.28	-0.28	32.05	2.67
1962	-0.36	-0.49	1.11	3.45	5.25	5.63	4.71	6.04	1.64	2.52	-0.30	-0.14	29.06	2.42
1963	-0.42	-0.74	1.29	3.45	4.54	6.09	7.85	5.30	4.24	3.10	0.26	-0.15	34.82	2.90
1964	-0.77	-1.19	1.11	3.39	5.10	5.60	7.85	7.00	2.88	3.12	-0.01	-0.23	33.86	2.82
1965	-0.11	-0.80	0.97	3.28	5.00	5.65	6.53	6.43	3.99	2.98	0.26	-0.45	33.72	2.81
1966	-0.51	-0.03	1.09	1.67	4.89	4.49	8.14	4.61	3.80	2.92	0.32	0.0	31.41	2.62
1967	0.0	-0.19	1.41	3.85	5.19	3.50	6.94	3.75	3.78	3.03	0.09	-1.02	30.32	2.53
1968	-1.42	-1.12	-0.66	2.99	4.25	5.72	3.23	4.24	4.22	2.58	-0.79	-0.21	23.04	1.92

* Inches, total inches, and feet.

MONTHLY CONSUMPTIVE USE MINUS EFFECTIVE PRECIPITATION FOR COTTON NEAR ROSWELL*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	
19 5	-0.53	-2.39	-2.64	-0.03	2.59	2.74	5.71	7.30	5.04	2.23	-2.21	-1.01	16.81	1.40
19 6	-0.51	-0.45	-0.23	-0.67	2.19	4.06	4.53	5.31	5.15	1.83	-3.34	-0.95	16.93	1.41
19 7	-0.34	0.0	0.0	1.18	1.33	2.37	5.25	5.42	4.66	0.04	-1.29	-0.14	18.47	1.54
19 8	-0.25	-0.27	-0.01	0.57	2.48	3.71	4.62	4.48	4.13	2.60	-0.67	-0.01	21.39	1.78
19 9	-0.02	-0.02	-0.93	1.81	2.48	3.40	5.17	5.30	5.03	2.03	-0.28	-0.30	23.68	1.97
1910	-0.09	-0.10	-0.05	1.75	2.47	3.76	6.59	5.42	5.32	2.29	-0.21	-0.01	27.13	2.26
1911	-0.13	-1.80	-0.28	-0.15	-0.33	3.98	4.23	6.05	4.22	1.53	-0.44	-0.54	16.34	1.36
1912	-0.03	-1.26	-0.04	1.58	2.29	3.07	5.15	4.71	2.82	1.77	-0.41	-1.05	18.61	1.55
1913	-0.57	-0.53	-0.71	0.63	2.62	0.80	6.15	7.04	2.78	1.80	-0.93	-0.84	18.24	1.52
1914	-0.04	-0.10	-0.13	0.70	-0.60	3.02	5.00	5.97	5.59	-0.25	-0.29	-1.68	17.19	1.43
1915	-0.37	-0.91	-1.74	-2.25	1.38	4.21	6.44	5.30	3.39	2.64	0.0	-0.95	17.13	1.43
1916	-0.42	0.0	-0.55	0.69	2.48	4.10	5.87	2.94	5.04	0.50	-0.42	-0.34	19.87	1.66
1917	-0.18	-0.25	-0.28	1.76	1.48	4.34	7.05	4.37	4.53	2.65	-0.06	0.0	25.41	2.12
1918	-0.70	-0.02	0.0	1.68	2.06	4.19	5.59	5.88	4.25	2.03	-1.61	-0.92	22.44	1.87
1919	-0.02	-0.14	-3.82	-1.32	1.61	0.75	6.60	6.65	1.48	2.13	-0.53	-0.23	13.16	1.10
1920	-1.31	-0.63	-0.11	1.69	0.95	2.18	6.12	5.02	3.31	1.87	-0.14	0.0	18.93	1.58
1921	-0.16	-0.45	-0.71	1.76	1.23	0.24	4.72	6.57	5.63	2.87	0.0	0.0	21.71	1.81
1922	-0.04	-0.15	-0.69	0.49	1.21	2.74	6.88	7.36	5.64	2.64	-0.51	-0.01	25.56	2.13
1923	-0.42	-1.81	-0.23	0.91	2.56	3.36	4.58	6.51	1.60	-0.18	-1.00	-1.78	14.11	1.18
1924	-0.24	-0.73	-0.34	1.24	2.37	4.61	4.39	7.32	5.53	2.36	-0.11	-0.30	26.10	2.18
1925	-0.46	0.0	0.0	1.96	2.15	4.38	3.72	5.51	2.41	1.70	0.0	-0.07	21.30	1.78
1926	-0.84	0.0	-1.51	0.88	0.64	3.40	5.39	6.89	2.46	1.38	-0.13	-1.04	17.52	1.46
1927	-0.02	-0.13	-0.09	1.88	2.77	2.48	5.91	6.85	5.47	2.50	0.0	-0.33	27.28	2.27
1928	0.0	-0.80	0.0	1.06	0.81	3.03	6.07	3.49	5.03	-0.05	-0.30	-0.61	17.72	1.48
1929	-0.03	-0.44	-0.77	1.86	0.39	3.32	3.26	6.44	5.22	2.20	-1.04	0.0	20.41	1.70
1930	-0.25	0.0	-0.92	1.45	2.09	2.82	6.45	5.63	5.28	0.27	-0.41	-0.25	22.17	1.85
1931	-0.40	-1.14	-0.36	-1.84	1.84	3.60	6.05	4.66	6.02	2.55	-0.36	-1.70	18.92	1.58
1932	-0.62	-0.62	-1.31	1.36	0.83	3.14	5.14	3.72	1.59	2.04	0.0	-0.30	14.96	1.25
1933	-0.14	-0.37	0.0	1.57	2.11	3.88	6.37	4.46	4.36	2.83	-1.08	0.0	23.99	2.00
1934	-0.04	-0.04	-1.07	1.78	1.91	3.85	7.18	6.17	5.69	2.57	-1.70	-0.05	26.27	2.19
1935	-0.06	-0.51	-0.54	1.51	0.27	3.49	6.53	6.16	2.62	2.80	-0.72	-0.12	21.42	1.78
1936	-0.94	-0.04	-0.09	1.81	0.59	3.62	5.59	7.14	1.71	2.37	-0.27	-0.15	21.35	1.78
1937	-0.10	-0.20	-1.36	0.67	-0.57	3.59	6.18	7.20	2.75	2.25	-0.08	-0.16	20.18	1.68
1938	-1.10	-0.89	-0.36	1.71	2.61	2.80	5.37	6.95	4.29	1.93	-0.02	-0.23	23.07	1.92
1939	-0.74	-0.09	-1.10	1.33	1.85	3.95	3.12	5.88	5.18	2.53	-0.36	-0.67	20.88	1.74
1940	-0.10	-0.74	0.0	0.63	0.18	0.87	5.49	6.46	5.21	1.92	-0.98	-0.08	18.87	1.57
1941	-0.47	-0.80	-2.54	-1.52	-1.49	3.41	3.58	5.40	1.42	-0.24	-0.10	-0.32	6.32	0.53
1942	-0.14	-0.20	-0.16	-0.42	2.60	3.93	5.15	4.12	3.18	1.42	0.0	-1.68	17.80	1.48
1943	-0.05	0.0	0.0	1.76	1.52	2.32	6.32	7.52	4.88	2.72	-0.55	-2.42	24.02	2.00
1944	-0.86	-0.55	-0.10	1.70	2.50	2.64	5.60	4.20	4.63	1.95	-0.25	-0.20	21.26	1.77
1945	-0.03	0.0	-0.18	1.59	2.73	4.10	5.54	5.77	4.93	1.42	0.0	-0.71	25.17	2.10
1946	-1.10	-0.07	-0.51	1.67	2.35	2.94	5.86	6.63	3.11	1.62	-0.34	-0.75	21.40	1.78
1947	-0.78	0.0	-0.33	1.33	1.06	3.93	6.95	5.86	5.35	2.42	-0.89	-0.79	24.11	2.01
1948	-0.65	-1.16	-0.61	1.66	1.78	3.02	5.22	6.40	5.40	2.02	0.0	-0.14	22.93	1.91
1949	-1.61	-0.40	0.0	1.29	1.98	1.88	4.21	5.95	3.86	1.57	-0.01	-0.78	17.96	1.50
1950	0.0	-0.03	0.0	1.71	1.00	2.57	3.25	6.64	1.66	1.28	0.0	-0.01	18.07	1.51
1951	-0.09	-0.33	-0.31	1.36	1.85	4.13	5.84	5.91	5.73	2.61	-0.14	-0.58	25.97	2.16
1952	-0.20	-0.20	-0.12	0.84	2.35	4.54	5.01	4.87	4.87	2.69	-0.53	-0.04	24.07	2.01
1953	-0.23	-0.47	-0.24	1.14	1.90	4.27	4.98	5.48	5.70	2.46	-0.25	-0.20	24.56	2.05
1954	-0.20	0.0	0.0	1.88	0.30	4.49	7.00	5.94	5.45	-0.70	0.0	-0.26	23.90	1.99
1955	-0.28	0.0	-0.09	1.69	2.26	4.25	4.83	6.83	3.15	1.19	-0.05	0.0	23.78	1.98
1956	-0.02	-1.35	-0.03	1.74	2.38	4.65	6.59	6.27	5.66	2.37	0.0	-0.04	28.22	2.35
1957	-0.09	-0.61	-0.77	1.45	2.16	4.46	6.48	6.31	4.45	0.05	-0.77	0.0	23.13	1.93
1958	-1.49	-0.80	-1.81	0.99	1.98	4.52	6.72	6.37	2.60	1.75	-0.18	-0.24	20.40	1.70
1959	-0.02	-0.09	-0.03	1.27	1.34	3.78	4.36	5.85	5.64	2.21	-0.23	-0.72	23.36	1.95
1960	-1.20	-0.41	-0.04	1.91	1.68	3.44	4.08	7.26	5.20	-0.30	0.0	-1.98	19.63	1.64
1961	-0.65	-0.04	-0.78	1.76	2.26	3.84	5.88	5.93	5.09	2.29	-1.53	-0.28	23.77	1.98
1962	-0.36	-0.49	-0.11	1.76	2.52	3.44	3.94	6.04	2.52	2.20	-0.59	-0.14	20.73	1.73
1963	-0.42	-0.74	0.0	1.73	1.85	3.87	7.05	5.30	5.14	2.75	-0.05	-0.15	26.34	2.19
1964	-0.77	-1.19	-0.14	1.76	2.41	3.38	7.05	7.00	3.78	2.78	-0.31	-0.23	25.53	2.13
1965	-0.11	-0.80	-0.20	1.54	2.33	3.42	5.73	6.43	4.87	2.66	-0.08	-0.45	25.35	2.11
1966	-0.51	-0.03	-0.24	-0.01	2.19	2.27	7.32	4.61	4.69	2.60	0.0	0.0	22.90	1.91
1967	0.0	-0.19	-0.07	2.01	2.54	1.32	6.15	3.75	4.64	2.70	-0.21	-1.02	21.62	1.80
1968	-1.42	-1.12	-1.81	1.54	1.85	3.62	2.52	4.24	5.03	2.26	-1.06	-0.21	15.44	1.29

* Inches, total inches, and feet.

MONTHLY CONSUMPTIVE USE MINUS EFFECTIVE PRECIPITATION FOR SORGHUM NEAR ROSWELL*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	
19 5	-0.53	-2.39	-2.64	-1.76	-0.01	2.00	6.44	6.20	0.52	-0.35	-2.21	-1.01	4.28	0.36
19 6	-0.51	-0.45	-0.23	-2.45	-0.44	3.32	5.27	4.26	0.66	-0.70	-3.34	-0.95	4.45	0.37
19 7	-0.34	0.0	0.0	-0.61	-1.10	1.66	6.02	4.32	0.20	-2.66	-1.29	-0.14	6.04	0.50
19 8	-0.25	-0.27	-0.01	-1.23	-0.07	2.98	5.36	3.42	-0.16	0.0	-0.67	-0.01	9.11	0.76
19 9	-0.02	-0.02	-0.93	0.0	-0.05	2.67	5.95	4.22	0.70	-0.60	-0.28	-0.30	11.35	0.95
1910	-0.09	-0.10	-0.05	-0.08	-0.14	3.01	7.38	4.32	0.73	-0.34	-0.21	-0.01	14.41	1.20
1911	-0.13	-1.80	-0.28	-2.01	-2.94	3.24	5.00	4.97	-0.45	-1.09	-0.44	-0.54	3.54	0.29
1912	-0.03	-1.26	-0.04	-0.14	-0.32	2.37	5.92	3.62	-1.38	-0.83	-0.41	-1.05	6.45	0.54
1913	-0.57	-0.53	-0.71	-1.15	-0.03	0.10	6.92	5.95	-1.38	-0.81	-0.93	-0.84	6.01	0.50
1914	-0.04	-0.10	-0.13	-1.09	-3.18	2.28	5.76	4.88	1.08	-2.93	-0.29	-1.68	4.57	0.38
1915	-0.37	-0.91	-1.74	-4.03	-1.13	3.48	7.20	4.26	-1.02	-0.11	0.0	-0.95	4.69	0.39
1916	-0.42	0.0	-0.55	-1.06	-0.16	3.35	6.64	1.89	0.73	-2.14	-0.42	-0.34	7.51	0.63
1917	-0.18	-0.25	-0.28	0.0	-0.93	3.61	7.84	3.28	0.06	-0.01	-0.06	0.0	13.09	1.09
1918	-0.70	-0.02	0.0	-0.07	-0.56	3.44	6.37	4.80	-0.04	-0.76	-1.61	-0.92	9.95	0.83
1919	-0.02	-0.14	-3.82	-3.14	-0.96	0.07	7.35	5.55	-2.96	-0.59	-0.53	-0.23	0.59	0.05
1920	-1.31	-0.63	-0.11	0.0	-1.64	1.48	6.89	3.97	-1.21	-0.85	-0.14	0.0	6.43	0.54
1921	-0.16	-0.45	-0.71	-0.01	-1.42	-0.45	5.47	5.48	0.93	0.0	0.0	0.0	8.68	0.72
1922	-0.04	-0.15	-0.69	-1.30	-1.42	2.02	7.66	6.23	1.03	-0.09	-0.51	-0.01	12.72	1.06
1923	-0.42	-1.81	-0.23	-0.92	-0.09	2.61	5.35	5.42	-2.86	-2.77	-1.00	-1.78	1.51	0.13
1924	-0.24	-0.73	-0.34	-0.51	-0.14	3.84	5.16	6.21	1.11	-0.39	-0.11	-0.30	13.55	1.13
1925	-0.46	0.0	0.0	0.0	-0.52	3.63	4.50	4.46	-2.04	-0.91	0.0	-0.07	8.59	0.72
1926	-0.84	0.0	-1.51	-0.82	-1.90	2.68	6.14	5.80	-2.09	-1.42	-0.13	-1.04	4.86	0.40
1927	-0.02	-0.13	-0.09	-0.01	-0.04	1.75	6.69	5.75	0.97	-0.31	0.0	-0.33	14.21	1.18
1928	0.0	-0.80	0.0	-0.69	-1.80	2.28	6.84	2.44	0.68	-2.91	-0.30	-0.61	5.13	0.43
1929	-0.03	-0.44	-0.77	0.0	-2.13	2.58	4.02	5.35	0.72	-0.55	-1.04	0.0	7.72	0.64
1930	-0.25	0.0	-0.92	-0.51	-0.46	2.08	7.23	4.52	0.64	-2.49	-0.41	-0.25	9.18	0.76
1931	-0.40	-1.14	-0.36	-3.58	-0.67	2.85	6.83	3.59	1.19	-0.35	-0.36	-1.70	5.90	0.49
1932	-0.62	-0.62	-1.31	-0.49	-1.76	2.40	5.92	2.63	-2.68	-0.54	0.0	-0.30	2.63	0.22
1933	-0.14	-0.37	0.0	-0.15	-0.48	3.14	7.17	3.36	-0.39	-0.09	-1.08	0.0	10.96	0.91
1934	-0.04	-0.04	-1.07	-0.13	-0.85	3.08	8.00	5.03	1.14	-0.45	-1.70	-0.05	12.93	1.08
1935	-0.06	-0.51	-0.54	-0.37	-2.19	2.76	7.30	5.04	-1.61	-0.05	-0.72	-0.12	8.93	0.74
1936	-0.94	-0.04	-0.09	-0.04	-2.05	2.87	6.36	6.04	-2.71	-0.28	-0.27	-0.15	8.72	0.73
1937	-0.10	-0.20	-1.36	-1.19	-3.24	2.85	6.96	6.08	-1.87	-0.59	-0.08	-0.16	7.09	0.59
1938	-1.10	-0.89	-0.36	-0.11	-0.03	2.06	6.13	5.84	-0.24	-0.92	-0.02	-0.23	10.12	0.84
1939	-0.74	-0.09	-1.10	-0.54	-0.84	3.19	3.89	4.80	0.54	-0.24	-0.36	-0.67	7.84	0.65
1940	-0.10	-0.74	0.0	-1.17	-2.46	0.16	6.28	5.37	0.61	-0.93	-0.98	-0.08	5.96	0.50
1941	-0.47	-0.80	-2.54	-3.28	-4.08	2.70	4.33	4.31	-3.00	-3.02	-0.10	-0.32	-6.27	-0.52
1942	-0.14	-0.20	-0.16	-2.22	-0.01	3.18	5.93	3.04	-1.20	-1.32	0.0	-1.68	5.22	0.44
1943	-0.05	0.0	0.0	-0.22	-1.12	1.57	7.10	6.36	0.37	-0.01	-0.55	-2.42	11.02	0.92
1944	-0.86	-0.55	-0.10	-0.07	-0.13	1.89	6.39	3.09	0.27	-0.85	-0.25	-0.20	8.62	0.72
1945	-0.03	0.0	-0.18	-0.14	-0.02	3.37	6.31	4.65	0.38	-1.32	0.0	-0.71	12.31	1.03
1946	-1.10	-0.07	-0.51	-0.32	-0.27	2.18	6.64	5.50	-1.47	-1.25	-0.34	-0.75	8.25	0.69
1947	-0.78	0.0	-0.33	-0.46	-1.62	3.19	7.74	4.76	0.77	-0.50	-0.89	-0.79	11.10	0.92
1948	-0.65	-1.16	-0.61	-0.27	-0.88	2.27	5.99	5.29	0.92	-0.68	0.0	-0.14	10.08	0.84
1949	-1.61	-0.40	0.0	-0.48	-0.72	1.14	5.00	4.87	-0.63	-1.05	-0.01	-0.78	5.33	0.44
1950	0.0	-0.03	0.0	-0.13	-1.68	1.80	4.02	5.54	-2.82	-1.71	0.0	-0.01	4.97	0.41
1951	-0.09	-0.33	-0.31	-0.42	-0.83	3.38	6.65	4.78	1.13	-0.28	-0.14	-0.58	12.95	1.08
1952	-0.20	-0.20	-0.12	-0.98	-0.29	3.76	5.78	3.72	0.39	0.0	-0.53	-0.04	11.31	0.94
1953	-0.23	-0.47	-0.24	-0.69	-0.67	3.48	5.79	4.37	1.14	-0.29	-0.25	-0.20	11.75	0.98
1954	-0.20	0.0	0.0	-0.10	-2.34	3.73	7.81	4.82	0.73	-3.53	0.0	-0.26	10.66	0.89
1955	-0.28	0.0	-0.09	-0.18	-0.39	3.51	5.60	5.72	-1.48	-1.62	-0.05	0.0	10.75	0.90
1956	-0.02	-1.35	-0.03	-0.03	-0.38	3.87	7.38	5.17	1.01	-0.52	0.0	-0.04	15.07	1.26
1957	-0.09	-0.61	-0.77	-0.30	-0.41	3.71	7.29	5.18	-0.01	-2.61	-0.77	0.0	10.62	0.89
1958	-1.49	-0.80	-1.81	-0.80	-0.74	3.74	7.54	5.23	-1.92	-0.94	-0.18	-0.24	7.59	0.63
1959	-0.02	-0.09	-0.03	-0.56	-1.37	3.02	5.14	4.71	1.01	-0.50	-0.23	-0.72	10.36	0.86
1960	-1.20	-0.41	-0.04	0.0	-0.98	2.67	4.85	6.15	0.70	-3.03	0.0	-1.98	6.72	0.56
1961	-0.65	-0.04	-0.78	-0.02	-0.42	3.10	6.65	4.85	0.68	-0.42	-1.53	-0.28	11.14	0.93
1962	-0.36	-0.49	-0.11	-0.09	-0.20	2.71	4.71	4.95	-1.91	-0.48	-0.59	-0.14	8.00	0.67
1963	-0.42	-0.74	0.0	-0.15	-0.84	3.13	7.85	4.19	0.55	-0.14	-0.05	-0.15	13.24	1.10
1964	-0.77	-1.19	-0.14	-0.02	-0.29	2.64	7.85	5.87	-0.78	0.0	-0.31	-0.23	12.64	1.05
1965	-0.11	-0.80	-0.20	-0.36	-0.33	2.68	6.53	5.35	0.39	-0.05	-0.08	-0.45	12.56	1.05
1966	-0.51	-0.03	-0.24	-1.85	-0.52	1.53	8.14	3.53	0.20	0.0	0.0	0.0	10.27	0.86
1967	0.0	-0.19	-0.07	0.0	-0.10	0.59	6.94	2.69	0.28	-0.02	-0.21	-1.02	8.89	0.74
1968	-1.42	-1.12	-1.81	-0.06	-0.54	2.92	3.23	3.24	0.93	-0.39	-1.06	-0.21	3.71	0.31

* Inches, total inches, and feet.

TABLE D-XIII

MONTHLY CONSUMPTIVE USE MINUS EFFECTIVE PRECIPITATION FOR SMALL GRAINS NEAR ROSWELL*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total (in)	Total (ft)
19 5	-0.53	-2.39	-1.10	0.11	3.24	1.63	-0.93	-0.01	-0.61	-0.35	-2.21	-1.01	-4.15	-0.35
19 6	-0.51	-0.45	1.24	-0.52	2.85	2.95	-2.13	-1.72	-0.46	-0.70	-3.34	-0.95	-3.74	-0.31
19 7	-0.34	0.0	1.70	1.33	1.93	1.30	-1.64	-1.92	-0.92	-2.66	-1.29	-0.14	-2.66	-0.22
19 8	-0.25	-0.27	1.65	0.73	3.12	2.62	-2.01	-2.58	-1.23	0.0	-0.67	-0.01	1.11	0.09
19 9	-0.02	-0.02	0.45	1.96	3.11	2.30	-1.82	-1.88	-0.38	-0.60	-0.28	-0.30	2.53	0.21
1910	-0.09	-0.10	1.61	1.91	3.12	2.64	-0.54	-1.90	-0.42	-0.34	-0.21	-0.01	5.66	0.47
1911	-0.13	-1.80	1.32	0.01	0.32	2.87	-2.62	-1.17	-1.62	-1.09	-0.44	-0.54	-4.88	-0.41
1912	-0.03	-1.26	1.35	1.73	2.94	2.02	-1.82	-2.52	-2.42	-0.83	-0.41	-1.05	-2.31	-0.19
1913	-0.57	-0.53	0.68	0.78	3.28	-0.25	-0.78	-0.27	-2.42	-0.81	-0.93	-0.84	-2.67	-0.22
1914	-0.04	-0.10	1.29	0.86	0.05	1.92	-1.85	-1.27	-0.05	-2.93	-0.29	-1.68	-4.08	-0.34
1915	-0.37	-0.91	-0.53	-2.09	2.00	3.12	-0.43	-1.67	-2.12	-0.11	0.0	-0.95	-4.06	-0.34
1916	-0.42	0.0	1.09	0.84	3.14	2.97	-0.99	-4.01	-0.35	-2.14	-0.42	-0.34	-0.64	-0.05
1917	-0.18	-0.25	1.14	1.91	2.08	3.25	-0.07	-2.85	-1.06	-0.01	-0.06	0.0	3.90	0.33
1918	-0.70	-0.02	1.59	1.83	2.71	3.07	-1.40	-1.33	-1.11	-0.76	-1.61	-0.92	1.37	0.11
1919	-0.02	-0.14	-2.39	-1.16	2.25	-0.27	-0.14	-0.69	-4.07	-0.59	-0.53	-0.23	-7.98	-0.66
1920	-1.31	-0.63	1.32	1.83	1.60	1.12	-0.78	-1.93	-2.35	-0.85	-0.14	0.0	-2.12	-0.18
1921	-0.16	-0.45	0.87	1.91	1.89	-0.80	-2.03	-0.74	-0.25	0.0	0.0	0.0	0.25	0.02
1922	-0.04	-0.15	0.74	0.64	1.87	1.65	-0.16	-0.14	-0.12	-0.09	-0.51	-0.01	3.69	0.31
1923	-0.42	-1.81	1.14	1.07	3.23	2.24	-2.36	-0.75	-3.97	-2.77	-1.00	-1.78	-7.19	-0.60
1924	-0.24	-0.73	1.02	1.39	3.00	3.45	-2.49	-0.11	0.0	-0.39	-0.11	-0.30	4.48	0.37
1925	-0.46	0.0	1.59	2.13	2.81	3.25	-3.32	-1.50	-3.16	-0.91	0.0	-0.07	0.37	0.03
1926	-0.84	0.0	-0.16	1.03	1.27	2.31	-1.37	-0.38	-3.23	-1.42	-0.13	-1.04	-3.96	-0.33
1927	-0.02	-0.13	1.39	2.05	3.47	1.39	-1.08	-0.52	-0.16	-0.31	0.0	-0.33	5.73	0.48
1928	0.0	-0.80	1.57	1.21	1.46	1.91	-0.91	-3.49	-0.41	-2.91	-0.30	-0.61	-3.29	-0.27
1929	-0.03	-0.44	0.68	2.02	1.02	2.21	-3.65	-0.81	-0.40	-0.55	-1.04	0.0	-0.99	-0.08
1930	-0.25	0.0	0.46	1.61	2.73	1.71	-0.57	-1.80	-0.53	-2.49	-0.41	-0.25	0.21	0.02
1931	-0.40	-1.14	1.02	-1.69	2.47	2.47	-0.94	-2.46	-0.02	-0.35	-0.36	-1.70	-3.09	-0.26
1932	-0.62	-0.62	0.02	1.52	1.47	2.04	-1.92	-3.57	-3.75	-0.54	0.0	-0.30	-6.28	-0.52
1933	-0.14	-0.37	1.54	1.71	2.75	2.76	-0.76	-2.87	-1.58	-0.09	-1.08	0.0	1.89	0.16
1934	-0.04	-0.04	0.43	1.95	2.60	2.70	-0.12	-1.41	0.0	-0.45	-1.70	-0.05	3.88	0.32
1935	-0.06	-0.51	1.06	1.67	0.89	2.39	-0.39	-1.27	-2.67	-0.05	-0.72	-0.12	0.23	0.02
1936	-0.94	-0.04	1.48	1.97	1.25	2.49	-1.35	-0.21	-3.81	-0.28	-0.27	-0.15	0.15	0.01
1937	-0.10	-0.20	-0.00	0.83	0.10	2.48	-0.90	-0.31	-3.02	-0.59	-0.08	-0.16	-1.96	-0.16
1938	-1.10	-0.89	1.22	1.87	3.28	1.69	-1.48	-0.46	-1.38	-0.92	-0.02	-0.23	1.58	0.13
1939	-0.74	-0.09	0.44	1.49	2.52	2.81	-3.86	-1.31	-0.62	-0.24	-0.36	-0.67	-0.64	-0.05
1940	-0.10	-0.74	1.53	0.79	0.84	-0.20	-1.55	-0.76	-0.54	-0.93	-0.98	-0.08	-2.71	-0.23
1941	-0.47	-0.80	-1.16	-1.36	-0.84	2.35	-3.22	-1.84	-4.10	-3.02	-0.10	-0.32	-14.89	-1.24
1942	-0.14	-0.20	1.26	-0.26	3.26	2.81	-1.84	-3.10	-2.29	-1.32	0.0	-1.68	-3.50	-0.29
1943	-0.05	0.0	1.48	1.93	2.18	1.19	-0.65	-0.21	-0.76	-0.01	-0.55	-2.42	2.14	0.18
1944	-0.86	-0.55	1.38	1.85	3.16	1.52	-1.44	-3.22	-0.82	-0.85	-0.25	-0.20	-0.28	-0.02
1945	-0.03	0.0	1.36	1.74	3.42	3.00	-1.38	-1.69	-0.76	-1.32	0.0	-0.71	3.63	0.30
1946	-1.10	-0.07	1.07	1.84	3.00	1.81	-1.20	-0.90	-2.62	-1.25	-0.34	-0.75	-0.51	-0.04
1947	-0.78	0.0	1.13	1.48	1.73	2.82	-0.12	-1.47	-0.37	-0.50	-0.89	-0.79	2.24	0.19
1948	-0.65	-1.16	0.72	1.82	2.45	1.90	-1.78	-0.98	-0.20	-0.68	0.0	-0.14	1.30	0.11
1949	-1.61	-0.40	1.55	1.45	2.65	0.77	-2.85	-1.27	-1.76	-1.05	-0.01	-0.78	-3.30	-0.27
1950	0.0	-0.03	1.50	1.87	1.66	1.42	-3.64	-0.71	-3.95	-1.71	0.0	-0.01	-3.60	-0.30
1951	-0.09	-0.33	1.13	1.51	2.52	3.01	-1.51	-1.66	-0.02	-0.28	-0.14	-0.58	3.56	0.30
1952	-0.20	-0.20	1.28	0.99	3.01	3.37	-1.97	-2.79	-0.73	0.0	-0.53	-0.04	2.20	0.18
1953	-0.23	-0.47	1.37	1.30	2.55	3.08	-2.27	-1.97	0.0	-0.29	-0.25	-0.20	2.63	0.22
1954	-0.20	0.0	1.49	2.06	0.96	3.34	-0.31	-1.52	-0.45	-3.53	0.0	-0.26	1.58	0.13
1955	-0.28	0.0	1.40	1.85	2.92	3.15	-2.09	-0.58	-2.64	-1.62	-0.05	0.0	2.07	0.17
1956	-0.02	-1.35	1.50	1.89	3.06	3.48	-0.52	-1.08	-0.15	-0.52	0.0	-0.04	6.26	0.52
1957	-0.09	-0.61	0.73	1.60	2.81	3.33	-0.83	-1.17	-1.13	-2.61	-0.77	0.0	1.27	0.11
1958	-1.49	-0.80	-0.47	1.14	2.66	3.34	-0.63	-1.21	-3.05	-0.94	-0.18	-0.24	-1.87	-0.16
1959	-0.02	-0.09	1.42	1.43	2.01	2.64	-2.66	-1.76	-0.15	-0.50	-0.23	-0.72	1.38	0.11
1960	-1.20	-0.41	1.45	2.07	2.34	2.28	-2.89	-0.15	-0.43	-3.03	0.0	-1.98	-1.94	-0.16
1961	-0.65	-0.04	0.67	1.91	2.93	2.73	-1.03	-1.30	-0.42	-0.42	-1.53	-0.28	2.57	0.21
1962	-0.36	-0.49	1.26	1.92	3.21	2.35	-2.98	-1.25	-3.02	-0.48	-0.59	-0.14	-0.57	-0.05
1963	-0.42	-0.74	1.46	1.89	2.52	2.76	-0.20	-2.09	-0.59	-0.14	-0.05	-0.15	4.25	0.35
1964	-0.77	-1.19	1.27	1.92	3.08	2.27	-0.16	-0.54	-1.92	0.0	-0.31	-0.23	3.42	0.28
1965	-0.11	-0.80	1.12	1.70	3.00	2.31	-1.42	-0.79	-0.73	-0.05	-0.08	-0.45	3.69	0.31
1966	-0.51	-0.03	1.26	0.15	2.86	1.16	-0.14	-2.59	-0.93	0.0	0.0	0.0	1.24	0.10
1967	0.0	-0.19	1.60	2.18	3.20	0.23	-0.93	-3.31	-0.81	-0.02	-0.21	-1.02	0.72	0.06
1968	-1.42	-1.12	-0.51	1.67	2.45	2.57	-3.91	-2.42	-0.09	-0.39	-1.06	-0.21	-4.45	-0.37

* Inches, total inches, and feet.

TABLE D-XIV

MONTHLY CONSUMPTIVE USE MINUS EFFECTIVE PRECIPITATION FOR ALFALFA NEAR ARTESIA*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	
19 5	-0.71	-2.14	-1.07	1.61	4.95	4.84	3.33	6.25	1.62	2.29	-0.63	-0.77	19.57	1.63
19 6	-0.33	-0.59	1.06	1.23	5.10	6.67	4.46	5.99	4.63	2.07	-1.96	-0.81	27.52	2.29
19 7	-0.13	0.0	1.79	3.27	4.17	4.77	6.06	4.31	4.12	-0.64	-0.66	-0.09	26.96	2.25
19 8	-0.25	-0.27	1.84	2.39	5.05	5.90	5.38	3.73	3.17	3.15	-0.09	-0.01	30.00	2.50
19 9	-0.02	-0.02	0.61	3.63	5.03	5.62	5.97	4.52	4.06	2.60	0.39	-0.30	32.09	2.67
1910	-0.08	0.0	1.91	3.59	5.13	6.59	8.08	4.85	3.54	2.89	0.05	-0.04	36.51	3.04
1911	-0.57	-1.62	1.32	1.73	4.82	5.75	3.43	4.53	3.99	2.49	0.16	-0.54	25.48	2.12
1912	0.0	-0.40	1.63	3.49	5.25	5.37	6.05	6.14	3.91	2.56	-0.06	-0.81	33.13	2.76
1913	-0.09	-0.40	1.45	2.02	4.59	4.72	7.71	6.18	1.31	2.41	-0.17	-0.76	28.98	2.41
1914	-0.04	-0.22	1.56	2.77	3.53	5.40	4.73	5.80	4.27	0.74	0.00	-1.37	27.18	2.26
1915	-0.31	-0.76	0.15	-0.17	5.32	6.34	6.26	6.31	2.68	3.37	0.66	-0.46	29.40	2.45
1916	-0.19	0.0	1.72	2.61	5.46	6.74	6.08	2.43	3.76	1.22	0.13	-0.29	29.67	2.47
1917	-0.14	0.0	1.52	3.74	4.86	6.76	8.18	5.42	3.13	3.38	0.40	0.0	37.26	3.10
1918	-0.83	0.0	1.86	3.72	4.68	6.49	7.74	5.37	4.38	2.11	-0.57	-0.43	34.51	2.88
1919	-0.14	-0.02	-1.89	2.92	4.85	4.91	6.61	6.54	0.68	2.57	0.08	-0.29	26.82	2.23
1920	-0.78	-0.30	1.70	3.64	4.44	3.70	6.25	4.43	3.79	0.34	-0.02	0.0	27.19	2.27
1921	-0.30	-1.09	1.83	3.56	4.12	2.66	3.73	5.62	4.01	3.20	0.58	-0.01	27.93	2.33
1922	-0.09	-0.04	1.59	1.52	3.82	5.59	7.83	6.37	4.49	3.21	-0.12	0.0	34.18	2.85
1923	-0.36	-1.91	1.07	2.59	5.41	3.86	7.12	6.49	4.11	1.53	-0.38	-1.97	27.56	2.30
1924	0.0	-0.53	1.15	3.58	5.05	6.99	5.31	6.58	4.39	2.83	0.66	-0.33	35.69	2.97
1925	-0.19	0.0	1.83	3.94	4.14	6.47	5.90	3.65	3.96	2.31	0.60	0.0	32.61	2.72
1926	-0.88	0.0	0.16	1.94	2.82	6.24	5.01	5.02	1.44	2.41	0.43	-0.97	23.62	1.97
1927	-0.36	-0.39	1.65	3.84	5.59	4.45	6.32	6.46	4.33	3.36	0.69	-1.35	34.60	2.88
1928	0.0	-1.17	1.85	3.01	3.73	6.77	5.37	2.66	3.74	2.11	0.09	-0.52	27.64	2.30
1929	0.0	-0.65	1.44	3.89	1.88	4.68	6.35	5.92	3.49	2.78	-0.39	-0.11	29.28	2.44
1930	-0.17	0.0	1.49	2.96	2.63	4.97	7.40	5.41	4.77	-0.01	0.55	-0.18	29.81	2.48
1931	-0.72	-0.94	0.46	-0.20	4.22	6.45	7.07	2.99	4.95	3.05	-0.06	-2.22	25.06	2.09
1932	-0.60	-1.26	0.62	3.03	1.53	5.90	7.47	4.28	0.53	1.97	0.60	-0.72	23.35	1.95
1933	-0.10	-0.52	1.73	3.22	4.83	5.99	5.85	5.94	3.69	3.16	0.67	0.0	34.46	2.87
1934	0.0	0.0	0.53	3.73	4.24	6.67	7.91	5.13	4.75	2.75	0.52	-0.09	36.14	3.01
1935	0.0	-0.59	1.46	3.24	3.28	5.90	6.25	5.46	2.21	3.48	-0.21	-0.08	30.39	2.53
1936	-0.54	0.0	1.63	3.60	2.59	6.70	6.27	6.10	1.56	2.31	-0.03	-0.08	30.11	2.51
1937	0.0	-0.33	-0.02	3.78	1.67	6.72	6.58	5.69	4.22	2.41	0.52	-0.09	31.13	2.59
1938	-0.97	-0.19	1.57	3.58	5.12	3.56	4.85	6.53	2.92	2.31	0.19	-0.33	29.13	2.43
1939	-0.76	-0.09	0.67	3.43	4.21	6.77	6.72	4.65	4.40	2.47	-0.02	-0.57	31.87	2.66
1940	-0.09	-0.72	1.72	2.85	3.41	3.93	6.86	5.26	4.71	2.91	-0.32	-0.06	30.46	2.54
1941	-1.58	-0.69	-0.77	2.80	1.19	5.70	4.35	3.47	0.52	1.55	0.46	-0.67	16.33	1.36
1942	-0.33	-0.29	1.34	1.73	5.21	5.31	5.87	4.38	3.23	1.91	0.64	-1.78	27.22	2.27
1943	-0.43	-0.02	1.53	3.86	4.62	3.70	6.18	5.97	4.48	2.69	0.06	-1.47	31.18	2.60
1944	-0.61	-0.33	1.62	3.50	5.31	5.14	4.91	3.96	1.15	3.09	0.26	-0.14	27.86	2.32
1945	-0.67	0.0	1.67	3.53	5.52	6.67	7.32	4.85	3.58	1.79	0.66	-0.43	34.50	2.88
1946	-0.43	0.0	1.40	4.04	3.61	5.91	5.15	5.48	4.00	1.93	0.09	-0.14	31.06	2.59
1947	-0.65	0.0	1.33	3.44	4.50	6.86	7.90	5.59	4.44	3.40	0.11	-0.19	36.74	3.06
1948	-0.57	-1.33	1.49	3.81	5.46	2.95	6.73	6.69	4.71	2.85	0.59	-0.42	32.95	2.75
1949	-1.33	-0.05	1.78	3.32	5.32	3.23	6.74	4.73	1.59	2.40	0.69	-0.33	28.09	2.34
1950	0.0	-0.07	1.75	3.85	5.44	4.58	4.79	5.67	2.29	2.75	0.65	0.0	31.69	2.64
1951	-0.07	-0.19	1.27	3.64	4.68	6.86	4.69	6.60	4.87	2.73	0.62	-0.14	35.56	2.96
1952	-0.05	-0.29	1.08	3.11	4.57	6.16	6.39	6.40	3.92	3.39	0.08	0.0	34.77	2.90
1953	-0.13	-0.05	1.61	3.15	4.05	6.95	6.54	5.83	4.38	2.94	0.68	-0.28	35.66	2.97
1954	-0.03	0.0	1.71	3.26	4.50	6.56	8.10	3.79	4.98	0.68	0.68	-0.11	34.12	2.84
1955	-0.42	0.0	1.77	3.75	4.88	6.40	4.47	6.28	3.60	1.77	0.43	0.0	32.91	2.74
1956	-0.05	-0.43	1.76	3.64	4.80	5.15	7.26	5.00	4.72	2.82	0.57	0.0	35.25	2.94
1957	-0.14	-0.27	1.50	3.60	4.43	6.85	7.67	6.39	4.62	1.06	-0.02	0.0	35.69	2.97
1958	-1.37	-1.09	-0.91	2.51	5.43	4.46	6.92	4.88	1.06	1.60	-0.03	-0.01	23.45	1.95
1959	0.0	-0.12	1.67	3.56	3.29	6.63	5.88	6.63	4.97	3.23	0.56	-0.27	36.01	3.00
1960	-0.78	-0.17	1.55	3.70	5.30	5.98	4.64	6.00	4.68	0.64	0.56	-1.60	30.49	2.54
1961	-0.68	-0.15	1.30	3.78	5.10	5.93	7.04	5.68	4.50	3.42	-0.77	-0.29	34.86	2.91
1962	-0.43	-0.39	1.52	3.27	5.09	5.95	5.10	6.73	2.70	2.25	0.43	-0.59	31.62	2.64
1963	-0.08	-0.65	1.75	3.95	4.74	5.54	8.14	4.83	4.80	3.56	0.52	-0.05	37.05	3.09
1964	0.0	-0.22	1.39	3.78	4.87	5.18	8.16	6.13	4.11	3.54	0.50	-0.27	37.17	3.10
1965	-0.02	-0.34	1.48	3.92	4.71	6.04	6.62	4.70	4.10	3.34	0.67	-0.98	34.24	2.85
1966	-0.48	-0.03	1.19	2.59	5.02	5.64	7.93	2.37	4.18	3.32	0.65	0.0	32.39	2.70
1967	0.0	-0.14	1.78	3.99	5.07	6.23	7.33	4.54	3.95	3.47	0.04	-0.47	35.78	2.98
1968	-1.63	-0.78	0.90	3.30	4.20	6.70	4.21	4.12	4.27	2.34	-0.74	-0.25	26.65	2.22

* Inches, total inches, and feet.

TABLE D-XV

MONTHLY CONSUMPTIVE USE MINUS EFFECTIVE PRECIPITATION FOR COTTON NEAR ARTESIA*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	
19 5	-0.71	-2.14	-2.53	-0.09	2.34	2.62	2.59	6.97	2.49	2.51	-1.08	-0.77	12.22	1.02
19 6	-0.33	-0.59	-0.37	-0.55	2.44	4.45	3.72	6.69	5.50	2.30	-2.38	-0.81	20.06	1.67
19 7	-0.13	0.0	0.18	1.50	1.73	2.63	5.29	5.04	4.98	-0.40	-1.07	-0.09	19.65	1.64
19 8	-0.25	-0.27	0.28	0.61	2.49	3.72	4.64	4.43	3.99	3.38	-0.51	-0.01	22.50	1.88
19 9	-0.02	-0.02	-0.69	1.84	2.49	3.41	5.19	5.24	4.89	2.83	-0.09	-0.30	24.77	2.06
1910	-0.08	0.0	0.29	1.72	2.44	4.29	7.27	5.60	4.45	3.13	-0.44	-0.04	28.62	2.38
1911	-0.57	-1.62	-0.25	-0.17	2.12	3.51	2.67	5.24	4.90	2.73	-0.28	-0.54	17.72	1.48
1912	0.0	-0.40	0.23	1.73	2.55	3.21	5.26	6.88	5.12	2.79	-0.50	-0.81	26.05	2.17
1913	-0.09	-0.40	0.08	0.21	1.85	2.57	6.93	6.92	2.13	2.64	-0.65	-0.76	21.44	1.79
1914	-0.04	-0.22	0.14	0.92	0.85	3.14	3.94	6.55	5.17	0.98	-0.48	-1.37	19.58	1.63
1915	-0.31	-0.76	-1.13	-2.05	2.66	4.07	5.47	7.04	3.56	3.61	0.18	-0.46	21.89	1.82
1916	-0.19	0.0	0.09	0.79	2.69	4.38	5.28	3.15	4.62	1.46	-0.29	-0.29	21.69	1.81
1917	-0.14	0.0	0.09	1.90	2.30	4.51	7.37	6.17	4.02	3.62	-0.08	0.0	29.75	2.48
1918	-0.83	0.0	0.29	1.89	1.97	4.16	6.92	6.12	5.25	2.36	-1.00	-0.43	26.69	2.22
1919	-0.14	-0.02	-3.33	1.01	2.13	2.74	5.81	7.31	1.57	2.82	-0.38	-0.29	19.23	1.60
1920	-0.78	-0.30	0.26	1.85	1.70	1.53	5.45	5.14	4.69	0.58	-0.46	0.0	19.67	1.64
1921	-0.30	-1.09	0.28	1.79	1.57	0.53	2.98	6.36	4.94	3.45	0.09	-0.01	20.60	1.72
1922	-0.09	-0.04	0.18	-0.30	1.12	3.43	7.04	7.12	5.39	3.45	-0.57	0.0	26.74	2.23
1923	-0.36	-1.91	-0.29	0.75	2.70	1.59	6.34	7.22	4.99	1.76	-0.82	-1.97	20.01	1.67
1924	0.0	-0.53	-0.17	1.79	2.34	4.66	4.54	7.33	5.25	3.08	0.18	-0.33	28.14	2.34
1925	-0.19	0.0	0.28	1.98	1.42	4.18	5.10	4.35	4.84	2.55	0.17	0.0	24.68	2.06
1926	-0.88	0.0	-1.16	0.20	0.26	4.06	4.25	5.74	2.33	2.66	-0.02	-0.97	16.48	1.37
1927	-0.36	-0.39	0.23	1.95	2.80	2.25	5.54	7.19	5.19	3.60	0.19	-1.35	26.82	2.24
1928	0.0	-1.17	0.28	1.21	1.04	4.45	4.56	3.37	4.58	2.37	-0.35	-0.52	19.82	1.65
1929	0.0	-0.65	0.03	1.97	-0.75	2.44	5.57	6.65	4.35	3.03	-0.79	-0.11	21.73	1.81
1930	-0.17	0.0	0.13	0.99	0.06	2.73	6.60	6.15	5.67	0.23	0.11	-0.18	22.33	1.86
1931	-0.72	-0.94	-0.91	-1.92	1.62	4.17	6.28	3.70	5.88	3.30	-0.51	-2.22	17.73	1.48
1932	-0.60	-1.26	-0.71	1.30	-0.93	3.78	6.70	5.02	1.40	2.21	0.17	-0.72	16.35	1.36
1933	-0.10	-0.52	0.27	1.52	2.35	3.76	5.05	6.66	4.61	3.42	0.19	0.0	27.21	2.27
1934	0.0	0.0	-0.92	1.81	1.40	4.34	7.11	5.89	5.64	3.01	0.06	-0.09	28.24	2.35
1935	0.0	-0.59	-0.03	1.35	0.72	3.67	5.48	6.20	3.04	3.73	-0.66	-0.08	22.83	1.90
1936	-0.54	0.0	0.11	1.78	-0.09	4.43	5.49	6.82	2.43	2.53	-0.45	-0.08	22.43	1.87
1937	0.0	-0.33	-1.29	1.92	-1.06	4.48	5.80	6.43	5.11	2.66	0.07	-0.09	23.70	1.97
1938	-0.97	-0.19	0.06	1.73	2.44	1.33	4.08	7.26	3.78	2.56	-0.22	-0.33	21.53	1.79
1939	-0.76	-0.09	-0.77	1.58	1.51	4.46	5.94	5.36	5.28	2.71	-0.43	-0.57	24.22	2.02
1940	-0.09	-0.72	0.26	0.99	0.69	1.75	6.07	5.98	5.61	3.16	-0.75	-0.06	22.90	1.91
1941	-1.58	-0.69	-2.10	1.02	-1.42	3.59	3.59	4.19	1.37	1.79	0.01	-0.67	9.11	0.76
1942	-0.33	-0.29	0.03	-0.10	2.55	3.12	5.11	5.09	4.05	2.14	0.18	-1.78	19.75	1.65
1943	-0.43	-0.02	0.20	1.95	2.00	1.43	5.39	6.73	5.35	2.92	-0.36	-1.47	23.70	1.97
1944	-0.61	-0.33	0.25	1.75	2.66	2.86	4.13	4.69	1.99	3.33	-0.17	-0.14	20.40	1.70
1945	-0.67	0.0	0.26	1.79	2.73	4.45	6.55	5.60	4.46	2.03	0.18	-0.43	26.96	2.25
1946	-0.43	0.0	-0.15	2.05	0.96	3.61	4.36	6.23	4.91	2.18	-0.34	-0.14	23.24	1.94
1947	-0.65	0.0	-0.05	1.63	1.72	4.54	7.10	6.33	5.34	3.66	-0.31	-0.19	29.11	2.43
1948	-0.57	-1.33	0.15	1.79	2.67	0.63	5.93	7.45	5.60	3.09	0.16	-0.42	25.16	2.10
1949	-1.33	-0.05	0.25	1.53	2.56	0.97	5.94	5.44	2.47	2.64	0.19	-0.33	20.28	1.69
1950	0.0	-0.07	0.27	1.92	2.71	2.25	4.02	6.40	3.17	3.01	0.18	0.0	23.87	1.99
1951	-0.07	-0.19	-0.17	1.82	1.93	4.56	3.88	7.36	5.78	2.99	0.17	-0.14	27.93	2.33
1952	-0.05	-0.29	-0.30	1.27	1.88	3.80	5.62	7.17	4.80	3.63	-0.34	0.0	27.19	2.27
1953	-0.13	-0.05	0.06	1.28	1.40	4.57	5.72	6.57	5.26	3.19	0.19	-0.28	27.78	2.32
1954	-0.03	0.0	0.26	1.26	1.84	4.28	7.28	4.55	5.92	0.94	0.19	-0.11	26.39	2.20
1955	-0.42	0.0	0.27	1.83	2.14	4.16	3.69	7.02	4.51	2.02	-0.05	0.0	25.17	2.10
1956	-0.05	-0.43	0.27	1.83	1.96	2.79	6.46	5.74	5.63	3.08	0.16	0.0	27.44	2.29
1957	-0.14	-0.27	0.02	1.80	1.79	4.55	6.85	7.15	5.50	1.30	-0.45	0.0	28.10	2.34
1958	-1.37	-1.09	-2.19	0.71	2.65	2.09	6.10	5.63	1.95	1.84	-0.49	-0.01	15.81	1.32
1959	0.0	-0.12	0.25	1.71	0.51	4.32	5.09	7.39	5.90	3.47	0.13	-0.27	28.39	2.37
1960	-0.78	-0.17	0.13	1.74	2.57	3.61	3.86	6.75	5.59	0.89	0.08	-1.60	22.67	1.89
1961	-0.68	-0.15	-0.16	1.92	2.32	3.64	6.24	6.43	5.39	3.67	-1.18	-0.29	27.14	2.26
1962	-0.43	-0.39	0.15	1.34	2.23	3.67	4.30	7.50	3.61	2.51	-0.05	-0.59	23.83	1.99
1963	-0.08	-0.65	0.27	1.95	1.93	3.25	7.31	5.58	5.72	3.83	0.03	-0.05	29.10	2.43
1964	0.0	-0.22	-0.04	1.91	2.05	2.92	7.34	6.90	5.01	3.79	0.02	-0.27	29.40	2.45
1965	-0.02	-0.34	0.18	1.97	1.96	3.76	5.80	5.44	4.99	3.59	0.15	-0.98	26.49	2.21
1966	-0.48	-0.03	-0.29	0.74	2.32	3.42	7.10	3.09	5.07	3.56	0.18	0.0	24.69	2.06
1967	0.0	-0.14	0.20	2.02	2.46	4.00	6.53	5.26	4.81	3.72	-0.44	-0.47	27.96	2.33
1968	-1.63	-0.78	-0.52	1.55	1.57	4.47	3.46	4.82	5.07	2.58	-1.17	-0.25	19.17	1.60

* Inches, total inches, and feet.

TABLE D-XVI

MONTHLY CONSUMPTIVE USE MINUS EFFECTIVE PRECIPITATION FOR SORGHUM NEAR ARTESIA*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	
19 5	-0.71	-2.14	-2.79	-1.85	0.97	1.89	3.33	5.88	-1.92	-0.85	-1.25	-0.77	-0.20	-0.02
19 6	-0.33	-0.59	-0.63	-2.39	1.04	3.71	4.46	5.63	1.10	-1.08	-2.54	-0.81	7.57	0.63
19 7	-0.13	0.0	-0.11	-0.32	0.45	1.92	6.06	3.95	0.63	-3.92	-1.23	-0.09	7.19	0.60
19 8	-0.25	-0.27	-0.01	-1.23	1.15	2.99	5.38	3.38	-0.18	0.0	-0.67	-0.01	10.28	0.86
19 9	-0.02	-0.02	-0.93	0.0	1.16	2.67	5.97	4.17	0.67	-0.60	-0.28	-0.30	12.51	1.04
1910	-0.08	0.0	-0.01	-0.20	1.02	3.52	8.08	4.48	-0.13	-0.44	-0.63	-0.04	15.57	1.30
1911	-0.57	-1.62	-0.54	-2.13	0.69	2.76	3.43	4.17	0.31	-0.88	-0.45	-0.54	4.63	0.39
1912	0.0	-0.40	-0.03	-0.09	1.14	2.49	6.05	5.77	-0.98	-0.76	-0.67	-0.81	11.71	0.98
1913	-0.09	-0.40	-0.17	-1.65	0.41	1.85	7.71	5.81	-2.03	-0.90	-0.84	-0.76	8.96	0.75
1914	-0.04	-0.22	-0.12	-0.99	-0.56	2.38	4.73	5.43	0.58	-2.67	-0.67	-1.37	6.48	0.54
1915	-0.31	-0.76	-1.37	-3.98	1.26	3.32	6.26	5.95	-0.92	-0.09	0.0	-0.46	8.90	0.74
1916	-0.19	0.0	-0.21	-1.09	1.25	3.60	6.08	2.07	0.27	-2.19	-0.46	-0.29	8.84	0.74
1917	-0.14	0.0	-0.17	0.0	0.96	3.76	8.18	5.05	-0.51	0.0	-0.27	0.0	16.86	1.40
1918	-0.83	0.0	0.0	0.0	0.54	3.38	7.74	5.00	0.83	-1.41	-1.16	-0.43	13.66	1.14
1919	-0.14	-0.02	-3.59	-0.97	0.70	2.02	6.61	6.16	-2.95	-0.96	-0.55	-0.29	6.02	0.50
1920	-0.78	-0.30	0.0	0.0	0.27	0.80	6.25	4.08	0.11	-3.08	-0.63	0.0	6.73	0.56
1921	-0.30	-1.09	0.0	-0.04	0.23	-0.18	3.73	5.26	0.25	-0.31	-0.09	-0.01	7.45	0.62
1922	-0.09	-0.04	-0.08	-2.17	-0.30	2.71	7.83	5.99	0.84	-0.17	-0.74	0.0	13.81	1.15
1923	-0.36	-1.91	-0.54	-1.15	1.28	0.84	7.12	6.12	0.56	-1.77	-0.98	-1.97	7.26	0.61
1924	0.0	-0.53	-0.41	-0.05	0.91	3.88	5.31	6.21	0.88	-0.61	0.0	-0.33	15.26	1.27
1925	-0.19	0.0	0.0	-0.05	-0.00	3.42	5.90	3.30	0.38	-1.00	0.0	0.0	11.75	0.98
1926	-0.88	0.0	-1.40	-1.59	-1.08	3.33	5.01	4.66	-2.16	-1.09	-0.19	-0.97	3.65	0.30
1927	-0.36	-0.39	-0.03	0.0	1.33	1.51	6.32	6.09	0.85	-0.04	0.0	-1.35	13.94	1.16
1928	0.0	-1.17	0.0	-0.65	-0.37	3.67	5.37	2.30	0.30	-1.45	-0.52	-0.52	6.97	0.58
1929	0.0	-0.65	-0.23	-0.01	-2.13	1.69	6.35	5.55	-0.00	-0.69	-0.95	-0.11	8.82	0.73
1930	-0.17	0.0	-0.11	-1.03	-1.29	1.99	7.40	5.04	1.09	-3.46	-0.07	-0.18	9.21	0.77
1931	-0.72	-0.94	-1.16	-3.70	0.26	3.41	7.07	2.64	1.18	-0.46	-0.69	-2.22	4.66	0.39
1932	-0.60	-1.26	-0.96	-0.48	-2.22	3.07	7.47	3.90	-3.00	-1.35	0.0	-0.72	3.85	0.32
1933	-0.10	-0.52	0.0	-0.24	1.05	3.02	5.85	5.58	-0.06	-0.47	0.0	0.0	14.11	1.18
1934	0.0	0.0	-1.18	-0.17	-0.09	3.57	7.91	4.76	1.13	-0.89	-0.12	-0.09	14.81	1.23
1935	0.0	-0.59	-0.30	-0.60	-0.62	2.93	6.25	5.08	-1.16	0.0	-0.83	-0.08	10.08	0.84
1936	-0.54	0.0	-0.17	-0.09	-1.50	3.68	6.27	5.74	-1.97	-0.88	-0.61	-0.08	9.85	0.82
1937	0.0	-0.33	-1.52	0.0	-2.49	3.73	6.58	5.32	0.59	-1.00	-0.09	-0.09	10.68	0.89
1938	-0.97	-0.19	-0.22	-0.17	1.03	0.59	4.85	6.16	-0.60	-1.14	-0.38	-0.33	8.64	0.72
1939	-0.76	-0.09	-1.03	-0.31	0.09	3.70	6.72	4.29	0.83	-0.84	-0.58	-0.57	11.43	0.95
1940	-0.09	-0.72	0.0	-0.92	-0.74	1.03	6.86	4.90	1.08	-0.54	-0.92	-0.06	9.89	0.82
1941	-1.58	-0.69	-2.34	-0.81	-2.78	2.89	4.35	3.11	-2.94	-1.92	-0.17	-0.67	-3.56	-0.30
1942	-0.33	-0.29	-0.21	-1.98	1.15	2.39	5.87	4.03	-0.09	-1.29	0.0	-1.78	7.46	0.62
1943	-0.43	-0.02	-0.05	-0.02	0.63	0.68	6.18	5.59	0.96	-0.55	-0.53	-1.47	10.97	0.91
1944	-0.61	-0.33	0.0	-0.05	1.26	2.10	4.91	3.60	-2.23	-0.24	-0.33	-0.14	7.93	0.66
1945	-0.67	0.0	0.0	0.0	1.27	3.71	7.32	4.48	0.01	-1.56	0.0	-0.43	14.13	1.18
1946	-0.43	0.0	-0.43	0.0	-0.44	2.84	5.15	5.10	0.32	-1.61	-0.51	-0.14	9.87	0.82
1947	-0.65	0.0	-0.30	-0.24	0.27	3.77	7.90	5.22	0.80	-0.30	-0.48	-0.19	15.79	1.32
1948	-0.57	-1.33	-0.09	-0.29	1.21	-0.14	6.73	6.31	1.09	-0.61	0.0	-0.42	11.88	0.99
1949	-1.33	-0.05	-0.03	-0.31	1.10	0.22	6.74	4.37	-1.99	-0.92	0.0	-0.33	7.47	0.62
1950	0.0	-0.07	0.0	-0.06	1.28	1.48	4.79	5.30	-1.29	-0.97	0.0	0.0	10.47	0.87
1951	-0.07	-0.19	-0.43	-0.05	0.49	3.79	4.69	6.22	1.16	-0.91	0.0	-0.14	14.57	1.21
1952	-0.05	-0.29	-0.55	-0.62	0.46	3.01	6.39	6.01	0.34	0.0	-0.51	0.0	14.21	1.18
1953	-0.13	-0.05	-0.22	-0.65	0.02	3.78	6.54	5.46	0.81	-0.63	0.0	-0.28	14.64	1.22
1954	-0.03	0.0	0.0	-0.79	0.45	3.52	8.10	3.41	1.15	-2.97	0.0	-0.11	12.73	1.06
1955	-0.42	0.0	0.0	-0.14	0.70	3.41	4.47	5.91	-0.12	-1.74	-0.23	0.0	11.83	0.99
1956	-0.05	-0.43	0.0	-0.04	0.48	2.00	7.26	4.64	1.03	-0.83	0.0	0.0	14.07	1.17
1957	-0.14	-0.27	-0.25	-0.06	0.41	3.78	7.67	6.01	1.05	-2.27	-0.61	0.0	15.32	1.28
1958	-1.37	-1.09	-2.42	-1.14	1.19	1.30	6.92	4.50	-2.55	-1.69	-0.67	-0.01	2.97	0.25
1959	0.0	-0.12	-0.01	-0.18	-0.95	3.55	5.88	6.24	1.18	-0.22	-0.04	-0.27	15.06	1.26
1960	-0.78	-0.17	-0.13	-0.28	1.14	2.82	4.64	5.63	0.97	-2.86	-0.10	-1.60	9.28	0.77
1961	-0.68	-0.15	-0.43	0.0	0.86	2.87	7.04	5.31	0.87	-0.13	-1.34	-0.29	13.93	1.16
1962	-0.43	-0.39	-0.10	-0.64	0.73	2.91	5.10	6.34	-0.99	-1.32	-0.24	-0.59	10.37	0.86
1963	-0.08	-0.65	0.0	-0.10	0.45	2.49	8.14	4.45	1.07	-0.16	-0.15	-0.05	15.41	1.28
1964	0.0	-0.22	-0.30	-0.02	0.57	2.16	8.16	5.75	0.46	0.0	-0.16	-0.27	16.12	1.34
1965	-0.02	-0.34	-0.06	-0.05	0.52	3.00	6.62	4.33	0.49	-0.10	-0.05	-0.98	13.36	1.11
1966	-0.48	-0.03	-0.55	-1.17	0.91	2.68	7.93	2.01	0.56	0.0	0.0	0.0	11.86	0.99
1967	0.0	-0.14	-0.09	0.0	1.09	3.26	7.33	4.18	0.44	0.0	-0.62	-0.47	14.98	1.25
1968	-1.63	-0.78	-0.78	-0.26	0.19	3.72	4.21	3.77	0.99	-1.00	-1.34	-0.25	6.85	0.57

* Inches, total inches, and feet-

TABLE D-XVII

MONTHLY CONSUMPTIVE USE MINUS EFFECTIVE PRECIPITATION FOR SMALL GRAINS NEAR ARTESIA*

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total	
19 5	-0.71	-2.14	-1.25	0.16	2.99	3.58	-4.06	-0.28	-3.03	-0.85	-1.25	-0.77	-7.59	-0.63
19 6	-0.33	-0.59	0.89	-0.29	3.10	5.41	-2.95	-0.34	0.0	-1.08	-2.54	-0.81	0.46	0.04
19 7	-0.13	0.0	1.59	1.76	2.34	3.56	-1.62	-2.24	-0.46	-3.92	-1.23	-0.09	-0.46	-0.04
19 8	-0.25	-0.27	1.65	0.87	3.13	4.67	-2.01	-2.58	-1.23	0.0	-0.67	-0.01	3.31	0.28
19 9	-0.02	-0.02	0.46	2.10	3.12	4.37	-1.82	-1.88	-0.38	-0.60	-0.28	-0.30	4.76	0.40
1910	-0.08	0.0	1.71	1.99	3.11	5.28	-0.03	-1.91	-1.28	-0.44	-0.63	-0.04	7.71	0.64
1911	-0.57	-1.62	1.13	0.11	2.79	4.48	-4.11	-1.86	-0.83	-0.88	-0.45	-0.54	-2.37	-0.20
1912	0.0	-0.40	1.46	1.99	3.23	4.14	-1.85	-0.55	-2.50	-0.76	-0.67	-0.81	3.28	0.27
1913	-0.09	-0.40	1.28	0.48	2.53	3.50	-0.09	-0.46	-3.07	-0.90	-0.84	-0.76	1.19	0.10
1914	-0.04	-0.22	1.39	1.19	1.52	4.12	-3.14	-0.94	-0.57	-2.67	-0.67	-1.37	-1.40	-0.12
1915	-0.31	-0.76	-0.00	-1.77	3.33	5.06	-1.65	-0.20	-2.04	-0.09	0.0	-0.46	1.09	0.09
1916	-0.19	0.0	1.52	1.06	3.38	5.40	-1.87	-4.01	-0.81	-2.19	-0.46	-0.29	1.54	0.13
1917	-0.14	0.0	1.35	2.17	2.94	5.48	0.0	-1.29	-1.64	0.0	-0.27	0.0	8.61	0.72
1918	-0.83	0.0	1.67	2.16	2.64	5.17	-0.46	-1.35	-0.28	-1.41	-1.16	-0.43	5.72	0.48
1919	-0.14	-0.02	-2.06	1.29	2.81	3.68	-1.34	-0.35	-4.08	-0.96	-0.55	-0.29	-2.02	-0.17
1920	-0.78	-0.30	1.53	2.11	2.38	2.47	-1.71	-1.95	-1.03	-3.08	-0.63	0.0	-0.99	-0.08
1921	-0.30	-1.09	1.65	2.05	2.21	1.45	-3.80	-0.97	-0.92	-0.31	-0.09	-0.01	-0.13	-0.01
1922	-0.09	-0.04	1.42	-0.03	1.80	4.37	-0.16	-0.39	-0.30	-0.17	-0.74	0.0	5.67	0.47
1923	-0.36	-1.91	0.91	1.02	3.38	2.57	-0.74	-0.09	-0.54	-1.77	-0.98	-1.97	-0.47	-0.04
1924	0.0	-0.53	0.99	2.05	3.02	5.67	-2.44	-0.14	-0.22	-0.61	0.0	-0.33	7.45	0.62
1925	-0.19	0.0	1.64	2.26	2.10	5.17	-2.07	-2.66	-0.74	-1.00	0.0	0.0	4.52	0.38
1926	-0.88	0.0	0.00	0.46	0.90	5.00	-2.55	-1.46	-3.28	-1.09	-0.19	-0.97	-4.04	-0.34
1927	-0.36	-0.39	1.48	2.23	3.50	3.20	-1.52	-0.11	-0.23	-0.04	0.0	-1.35	6.40	0.53
1928	0.0	-1.17	1.66	1.47	1.72	5.46	-2.67	-3.71	-0.77	-1.45	-0.52	-0.52	-0.50	-0.04
1929	0.0	-0.65	1.27	2.25	-0.09	3.41	-1.43	-0.70	-1.09	-0.69	-0.95	-0.11	1.22	0.10
1930	-0.17	0.0	1.32	1.28	0.70	3.70	-0.58	-1.23	-0.06	-3.46	-0.07	-0.18	1.26	0.11
1931	-0.72	-0.94	0.30	-1.67	2.27	5.16	-0.82	-3.38	0.0	-0.46	-0.69	-2.22	-3.17	-0.26
1932	-0.60	-1.26	0.46	1.56	-0.31	4.70	-0.19	-2.41	-4.10	-1.35	0.0	-0.72	-4.23	-0.35
1933	-0.10	-0.52	1.56	1.77	2.97	4.73	-2.12	-0.58	-1.23	-0.47	0.0	0.0	6.00	0.50
1934	0.0	0.0	0.35	2.09	2.11	5.35	-0.09	-1.64	0.0	-0.89	-0.12	-0.09	7.06	0.59
1935	0.0	-0.59	1.28	1.62	1.36	4.64	-1.50	-1.27	-2.21	0.0	-0.83	-0.08	2.42	0.20
1936	-0.54	0.0	1.44	2.05	0.58	5.41	-1.52	-0.32	-3.07	-0.88	-0.61	-0.08	2.46	0.20
1937	0.0	-0.33	-0.17	2.19	-0.38	5.45	-1.19	-1.00	-0.54	-1.00	-0.09	-0.09	2.82	0.24
1938	-0.97	-0.19	1.39	2.00	3.11	2.30	-2.82	-0.05	-1.70	-1.14	-0.38	-0.33	1.23	0.10
1939	-0.76	-0.09	0.49	1.85	2.18	5.46	-1.11	-1.75	-0.29	-0.84	-0.58	-0.57	4.00	0.33
1940	-0.09	-0.72	1.54	1.26	1.37	2.70	-1.02	-1.24	-0.05	-0.54	-0.92	-0.06	2.24	0.19
1941	-1.58	-0.69	-0.93	1.28	-0.76	4.51	-3.24	-3.02	-4.02	-1.92	-0.17	-0.67	-11.22	-0.93
1942	-0.33	-0.29	1.18	0.17	3.21	4.07	-1.74	-1.99	-1.13	-1.29	0.0	-1.78	0.08	0.01
1943	-0.43	-0.02	1.37	2.23	2.66	2.42	-1.63	-0.91	-0.13	-0.55	-0.53	-1.47	3.00	0.25
1944	-0.61	-0.33	1.46	2.01	3.32	3.85	-2.88	-2.60	-3.28	-0.24	-0.33	-0.14	0.20	0.02
1945	-0.67	0.0	1.50	2.05	3.43	5.41	-0.38	-1.87	-1.10	-1.56	0.0	-0.43	6.38	0.53
1946	-0.43	0.0	1.21	2.34	1.62	4.61	-2.77	-1.29	-0.82	-1.61	-0.51	-0.14	2.21	0.18
1947	-0.65	0.0	1.17	1.90	2.42	5.54	-0.14	-1.04	-0.33	-0.30	-0.48	-0.19	7.88	0.66
1948	-0.57	-1.33	1.33	2.09	3.37	1.63	-1.29	-0.16	-0.04	-0.61	0.0	-0.42	4.00	0.33
1949	-1.33	-0.05	1.59	1.79	3.25	1.95	-1.27	-1.71	-3.10	-0.92	0.0	-0.33	-0.13	-0.01
1950	0.0	-0.07	1.57	2.21	3.39	3.26	-2.92	-0.97	-2.40	-0.97	0.0	0.0	3.10	0.26
1951	-0.07	-0.19	1.09	2.09	2.62	5.56	-3.49	-0.23	0.0	-0.91	0.0	-0.14	6.33	0.53
1952	-0.05	-0.29	0.92	1.54	2.55	4.82	-1.35	-0.55	-0.78	0.0	-0.51	0.0	6.31	0.53
1953	-0.13	-0.05	1.42	1.55	2.06	5.60	-1.61	-0.82	-0.30	-0.63	0.0	-0.28	6.82	0.57
1954	-0.03	0.0	1.53	1.55	2.51	5.27	-0.13	-3.06	-0.05	-2.97	0.0	-0.11	4.52	0.38
1955	-0.42	0.0	1.59	2.11	2.82	5.13	-3.28	-0.43	-1.28	-1.74	-0.23	0.0	4.28	0.36
1956	-0.05	-0.43	1.58	2.09	2.67	3.81	-0.78	-1.59	-0.11	-0.83	0.0	0.0	6.37	0.53
1957	-0.14	-0.27	1.32	2.06	2.45	5.54	-0.57	-0.45	-0.07	-2.27	-0.61	0.0	7.00	0.58
1958	-1.37	-1.09	-1.06	0.98	3.34	3.11	-1.28	-1.92	-3.67	-1.69	-0.67	-0.01	-5.32	-0.44
1959	0.0	-0.12	1.50	1.99	1.20	5.32	-2.00	-0.28	0.0	-0.22	-0.04	-0.27	7.09	0.59
1960	-0.78	-0.17	1.38	2.03	3.26	4.63	-3.16	-0.71	-0.19	-2.86	-0.10	-1.60	1.73	0.14
1961	-0.68	-0.15	1.13	2.19	3.01	4.63	-0.95	-1.05	-0.26	-0.13	-1.34	-0.29	6.11	0.51
1962	-0.43	-0.39	1.36	1.62	2.94	4.66	-2.89	-0.20	-2.14	-1.32	-0.24	-0.59	2.38	0.20
1963	-0.08	-0.65	1.57	2.24	2.63	4.25	-0.17	-1.97	-0.09	-0.16	-0.15	-0.05	7.37	0.61
1964	0.0	-0.22	1.22	2.18	2.75	3.90	-0.09	-0.77	-0.68	0.0	-0.16	-0.27	7.86	0.66
1965	-0.02	-0.34	1.32	2.25	2.65	4.75	-1.55	-1.92	-0.64	-0.10	-0.05	-0.98	5.37	0.45
1966	-0.48	-0.03	1.01	1.01	3.00	4.38	-0.38	-4.10	-0.56	0.0	0.0	0.0	3.85	0.32
1967	0.0	-0.14	1.58	2.31	3.11	4.97	-0.64	-1.92	-0.65	0.0	-0.62	-0.47	7.53	0.63
1968	-1.63	-0.78	0.73	1.80	2.23	5.43	-3.28	-2.18	-0.03	-1.00	-1.34	-0.25	-0.30	-0.02

* Inches, total inches, and feet.

TABLE D-XVIII

DAYTIME HOURS AND MONTHLY PERCENTAGES AT ARTESIA, NEW MEXICO

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	10.01	10.36	11.28	12.32	13.29	14.11	14.18	13.46	12.51	11.51	10.51	10.08
2	10.02	10.38	11.31	12.34	13.31	14.12	14.18	13.44	12.49	11.49	10.49	10.07
3	10.03	10.40	11.33	12.37	13.32	14.13	14.16	13.43	12.47	11.47	10.47	10.07
4	10.03	10.42	11.34	12.38	13.34	14.13	14.16	13.42	12.45	11.45	10.46	10.06
5	10.03	10.43	11.36	12.40	13.36	14.15	14.15	13.40	12.43	11.43	10.45	10.05
6	10.04	10.45	11.39	12.42	13.36	14.15	14.15	13.38	12.41	11.41	10.43	10.04
7	10.05	10.47	11.41	12.43	13.39	14.16	14.15	13.37	12.39	11.39	10.41	10.03
8	10.06	10.49	11.42	12.46	13.41	14.16	14.14	13.35	12.37	11.37	10.39	10.03
9	10.07	10.51	11.44	12.48	13.42	14.17	14.13	13.33	12.36	11.35	10.38	10.02
10	10.08	10.52	11.47	12.50	13.44	14.17	14.12	13.32	12.33	11.33	10.36	10.02
11	10.08	10.53	11.49	12.51	13.45	14.18	14.11	13.30	12.31	11.31	10.34	10.01
12	10.09	10.55	11.51	12.54	13.47	14.18	14.11	13.28	12.30	11.29	10.32	10.01
13	10.10	10.57	11.53	12.56	13.49	14.18	14.09	13.27	12.27	11.27	10.31	10.00
14	10.12	10.59	11.55	12.57	13.50	14.19	14.09	13.25	12.25	11.25	10.30	10.00
15	10.13	11.01	11.57	12.59	13.51	14.19	14.08	13.23	12.24	11.23	10.29	10.00
16	10.14	11.03	11.59	13.02	13.53	14.19	14.06	13.22	12.21	11.21	10.27	9.59
17	10.15	11.05	11.01	13.04	13.55	14.20	14.06	13.20	12.19	11.19	10.26	9.59
18	10.17	11.07	12.03	13.05	13.55	14.20	14.04	13.17	12.18	11.18	10.24	9.59
19	10.18	11.09	12.05	13.07	13.57	14.20	14.04	13.16	12.15	11.16	10.23	9.58
20	10.19	11.10	12.07	13.09	13.58	14.20	14.02	13.14	12.13	11.13	10.21	9.59
21	10.21	11.12	12.09	13.11	13.59	14.19	14.01	13.12	12.12	11.11	10.20	9.58
22	10.22	11.14	12.11	13.13	14.01	14.20	14.00	13.10	12.09	11.09	10.18	9.58
23	10.23	11.17	12.14	13.15	14.02	14.20	13.59	13.09	12.07	11.08	10.17	9.58
24	10.25	11.19	12.15	13.17	14.03	14.20	13.57	13.06	12.06	11.06	10.16	9.59
25	10.27	11.21	12.17	13.18	14.04	14.20	13.56	13.04	12.03	11.04	10.15	9.58

TABLE D-XVIII continued

26	10.27	11.22	12.20	13.20	14.05	14.20	13.55	13.03	12.01	11.02	10.14	9.59
27	10.28	11.24	12.22	13.22	14.05	14.20	13.53	13.01	11.59	11.00	10.13	9.59
28	10.30	11.26	12.23	13.24	14.06	14.19	13.52	12.58	11.59	10.58	10.12	9.59
29	10.31	11.28	12.26	13.25	14.09	14.19	13.50	12.57	11.57	10.57	10.10	10.00
30	10.33	-	12.28	13.27	14.09	14.19	13.49	12.55	11.54	10.55	10.09	10.00
31	10.35		12.29		14.10		13.48	12.53		10.53		10.00
Total												
Feb. 28 days	307.5	308.17	369.4	395.1	429.4	428.5	436.44	413.4	360.11	352.05	314.16	310.30
Feb. 29 days		319.5										
Percentage												
Feb. 28 days	6.95	6.96	8.34	8.92	9.70	9.68	9.86	9.34	8.13	7.95	7.09	7.01
Feb. 29 days	6.93	7.20	8.32	8.90	9.68	9.66	9.84	9.32	8.11	7.93	7.08	6.99

TABLE D-XIX

DAYTIME HOURS AND MONTHLY PERCENTAGES AT ROSWELL, NEW MEXICO*

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	9.59	10.35	11.28	12.32	13.31	14.13	14.20	13.48	12.52	11.51	10.51	10.06
2	10.00	10.36	11.30	12.34	13.32	14.14	14.20	13.46	12.50	11.49	10.49	10.05
3	10.00	10.38	11.32	12.36	13.34	14.15	14.19	13.44	12.48	11.46	10.47	10.05
4	10.01	10.40	11.34	12.39	13.36	14.15	14.19	13.43	12.46	11.45	10.45	10.04
5	10.01	10.42	11.36	12.40	13.38	14.17	14.17	13.41	12.44	11.43	10.43	10.03
6	10.02	10.43	11.38	12.42	13.39	14.17	14.17	13.40	12.42	11.40	10.41	10.02
7	10.03	10.45	11.41	12.45	13.40	14.18	14.16	13.38	12.40	11.39	10.39	10.01
8	10.04	10.47	11.42	12.46	13.42	14.18	14.16	13.37	12.38	11.37	10.38	10.01
9	10.05	10.49	11.44	12.48	13.44	14.19	14.15	13.35	12.36	11.35	10.36	10.01
10	10.06	10.51	11.46	12.50	13.45	14.19	14.14	13.33	12.34	11.32	10.34	10.00
11	10.07	10.53	11.49	12.53	13.47	14.20	14.13	13.32	12.31	11.31	10.33	9.59
12	10.07	10.55	11.50	12.54	13.49	14.20	14.13	13.30	12.30	11.29	10.32	9.59
13	10.08	10.57	11.52	12.56	13.51	14.20	14.11	13.28	12.28	11.26	10.30	9.58
14	10.10	10.59	11.55	12.58	13.52	14.21	14.11	13.26	12.25	11.24	10.29	9.58
15	10.11	11.01	11.57	13.01	13.54	14.21	14.10	13.24	12.24	11.23	10.27	9.58
16	10.12	11.03	11.59	13.02	13.55	14.21	14.08	13.22	17.22	11.21	10.25	9.57
17	10.13	11.04	12.01	13.04	13.56	14.22	14.08	13.20	12.19	11.19	10.24	9.57
18	10.15	11.06	12.03	13.06	13.57	14.22	14.06	13.19	12.18	11.16	10.22	9.57
19	10.16	11.08	12.05	13.08	13.59	14.22	14.05	13.17	12.15	11.14	10.21	9.56
20	10.17	11.10	12.08	13.10	14.00	14.23	14.04	13.15	12.13	11.13	10.19	9.57
21	10.19	11.12	12.09	13.12	14.01	14.22	14.03	13.14	12.12	11.11	10.19	9.56
22	10.20	11.14	12.11	13.14	14.02	14.22	14.01	13.11	12.09	11.09	10.17	9.56
23	10.21	11.16	12.14	13.16	14.04	14.22	14.00	13.09	12.07	11.07	10.15	9.56
24	10.23	11.18	12.15	13.17	14.04	14.22	13.59	13.08	12.08	11.05	10.14	9.57
25	10.24	11.19	12.17	13.19	14.06	14.21	13.57	13.06	12.03	11.04	10.14	9.57

TABLE D-XIX continued

26	10.26	11.22	12.20	13.21	14.07	14.22	13.57	13.04	12.01	11.02	10.12	9.57
27	10.27	11.24	12.22	13.24	14.08	14.22	13.56	13.01	11.59	11.00	10.11	9.57
28	10.29	11.26	12.23	13.25	14.09	14.21	13.53	13.00	11.57	10.57	10.10	9.57
29	10.31	11.27	12.26	13.27	14.11	14.21	13.52	12.58	11.55	10.55	10.09	9.58
30	10.32	-	12.28	12.29	14.11	14.21	13.51	12.55	11.53	10.54	10.07	9.58
31	10.34	-	12.30		14.12		13.49	12.54		10.52		9.58
Total Feb. 28 days	317.1	307.5	371.20	390.3	430.1	429.5	437.4	419.8	371.8	351.48	313.30	309.3
Feb. 29 days		319.20										
Percentage Feb. 28 days	7.12	6.92	8.30	8.77	9.66	9.66	9.83	9.42	8.34	7.90	7.04	6.95
Feb. 29 days	7.10	7.15	8.32	8.75	9.64	9.63	9.81	9.39	8.32	7.88	7.02	6.93

* Computed from the sunrise and sunset tables supplied by the State Climatologist.

TABLE D-XX

MONTHLY PERCENT OF DAYTIME HOURS AT ROSWELL AND AT ARTESIA, NEW MEXICO*

	Roswell		Artesia	
	February 28 days	February 29 days	February 28 days	February 29 days
January	7.12	7.10	6.95	6.93
February	6.92	7.15	6.96	7.20
March	8.30	8.32	8.34	8.32
April	8.77	8.75	8.92	8.90
May	9.66	9.64	9.70	9.68
June	9.66	9.63	9.68	9.66
July	9.83	9.81	9.86	9.84
August	9.42	9.39	9.34	9.32
September	8.34	8.32	8.13	8.11
October	7.90	7.88	7.95	7.93
November	7.04	7.02	7.09	7.08
December	6.95	6.93	7.01	6.99

* Calculated from the sunrise and sunset tables supplied by the State Climatologist.

TABLE D-XXI

MONTHLY CONSUMPTIVE USE COEFFICIENTS FOR IRRIGATED CROPS IN THE ROSWELL AND ARTESIA AREAS OF NEW MEXICO*

Month	Roswell				Artesia			
	Alfalfa	Cotton	Sorghum	Small Grains	Alfalfa	Cotton	Sorghum	Small Grains
Jan.								
Feb.								
Mar.	0.31			0.35	0.39	0.06		0.35
April	0.67	0.35		0.38	0.69	0.35		0.40
May	0.80	0.40		0.50	0.80	0.40	0.19	0.50
June	0.90	0.60	0.50	0.45	0.90	0.60	0.50	0.73
July	1.00	0.90	1.00		1.00	0.90	1.00	
Aug.	1.00	1.00	0.85		0.90	1.00	0.85	
Sept.	0.80	0.95	0.19		0.80	0.95	0.19	
Oct.	0.65	0.58			0.70	0.75		
Nov.	0.09				0.18	0.05		
Dec.								

* Adjusted for the growing seasons before and after the frost-free periods. Compiled from Blaney and Hanson [1965] and from Henderson and Sorensen [1968].

TABLE D-XXII

YEARLY CONSUMPTIVE IRRIGATION REQUIREMENT FOR CROPS IN CHAVES COUNTY, NEW MEXICO, ACRE-FEET

Year	Alfalfa	Cotton	Sorghum	Small Grains*	Total
1923	30,700	11,900	200	-4,300	38,500
1924	42,600	37,100	1,600	2,100	83,300
1925	35,400	34,100	900	200	70,600
1926	32,500	26,200	500	-2,500	56,800
1927	46,700	38,100	1,600	3,500	90,000
1928	30,000	30,700	700	-1,500	60,000
1929	31,700	36,600	1,300	-500	69,200
1937	35,600	63,900	7,700	-1,600	105,600
1938	59,500	42,200	20,800	1,000	123,400
1939	46,600	40,000	12,100	-600	98,100
1940	54,700	38,500	11,000	-1,400	102,800
1941	28,800	12,800	-14,800	-9,300	17,500
1942	50,100	39,300	10,200	-2,300	97,300
1943	70,500	53,200	26,900	1,400	152,000
1944	73,000	49,100	17,200	-200	139,100
1945	84,000	69,000	21,500	2,500	177,100
1946	75,000	59,000	15,800	-500	149,400
1947	66,300	93,200	17,100	1,500	178,000
1948	62,600	100,000	13,400	400	176,500
1949	52,800	82,300	10,200	-700	144,600
1950	77,600	54,000	8,700	-3,600	136,700
1951	91,600	125,500	16,200	1,200	234,500
1952	94,600	102,400	14,100	1,000	212,100
1953	96,600	120,900	11,700	1,300	230,600
1954	94,800	77,100	22,200	1,700	195,800
1955	93,800	63,900	22,400	2,800	182,900
1956	107,300	75,700	31,400	8,300	222,700
1957	91,700	60,900	23,900	1,800	178,300
1958	84,200	55,800	17,100	-2,800	154,200
1959	73,000	63,100	4,900	1,100	142,100
1960	71,600	66,300	3,400	-2,900	138,300
1961	90,800	69,300	8,500	4,100	172,700
1962	76,800	60,800	6,300	-900	143,000
1963	96,300	68,900	12,700	6,700	184,700
1964	101,000	66,700	11,600	4,800	184,100
1965	115,200	65,000	8,400	2,800	191,400
1966	108,900	47,100	8,600	1,000	165,500
1967	97,000	39,900	6,700	500	144,100
1968	79,500	34,100	2,600	-1,400	114,800

* Small grains and miscellaneous crops.

TABLE D-XXIII

YEARLY CONSUMPTIVE IRRIGATION REQUIREMENT FOR CROPS IN EDDY COUNTY, NEW MEXICO, ACRE-FEET

Year	Alfalfa	Cotton	Sorghum	Small Grains*	Total
1959	71,400	69,800	3,400	4,300	148,900
1960	63,500	60,600	2,200	1,200	127,500
1961	79,900	68,500	2,700	4,200	155,300
1962	71,100	59,400	1,900	1,500	134,000
1963	88,000	65,200	2,800	4,800	160,800
1964	81,900	59,800	1,300	1,200	144,200
1965	91,300	56,600	1,900	1,400	151,100
1966	85,600	42,700	1,700	1,300	131,200
1967	94,500	44,800	0	600	140,000
1968	77,700	36,600	700	0	115,000

* Small grains and miscellaneous crops.

TABLE D-XXIV

WELL-LOSS COEFFICIENTS, FORMATION-LOSS COEFFICIENTS, AND TRANSMISSIVITIES FROM ROUTINE STEP-DRAWDOWN TESTS IN THE PRINCIPAL CONFINED AQUIFER, ROSWELL BASIN, NEW MEXICO

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss coefficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
08S 24E 05 343	3.8	3.4	37
08S 24E 28 222	6.2	2.1	23
08S 24E 28 123	9.0	1.0	15
08S 24E 33 413	2.3	2.3	68
	4.7*	2.0*	31*
09S 24E 34 ---	8.4	6.7	16
	8.4*	6.7*	16*
10S 23E 27 222	3.0	0.2	50
10S 23E 24 143	3.0	0.5	53
10S 23E 34 432	9.4	2.3	14
	4.3*	0.6*	34*
10S 24E 15 131	0.4	1.1	387
10S 24E 15 323	9.8	33.2	14
10S 24E 15 332	1.8	5.3	86
10S 24E 15 342	8.5	53.1	16
10S 24E 17 141	5.0	5.8	27
10S 24E 17 324	4.3	5.6	33
10S 24E 20 234	1.7	1.0	89
10S 24E 21 424	8.4	0.7	166
10S 24E 22 331	3.6	0.5	40
10S 24E 22 343	1.0	2.0	162
10S 24E 27 421	12.3	25.0	11
	3.5*	4.2*	50*
11S 23E 03 100	8.1	20.7	17
11S 23E 12 442	0.8	4.6	199
11S 23E 12 444	3.3	5.2	44
11S 23E 13 232	3.8	2.8	39
11S 23E 28 223	1.4	0.7	97
	2.6*	4.0*	56*
11S 24E 01 313	9.6	3.5	13
11S 24E 04 114	0.7	0.4	225

TABLE D-XXIV continued

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss coefficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
11S 24E 06 310	9.1	4.2	15
11S 24E 08 124	0.4	1.0	410
11S 24E 08 124	8.8	2.2	16
11S 24E 11 243	2.2	1.6	68
11S 24E 12 113	0.3	0.9	670
11S 24E 12 231	2.3	7.6	65
11S 24E 13 233	7.5	1.7	19
11S 24E 14 213	4.1	1.4	36
11S 24E 14 324	0.3	1.1	640
11S 24E 14 343	5.0	1.1	27
11S 24E 15 431	13.4	1.1	11
11S 24E 18 242	1.3	0.3	98
11S 24E 18 333	7.1	29.5	20
11S 24E 19 ---	6.7	3.0	21
11S 24E 20 313	1.5	2.2	101
11S 24E 26 433	2.7	0.5	55
11S 24E 28 ---	6.4	21.6	22
11S 24E 28 313	15.3	12.2	8
11S 24E 36 211	8.1	21.6	17
	3.2*	2.4*	45*
11S 25E 29 333	8.1	4.7	17
11S 25E 32 133	2.2	3.0	66
	4.2*	3.7*	34*
12S 23E 01 413	2.1	1.3	71
12S 23E 06 214	6.8	0.2	21
	3.8*	0.5*	39*
12S 24E 21 333	3.9	4.2	37
	3.9*	4.2*	37*
12S 25E 13 111	0.8	0.6	205
12S 25E 35 131	0.4	1.1	445
	0.5*	0.8*	302*
13S 25E 13 133	8.5	26.3	16
13S 25E 24 333	0.7	3.1	232
13S 25E 26 411	2.5	0.1	61
	2.4*	2.0*	61*

TABLE D-XXIV continued

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss co-efficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
13S 26E 06 331	9.4	19.3	15
13S 26E 30 213	2.5	1.8	60
13S 26E 31 211	5.7	3.8	25
13S 26E 31 214	0.4	1.3	387
	2.8*	3.6*	54*
14S 26E 09 313	5.9	0.4	24
14S 26E 32 124	3.6	1.3	41
	4.6*	0.8*	32*
15S 25E 35 213	6.4	1.4	22
15S 25E 35 311	14.2	0.2	9
	9.5*	0.6*	14*
15S 26E 04 123	2.7	1.1	55
15S 26E 13 222	0.2	9.2	691
	0.8*	3.2*	195*
16S 24E 02 324	1.6	0.2	96
	1.6*	0.2*	96*
16S 25E 07 111	2.4	0.4	63
	2.4*	0.4*	63*
16S 26E 20 433	7.3	1.3	19
16S 26E 20 433	9.1	5.6	15
	8.1*	2.7*	17*
17S 26E 08 431	11.3	0.8	13
17S 26E 08 431	3.3	2.1	44
17S 26E 08 444	9.3	2.8	14
17S 26E 09 113	6.3	2.5	22
17S 26E 17 233	13.8	0.6	10
17S 26E 17 233	12.9	9.4	11
17S 26E 20 431	5.2	2.0	28

TABLE D-XXIV continued

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss coefficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
17S 26E 32 133	4.9	5.3	29
17S 26E 32 213	5.0	1.0	29
	7.2*	2.0*	20*
18S 26E 10 313	2.1	0.8	73
18S 26E 34 ---	7.9	3.5	18
18S 26E 34 ---	6.6	4.8	21
	4.8*	2.3*	30*
19S 26E 27 221	29.2	7.0	3
	29.2*	7.0*	3*

* Logarithmic average by township.

TABLE D-XXV

WELL-LOSS COEFFICIENTS, FORMATION-LOSS COEFFICIENTS, AND TRANSMISSIVITIES FROM ROUTINE STEP-DRAWDOWN TESTS IN THE UNCONFINED AQUIFER, ROSWELL BASIN, NEW MEXICO

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss co-efficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
10S 24E 36 413	22.6	4.7	3
	22.6*	4.7*	3*
11S 24E 02 221	30.6	1.6	2
11S 24E 12 321	5.5	0.7	13
11S 24E 13 144	4.7	3.8	15
11S 24E 14 314	16.3	1.3	9
	10.7*	1.5*	6*
11S 25E 06 332	20.4	2.0	3
11S 25E 06 332	30.2	1.7	2
11S 25E 16 ---	27.3	1.0	2
11S 25E 34 113	8.5	37.2	8
11S 25E 34 311	31.2	7.4	2
	21.4*	3.9*	3*
12S 25E 25 431	24.9	5.8	2
12S 25E 27 211	16.2	2.7	4
	20.1*	4.0*	3*
12S 26E 32 133	11.7	1.5	6
	11.7*	1.5*	6*
13S 25E 35 133	7.7	2.6	9
	7.7*	2.6*	9*
13S 26E 22 313	12.9	2.0	5
13S 26E 28 221	14.9	12.2	5
13S 26E 28 311	17.3	3.1	4
13S 26E 27 313	25.6	3.0	2
	17.1*	3.9*	4*

TABLE D-XXV continued

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss coefficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
14S 25E 13 311	5.7	0.3	12
	5.7*	0.3*	12*
14S 26E 03 433	3.2	6.8	23
14S 26E 06 142	7.4	1.1	9
14S 26E 06 211	2.0	1.9	39
14S 26E 08 342	31.1	38.9	2
14S 26E 08 433	10.3	1.0	7
14S 26E 09 221	10.9	2.0	6
14S 26E 10 133	0.5	0.9	181
14S 26E 14 113	19.4	21.3	3
14S 26E 17 233	4.7	0.6	15
14S 26E 17 444	0.3	11.7	287
14S 26E 18 211	3.9	2.0	18
14S 26E 18 324	10.7	2.3	6
14S 26E 20 ---	2.8	1.2	27
14S 26E 23 230	12.4	4.3	5
	4.8*	2.9*	15*
15S 26E 10 112	3.4	23.8	22
15S 26E 20 ---	8.1	3.7	8
15S 26E 29 321	0.5	2.7	184
15S 26E 29 344	6.9	10.4	10
15S 26E 32 344	6.3	9.5	11
	3.6*	7.5*	20*
16S 25E 06 223	4.6	0.4	15
16S 25E 25 211	24.5	0.7	3
	10.7*	0.5*	6*
16S 26E 19 411	13.0	0.9	5
16S 26E 29 331	13.6	5.7	5
16S 26E 32 213	17.7	0.1	4
16S 26E 32 311	20.7	4.8	3
	16.0*	1.4*	4*
17S 26E 08 ---	6.5	4.7	11
17S 26E 17 333	5.0	0.9	16
17S 26E 21 ---	12.4	15.1	5
17S 26E 35 133	9.5	11.5	7
	7.9*	5.2*	15*

TABLE D-XXV continued

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss coefficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
18S 26E 17 322	10.2	15.2	7
18S 26E 18 221	3.6	1.2	21
	6.0*	4.3*	12*
20S 26E 07 423	1.2	4.7	69
20S 26E 08 112	16.7	8.7	4
	4.5*	6.4*	16*

* Logarithmic average by township.

TABLE D-XXVI

WELL-LOSS COEFFICIENTS, FORMATION-LOSS COEFFICIENTS, AND TRANSMISSIVITIES FROM ROUTINE STEP-DRAWDOWN TESTS IN THE SHALLOW CONFINED AQUIFER, ROSWELL BASIN, NEW MEXICO

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss coefficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
08S 24E 35 224	33.2	3.4	4
08S 24E 35 343	2.5	1.0	60
	9.1*	1.8*	15*
09S 24E 02 414	9.4	1.2	63
09S 24E 02 421	8.7	6.5	16
09S 24E 11 133	3.0	2.7	50
	4.0*	2.8*	37*
10S 25E 31 413	13.4	0.5	10
	13.4*	0.5*	10*
11S 24E 01 334	0.6	1.7	282
11S 24E 06 310	9.1	4.2	15
11S 24E 06 423	0.8	0.7	184
11S 24E 18 333	7.1	29.5	20
11S 24E 18 444	3.5	7.1	42
	2.6*	4.0*	58*
11S 25E 08 123	17.1	3.3	8
11S 25E 28 243	6.4	5.5	22
11S 25E 28 234	15.5	12.9	9
	11.9*	6.1*	11*
12S 25E 05 111	0.5	14.0	302
12S 25E 36 111	33.5	1.9	4
	4.2*	5.1*	35*
13S 24E 25 212	42.0	6.7	3
	42.0*	6.7*	3*

TABLE D-XXVI continued

Well location	Formation-loss coefficient B ft/(ft^3/sec)	Well-loss coefficient C ft/(ft^3/sec)^2	Transmissivity T in thousands of ft^2/day
13S 25E 12 ---	8.4	0.3	16
13S 25E 35 232	9.3	0.5	15
13S 25E 27 211	6.2	0.1	23
	7.8*	0.2*	18*
14S 24E 18 222	7.5	0.6	19
	7.5*	0.6*	19*
14S 25E 12 331	11.2	4.6	12
	11.2*	4.6*	12*

* Logarithmic average by townships.

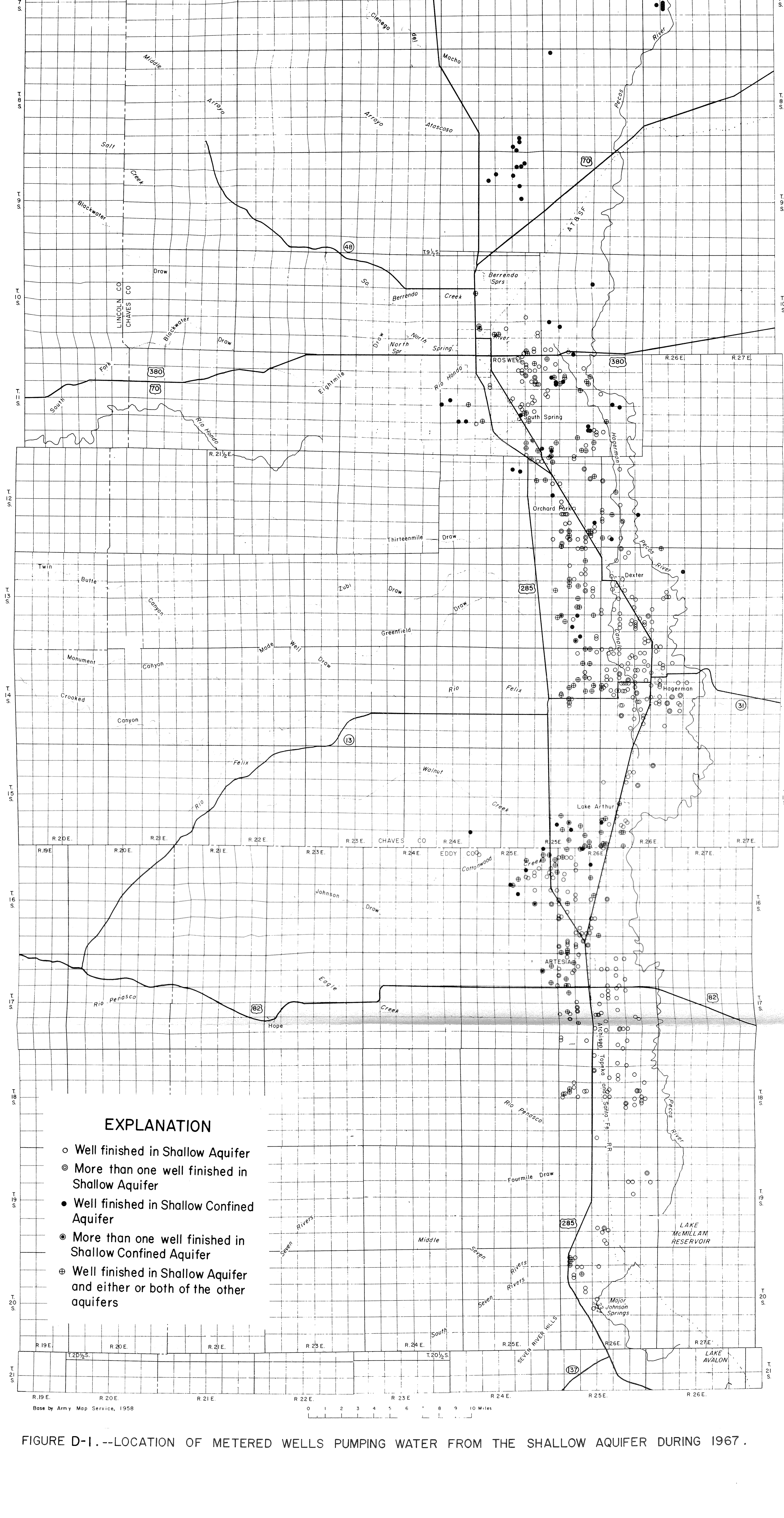
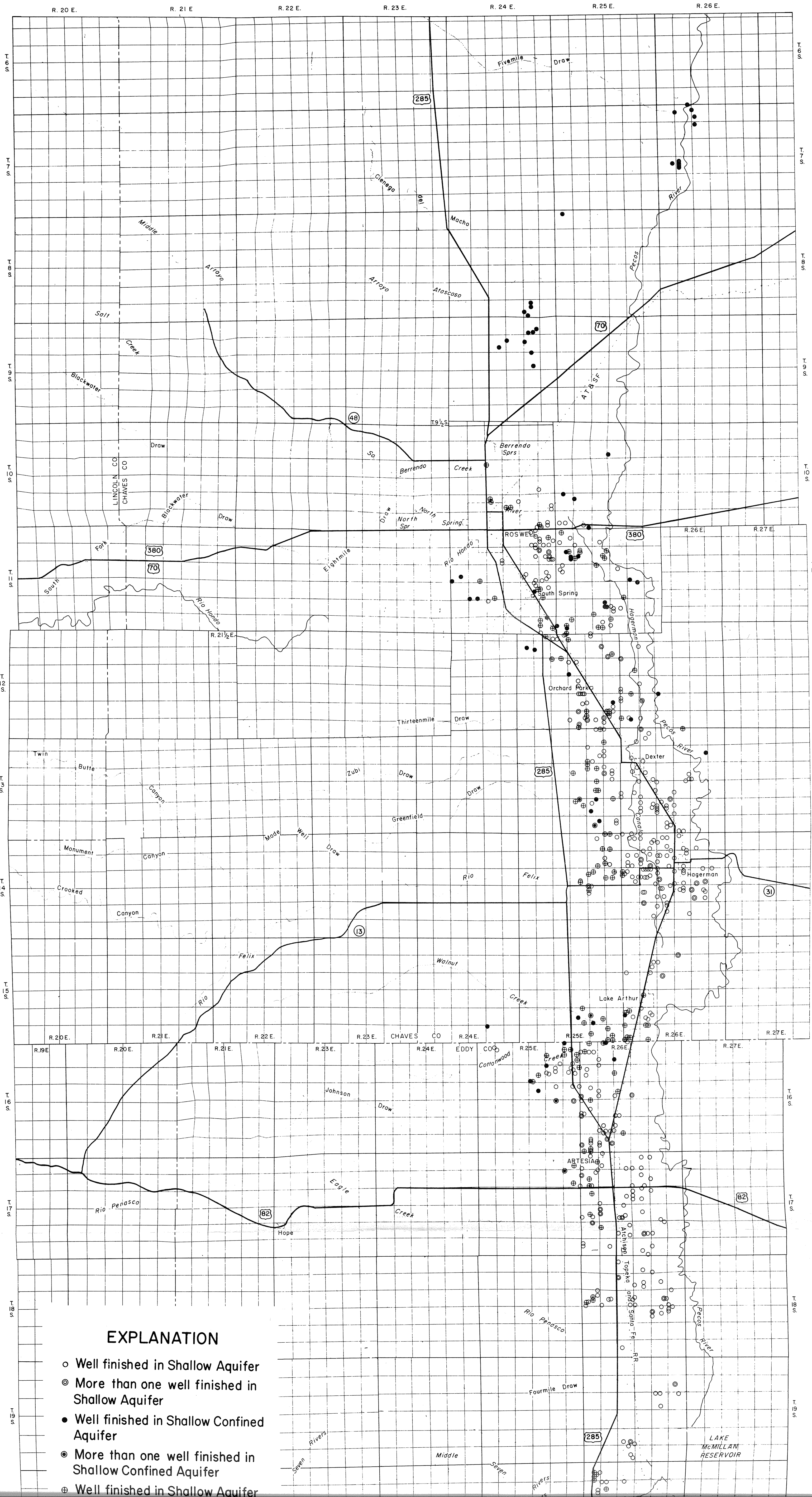


FIGURE D-1.--LOCATION OF METERED WELLS PUMPING WATER FROM THE SHALLOW AQUIFER DURING 1967.



EXPLANATION

- ○ Well finished in Shallow Aquifer
- ◎ More than one well finished in Shallow Aquifer
- ● Well finished in Shallow Confined Aquifer
- ◉ More than one well finished in Shallow Confined Aquifer
- ⊕ Well finished in Shallow Aquifer

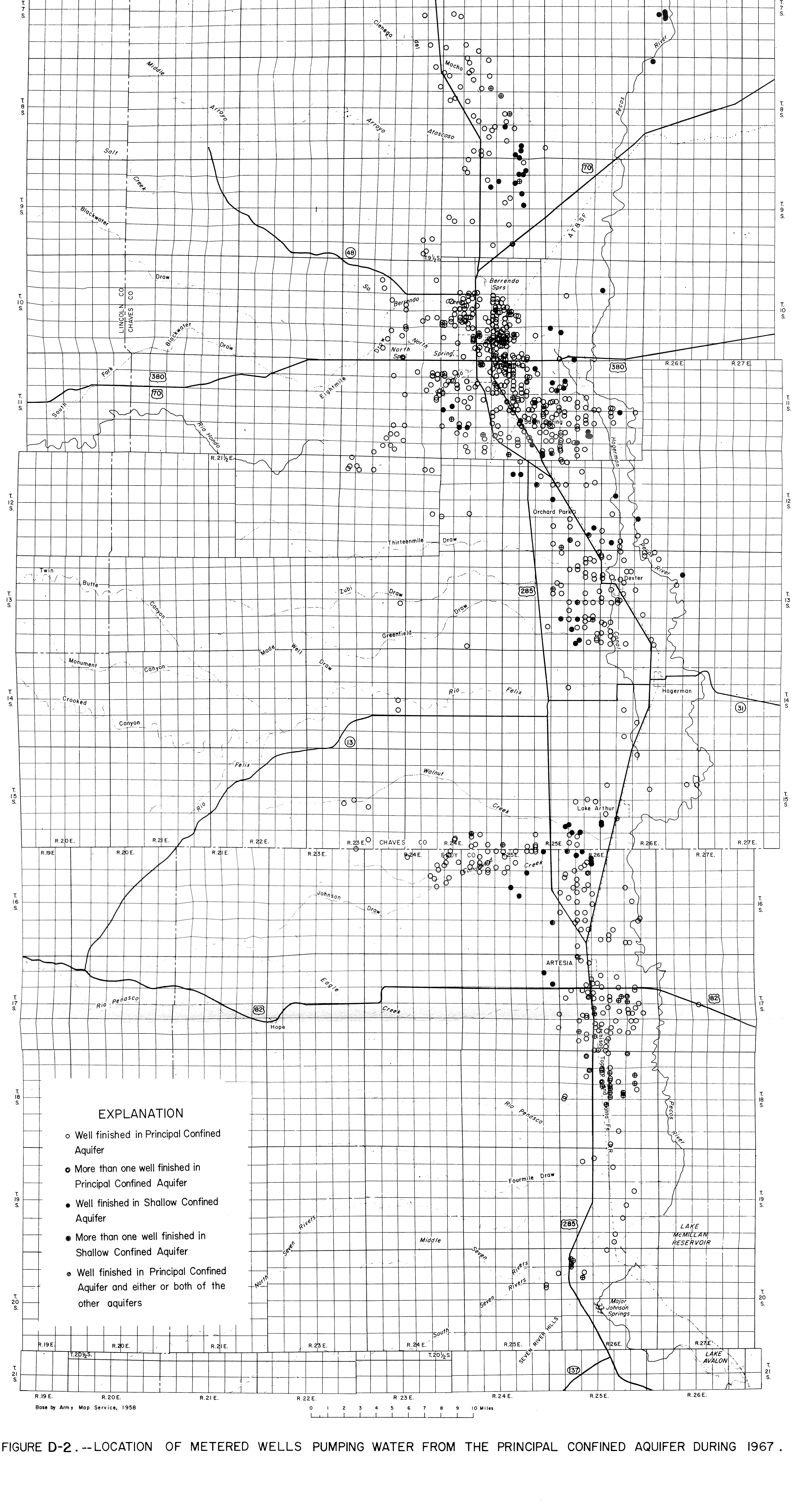
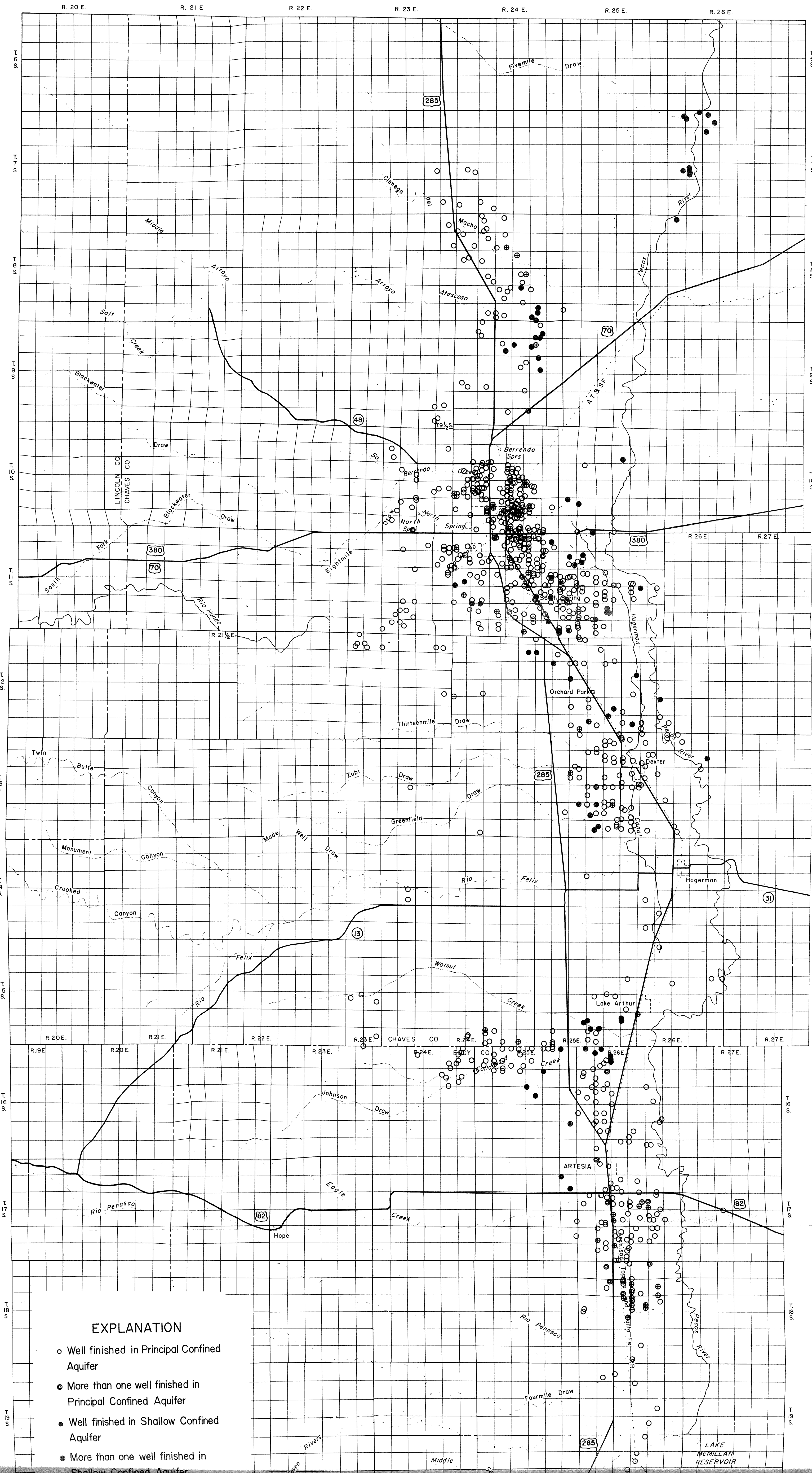


FIGURE D-2.--LOCATION OF METERED WELLS PUMPING WATER FROM THE PRINCIPAL CONFINED AQUIFER DURING 1967.



R. 20 E.
R. 21 E
R. 22 E.
R. 23 E.
R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
T. 10 S.
T. 11 S.
T. 12 S.
T. 13 S.
T. 14 S.
T. 15 S.
T. 16 S.
T. 17 S.
T. 18 S.
T. 19 S.
Fivemile Draw
Cienega del Macho
Middle Arroyo
Arroyo Atascoso
Salt Creek
Blackwater Draw
LINCOLN CO
CHAVES CO
South Fork
Rio Hondo
Berrendo Sprs
Berrendo Creek
North Spring
Eightmile
South Spring
Hogerman Canal
Orchard Park
Thirteenmile Draw
Pecos River
Dexter
Twin Butte Canyon
Zubi Draw
Greenfield Draw
Made Well Draw
Monument Canyon
Crooked Canyon
Rio Felix
Hagerman
Walnut Creek
Lake Arthur
CHAVES CO
EDDY CO
Cottonwood Creek
Johnson Draw
ARTESIA
Eagle Creek
Rio Penasco
Hope
Atchison Topeka and Santa Fe R.R.
Fourmile Draw
Rivers
Middle
LAKE MCMILLAN RESERVOIR
A.T.&S.F.
285
70
380
48
13
31
82
EXPLANATION
Well finished in Principal Confined Aquifer
More than one well finished in Principal Confined Aquifer
Well finished in Shallow Confined Aquifer
More than one well finished in Shallow Confined Aquifer

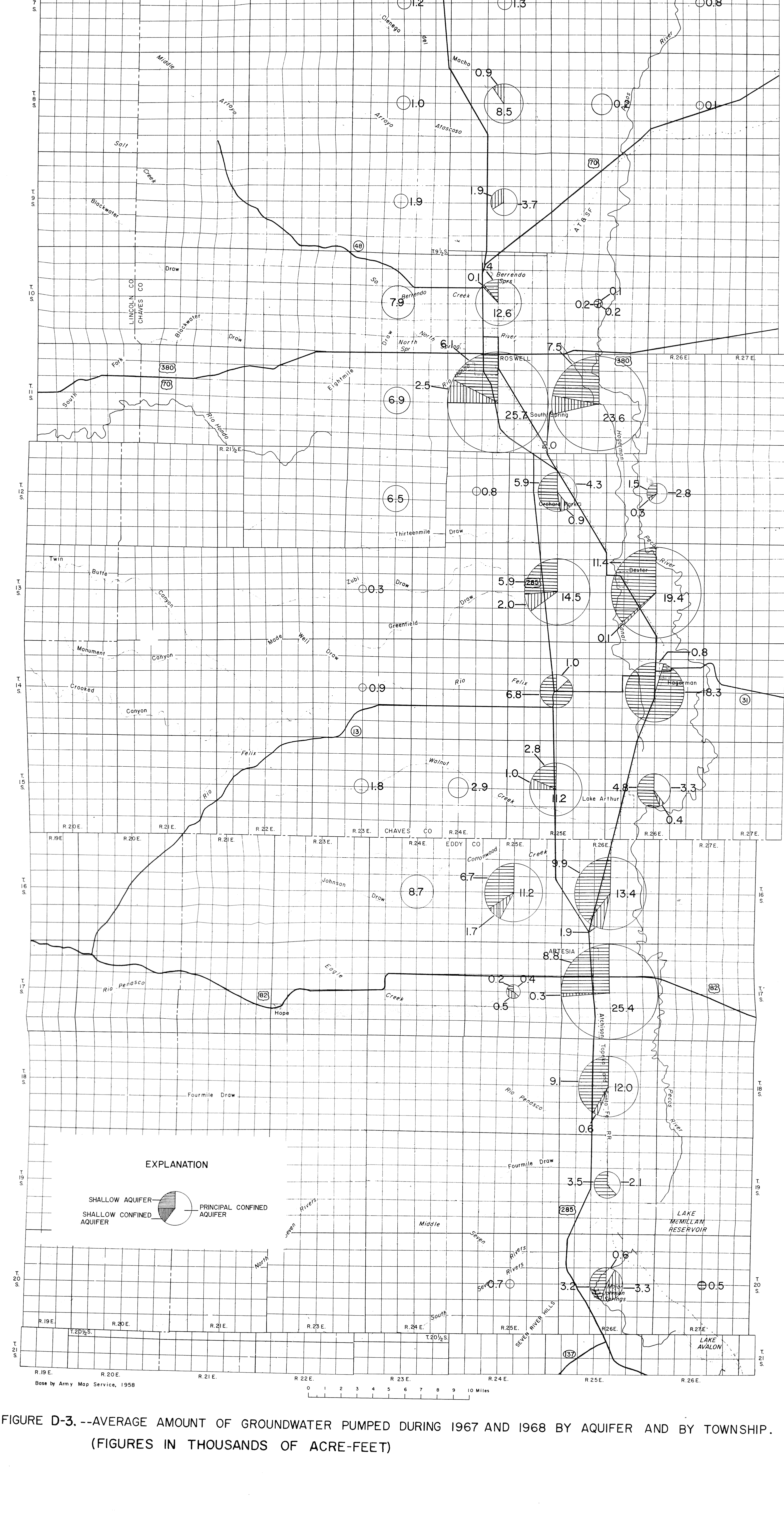
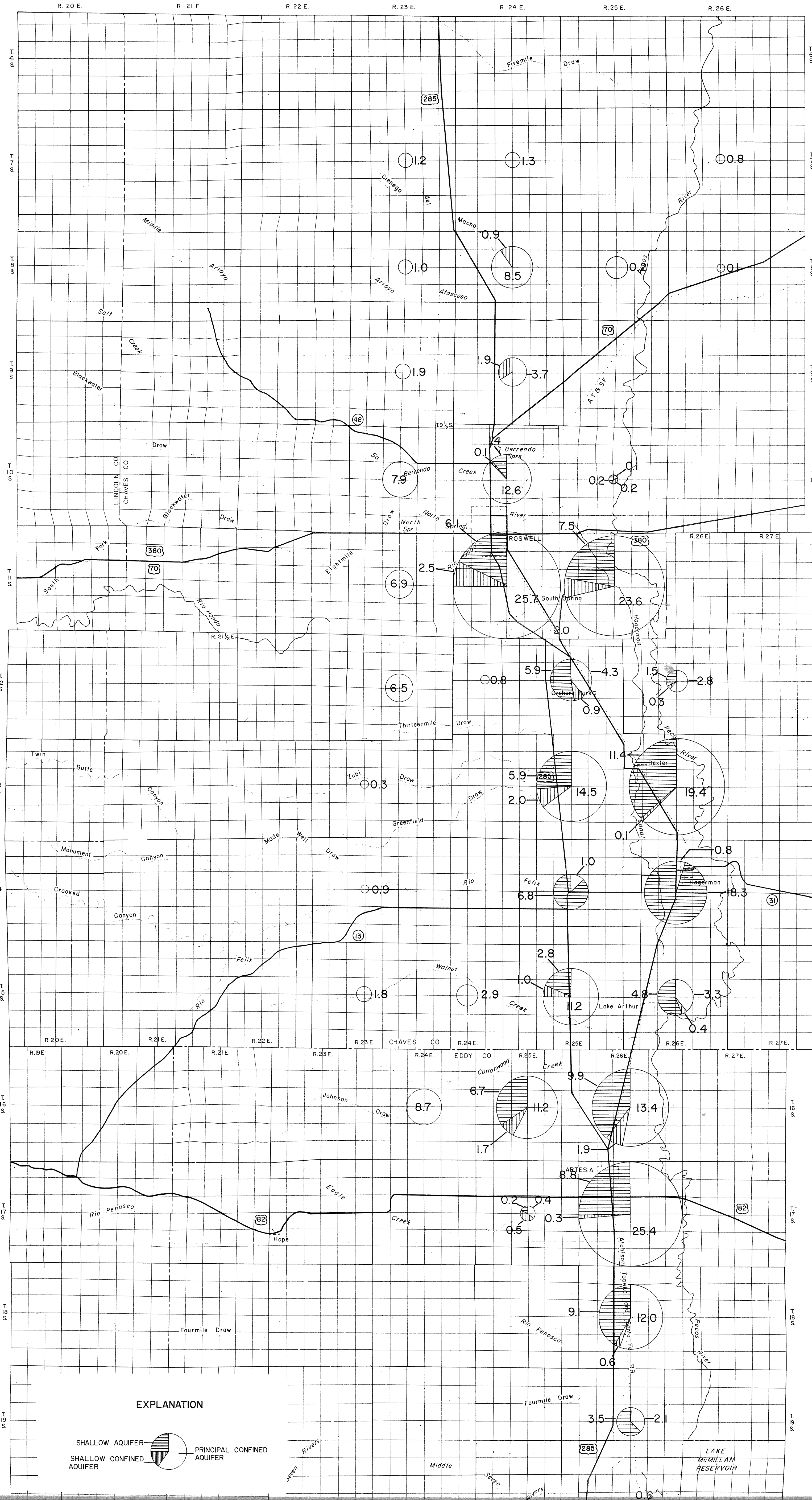


FIGURE D-3. --AVERAGE AMOUNT OF GROUNDWATER PUMPED DURING 1967 AND 1968 BY AQUIFER AND BY TOWNSHIP. (FIGURES IN THOUSANDS OF ACRE-FEET)


EXPLANATION
SHALLOW AQUIFER
SHALLOW CONFINED AQUIFER
PRINCIPAL CONFINED AQUIFER
ROSWELL
ARTESIA
Hagerman
Dexter
Lake Arthur
Hope
CHAVES CO
EDDY CO
LINCOLN CO
Pecos River
Rio Hondo
Rio Felix
Rio Penasco
LAKE McMILLAN RESERVOIR
Atchison Topeka and Santa Fe RR
Berrendo Sprs
South Spring
Orchard Park
Fivemile Draw
Thirteenmile Draw
Fourmile Draw
Eightmile
Walnut Creek
Cottonwood Creek
Eagle Creek
Johnson Draw

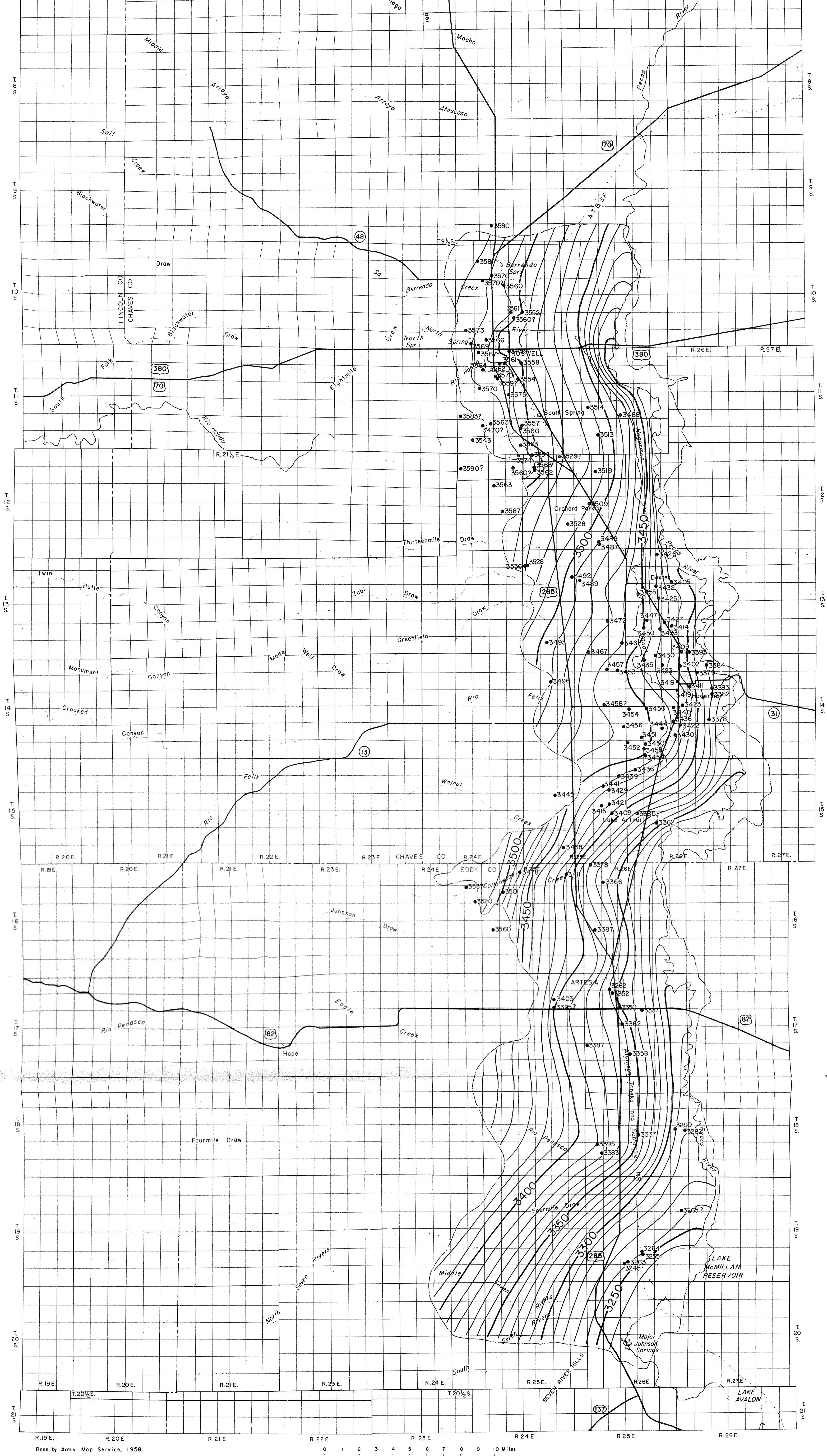
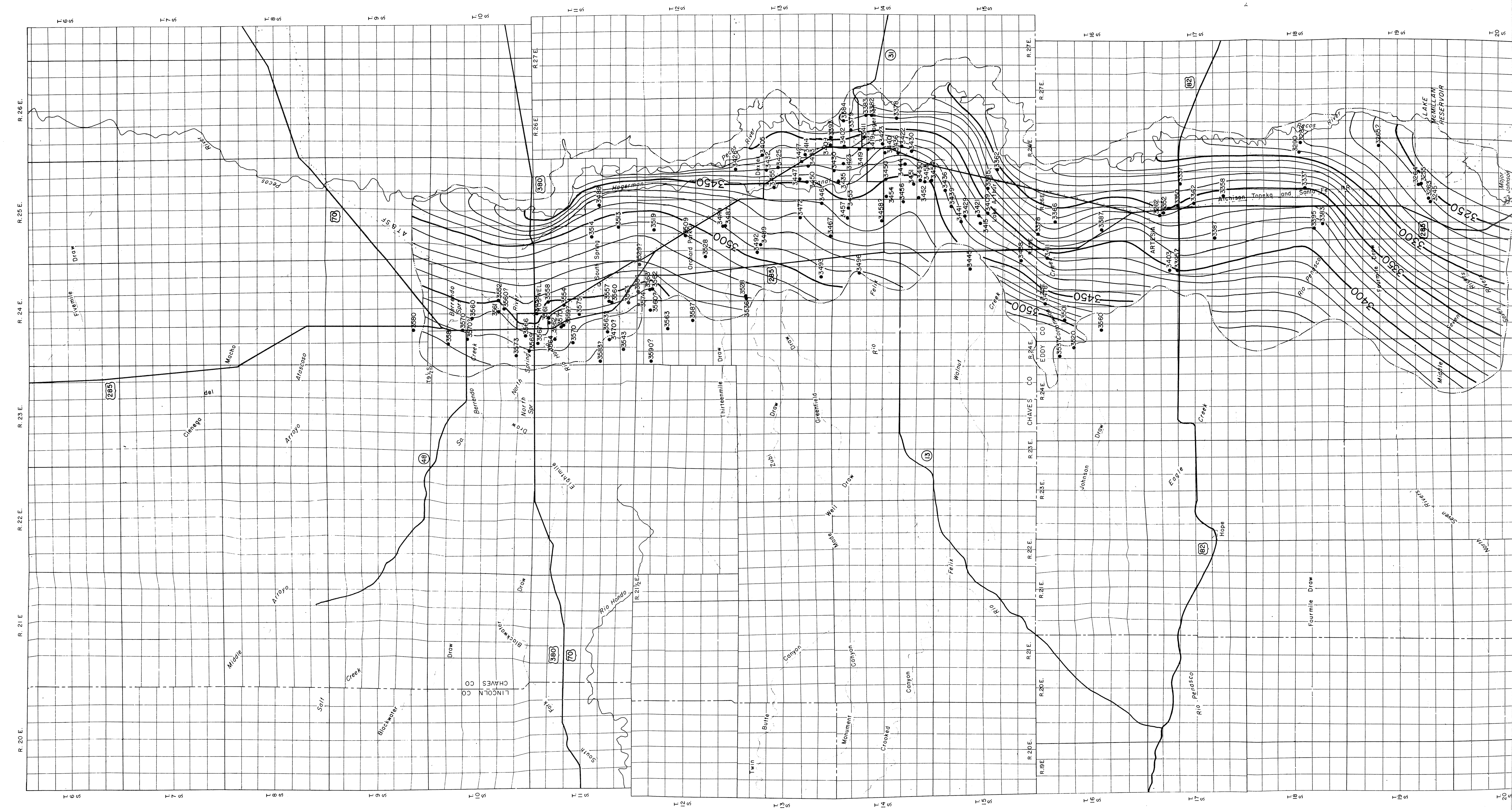


FIGURE D-4. --WATER-TABLE CONTOURS IN THE SHALLOW AQUIFER, JANUARY 1926.

(All control shown. Water-level elevations from U.S.G.S.)



LAKE McMILLAN RESERVOIR
Pecos River
Hagerman
Dexter
Lake Arthur
ARTESIA
Atchison Topeka and Santa Fe R.R.
Orchard Park
South Spring
Berrendo Spr.
Rio Hondo
Rio Felix
Rio Penasco
Fourmile Draw
Walnut Creek
Cottonwood Creek
Eagle Creek
Hope
Johnson Draw
Seven Rivers
Middle Arroyo
Salt Creek
Blackwater Draw
Macho
Arroyo del Alamosa
Cienega del Macho
Fivemile Draw
Thirteenmile Draw
Eightmile Draw
Greenfield Draw
Zuni Draw
Well Draw
Monument Canyon
Crooked Canyon
Twin Butte Canyon
North Spring River
CHAVES CO
EDDY CO
LINCOLN CO
3500
3450
3400
3350
3250

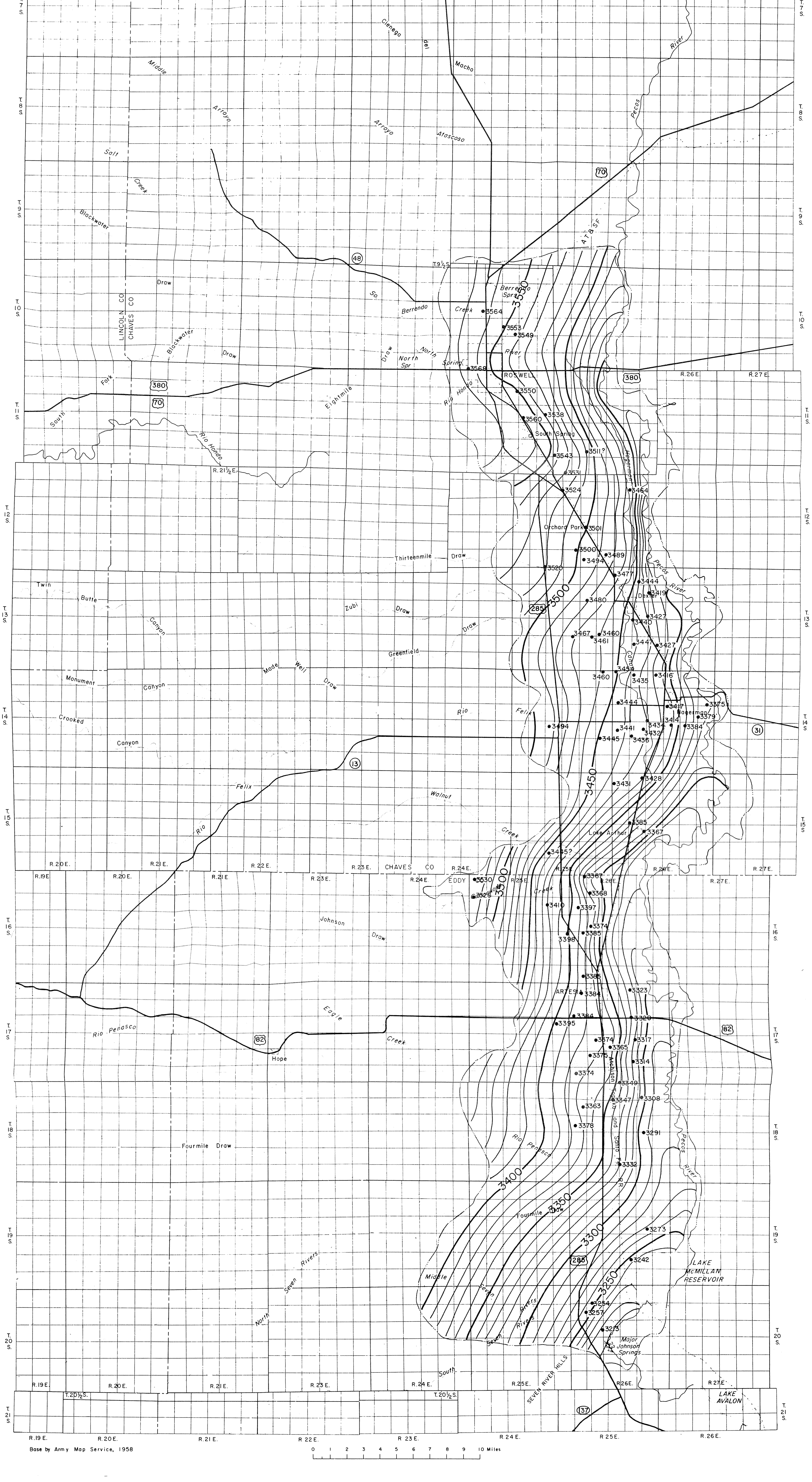
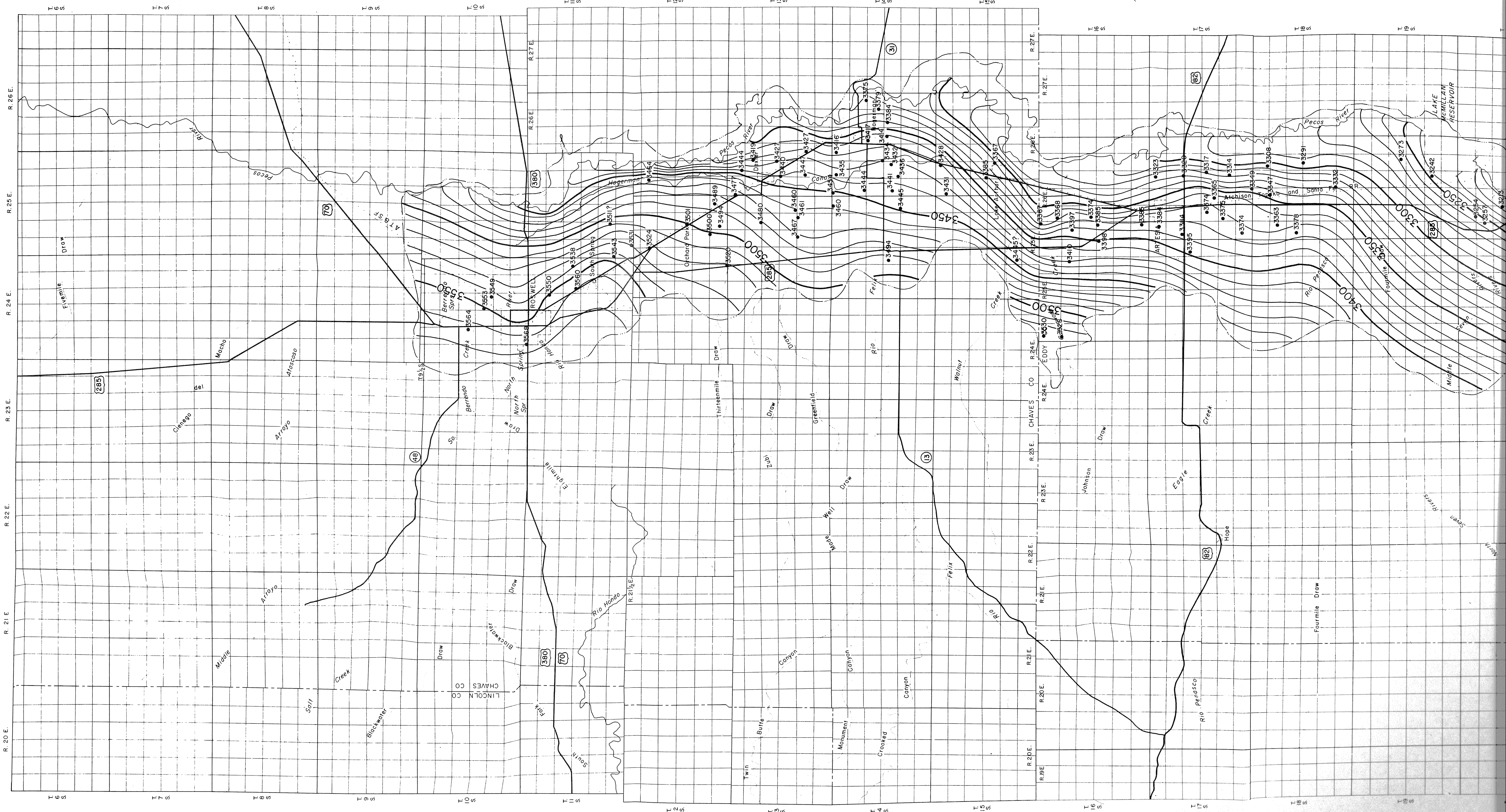


FIGURE D-5. --WATER-TABLE CONTOURS IN THE SHALLOW AQUIFER, JANUARY 1938.

(All control shown. Water-level elevations from U.S.G.S.)



T 6 S
T 7 S
T 8 S
T 9 S
T 10 S
T 11 S
T 12 S
T 13 S
T 14 S
T 15 S
T 16 S
T 17 S
T 18 S
T 19 S
R. 26 E.
R. 25 E.
R. 24 E.
R. 23 E.
R. 22 E.
R. 21 E.
R. 20 E.
R. 27 E.
ROSWELL
ARTESIA
Hagerman
Lake Arthur
Hope
Pecos River
LAKE McMILLAN RESERVOIR
Rio Felix
Rio Penasco
Rio Hondo
Fivemile Draw
Arroyo del Macho
Cienega del Macho
Atascoso
Salt Creek
Blackwater Draw
Middle Arroyo
Berrendo Creek
North Spring River
Thirteenmile Draw
Greenfield Draw
Walnut Creek
Eagle Creek
Fourmile Draw
Johnson Draw
Twin Butte Canyon
Monument Canyon
Crooked Canyon
Orchard Park
Dexter
Cottonwood
LINCOLN CO
CHAVES CO
EDDY CO
Atchison Topeka and Santa Fe R.R.
3550
3500
3450
3400
3350
285
380
70
48
13
31
82

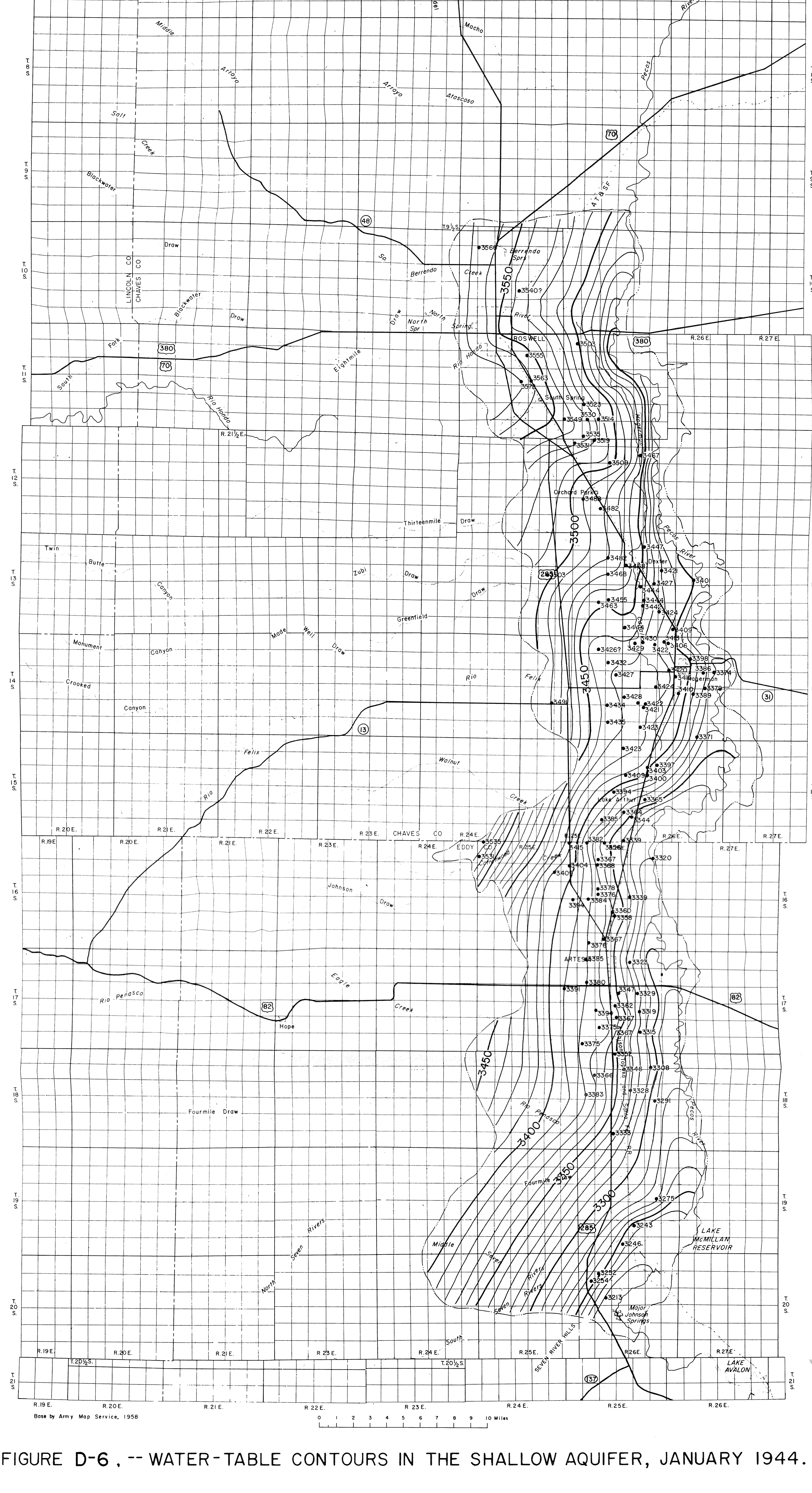
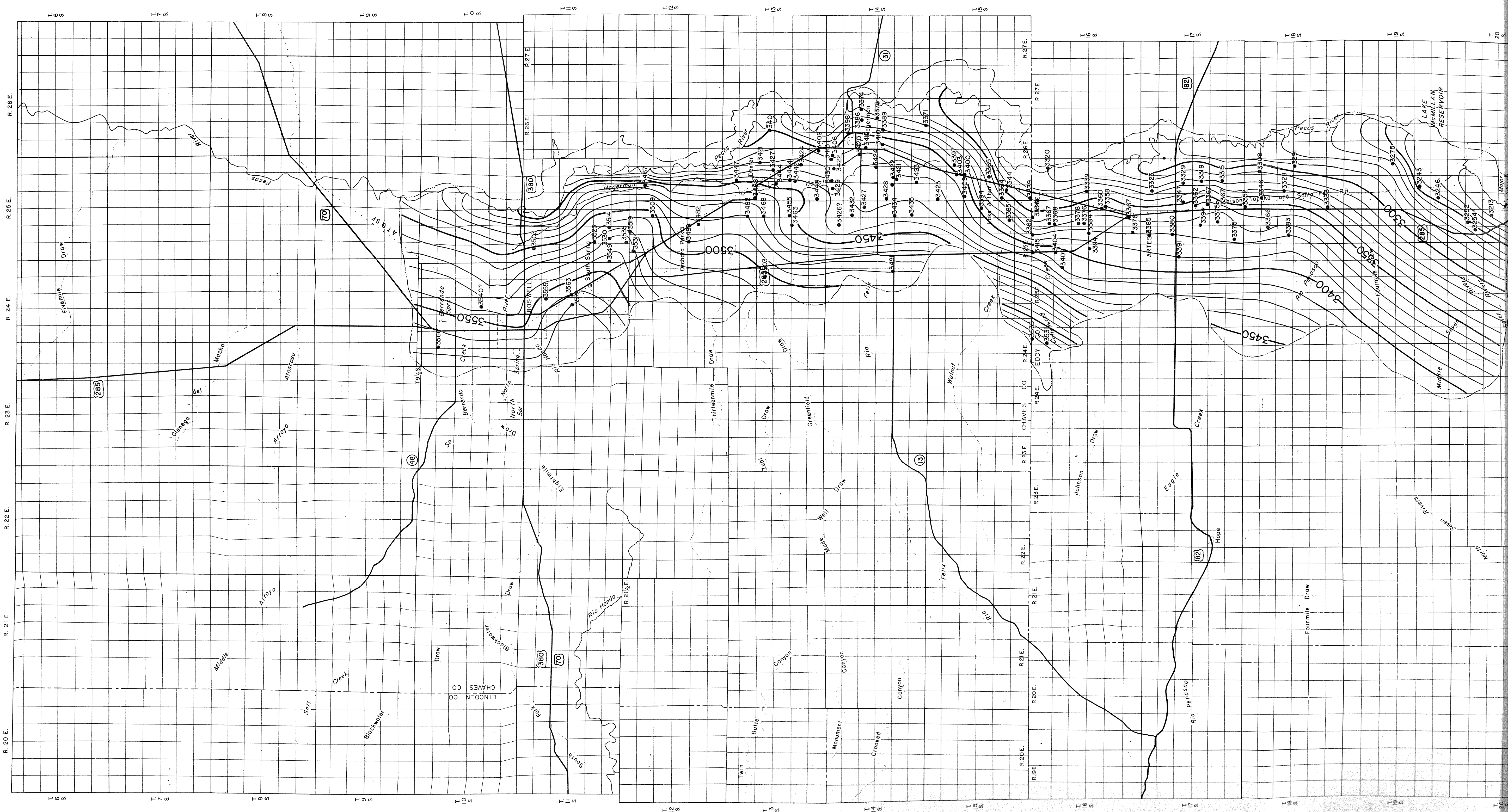


FIGURE D-6. -- WATER-TABLE CONTOURS IN THE SHALLOW AQUIFER, JANUARY 1944.

(All control shown. Water-level elevations from U.S.G.S.)



T 6 S
T 7 S
T 8 S
T 9 S
T 10 S
T 11 S
T 12 S
T 13 S
T 14 S
T 15 S
T 16 S
T 17 S
T 18 S
T 19 S
T 20 S
R. 26 E.
R. 25 E.
R. 24 E.
R. 23 E.
R. 22 E.
R. 21 E
R. 20 E.
R. 27 E.
R. 26E.
R. 21½ E.
Pecos River
Hagerman
Dexter
ROSWELL
ARTESIA
LAKE McMILLAN RESERVOIR
Fivemile Draw
Macho
Cienega del Arroyo
Arroyo Alascoso
Berrendo Spr
Berrendo Creek
So. Berrendo
North Spring River
North Spr Draw
South Spring
Orchard Park
Rio Hondo
Rio Felix
Felix
Walnut Creek
Eightmile
Blackwater Draw
Middle Arroyo
Salt Creek
Blackwater
South Fork
Thirteenmile Draw
Zuni Draw
Greenfield
Middle Well Draw
Twin Butte Canyon
Monument Canyon
Crooked Canyon
Johnson Draw
Eagle Creek
Hope
Rio Penasco
Fourmile Draw
Seven Rivers
North
Middle
Cottonwood Creek
CHAVES CO
EDDY CO
LINCOLN CO
A T & S F
3550
3500
3450
3400
3350
3300
285
70
380
48
13
31
82

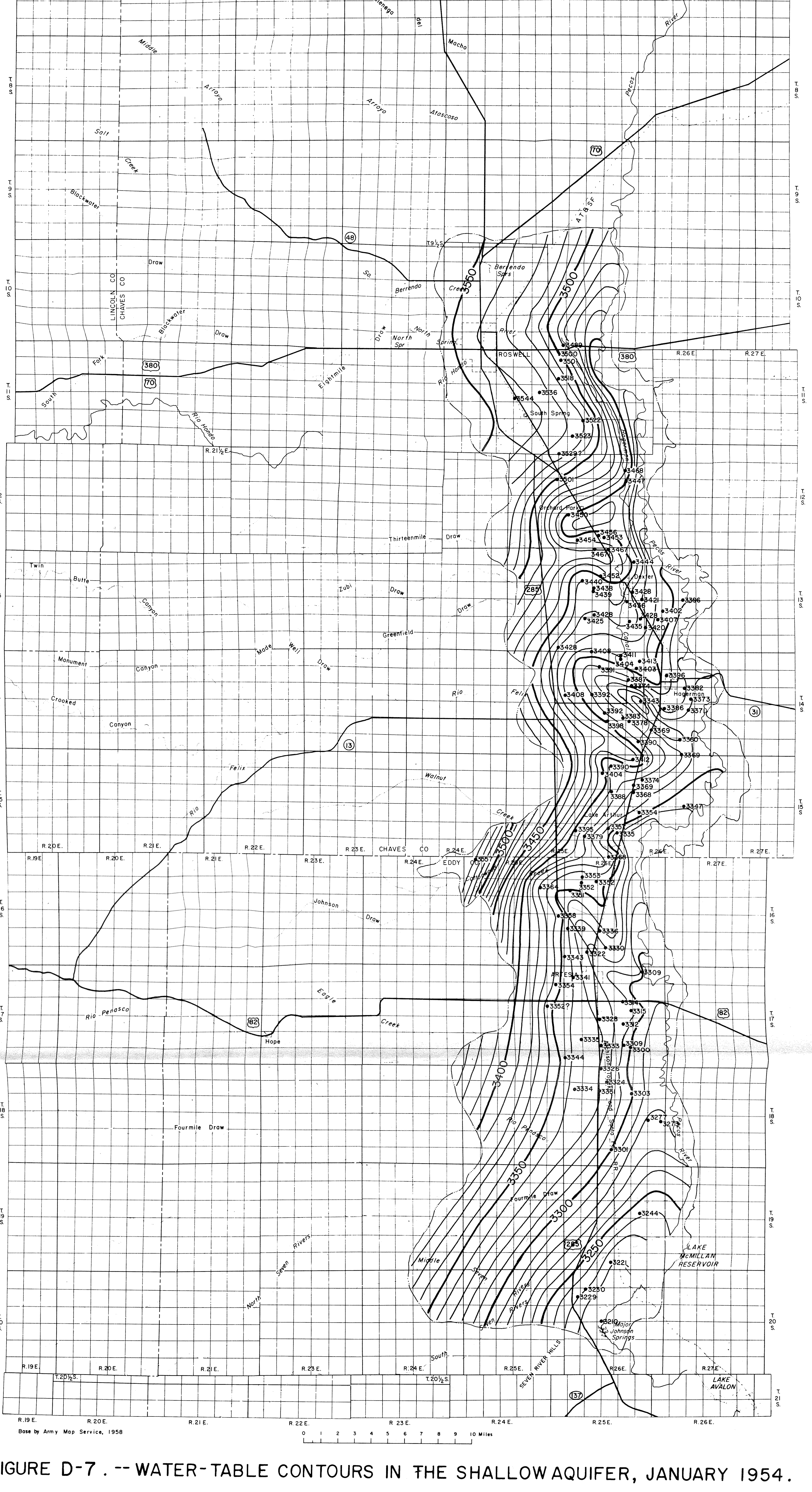
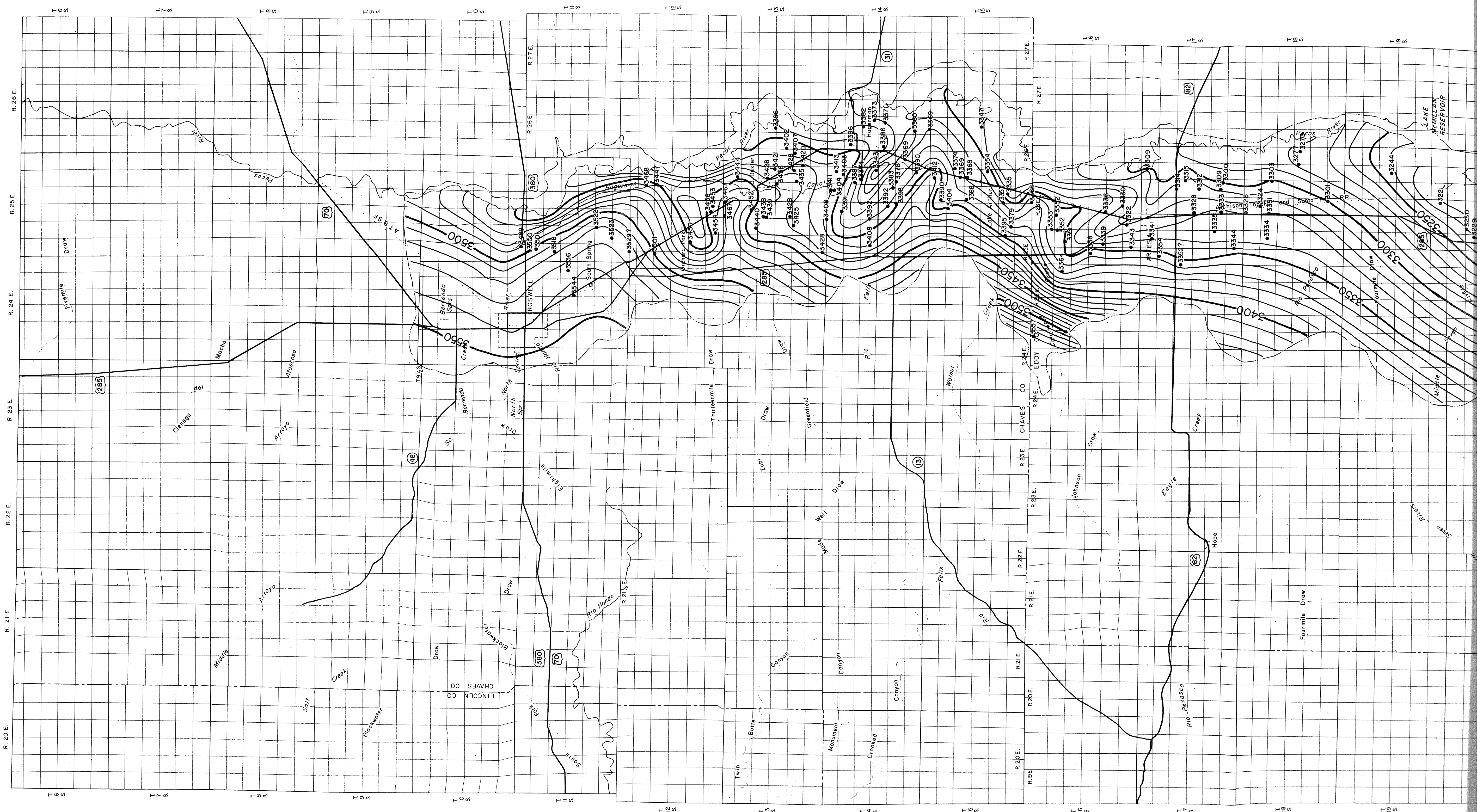


FIGURE D-7. -- WATER-TABLE CONTOURS IN THE SHALLOW AQUIFER, JANUARY 1954.

(All control shown. Water-level elevations from U.S.G.S.)



ROSWELL
LAKE McMILLAN RESERVOIR
Pecos River
Hagerman
Rio Hondo
Rio Felix
Rio Penasco
Fivemile Draw
Macho Draw
Cienega del Macho
Arroyo Atascoso
Berrendo Creek
Berrendo Sprs
South Spring
Thirteenmile Draw
Greenfield Draw
Mule Well Draw
Walnut Creek
Johnson Draw
Eagle Creek
Hope
Fourmile Draw
Seven Rivers
Blackwater Draw
Middle Arroyo
Salt Creek
Twin Butte Canyon
Monument Canyon
Crooked Canyon
Eightmile Draw
South Fork
CHAVES CO
EDDY CO
LINCOLN CO
3550
3500
3450
3400
3350
3300
3250
R. 20 E.
R. 21 E.
R. 22 E.
R. 23 E.
R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
T. 10 S.
T. 11 S.
T. 12 S.
T. 13 S.
T. 14 S.
T. 15 S.
T. 16 S.
T. 17 S.
T. 18 S.
T. 19 S.

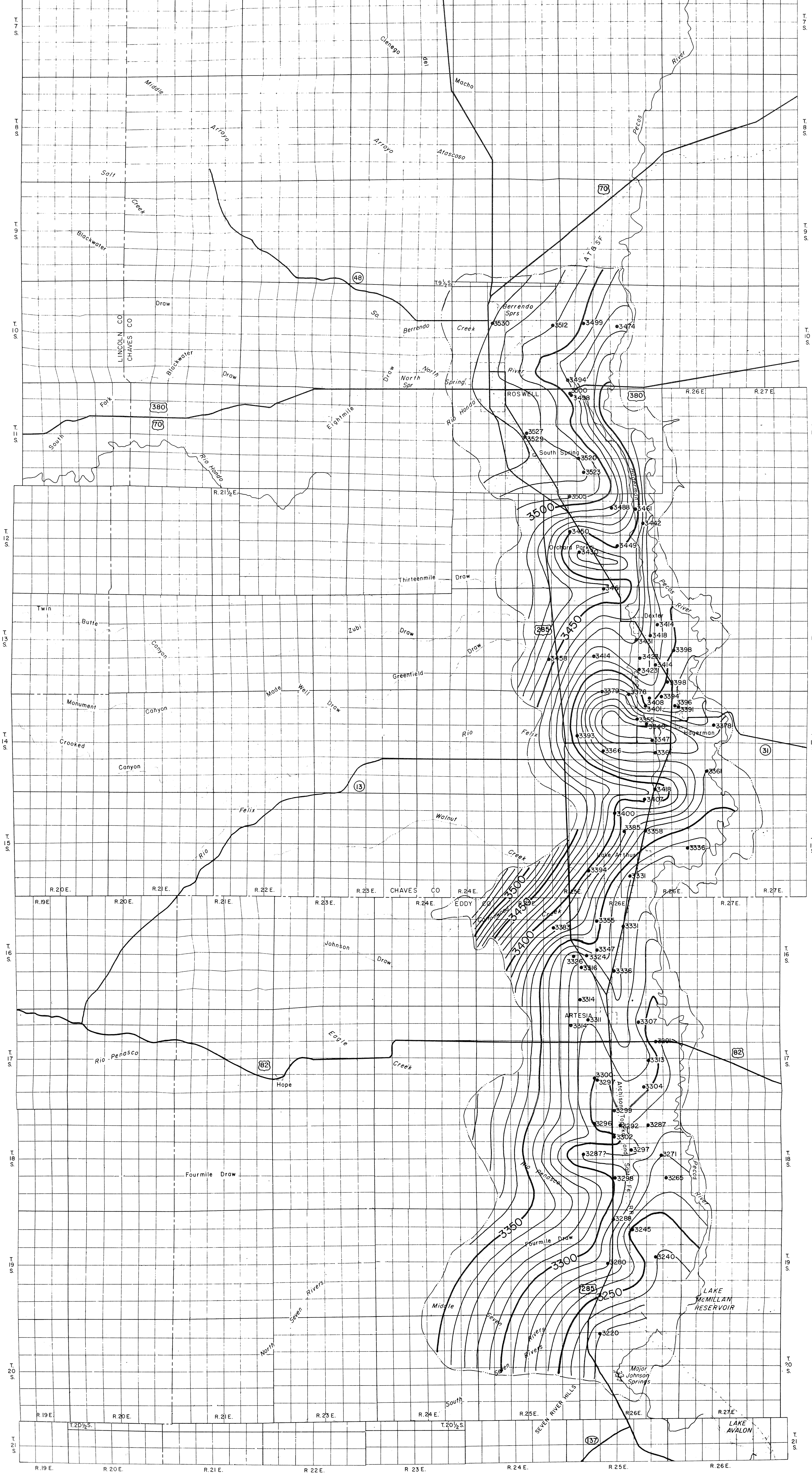


FIGURE D-8. --WATER-TABLE CONTOURS IN THE SHALLOW AQUIFER, JANUARY 1964.

(All control shown, Water-level elevations from U.S.G.S.)

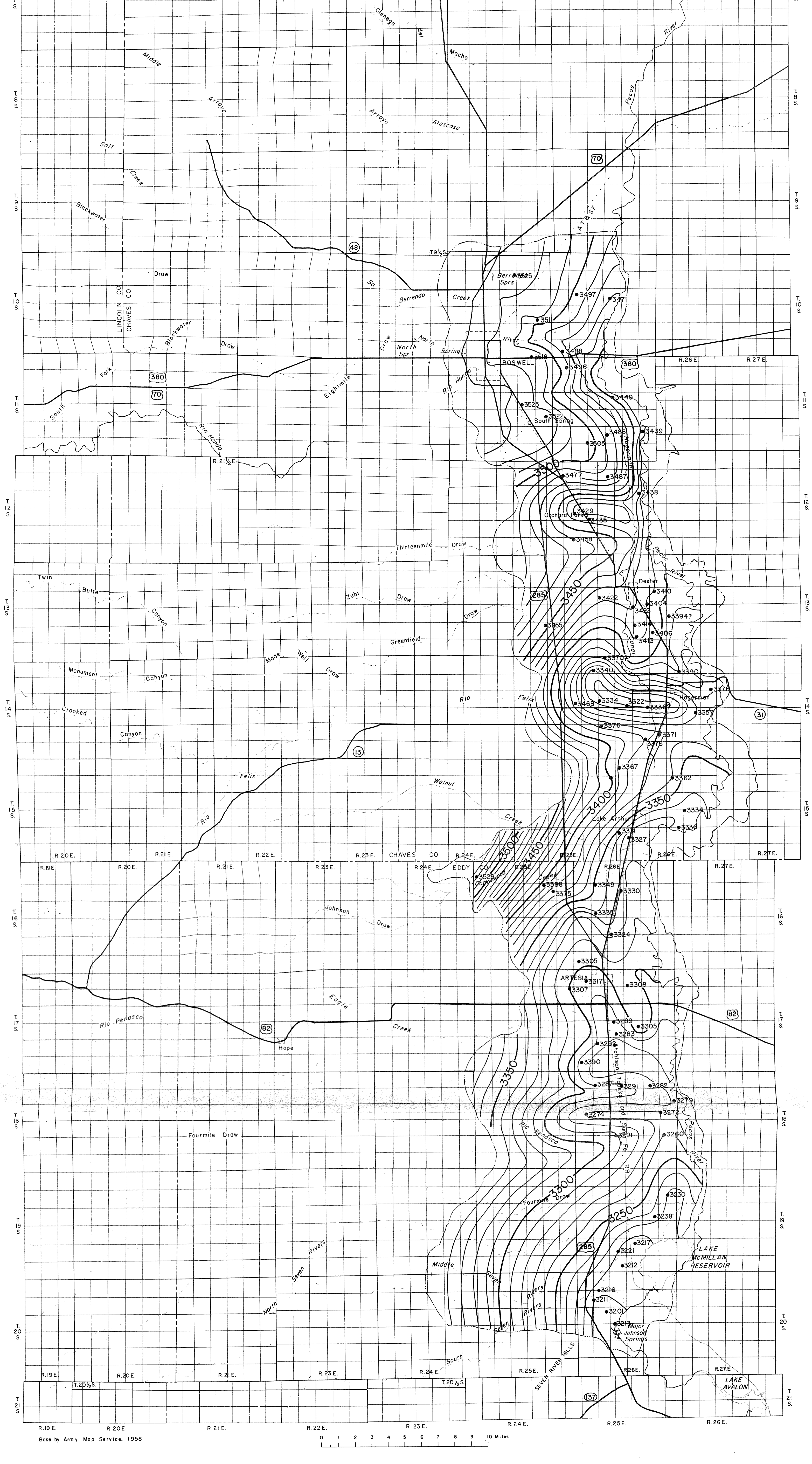
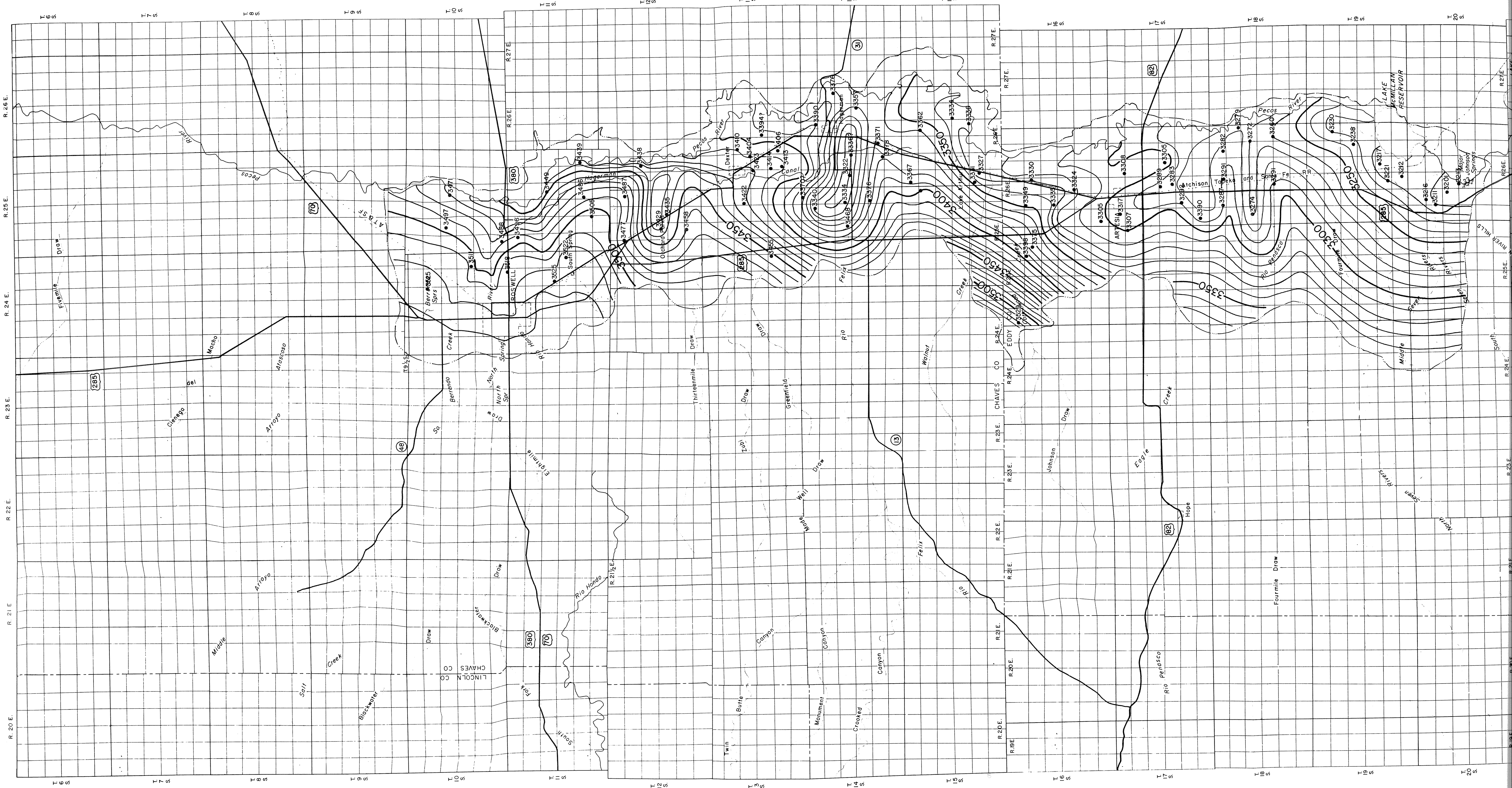


FIGURE D-9-- WATER-TABLE CONTOURS IN THE SHALLOW AQUIFER, JANUARY 1969.

(All control shown. Water-level elevations from U.S.G.S.)



T 6 S.
T 7 S.
T 8 S.
T 9 S.
T 10 S.
T 11 S.
T 12 S.
T 13 S.
T 14 S.
T 15 S.
T 16 S.
T 17 S.
T 18 S.
T 19 S.
T 20 S.
R. 26 E.
R. 25 E.
R. 24 E.
R. 23 E.
R. 22 E.
R. 21 E.
R. 20 E.
R. 27 E.
Pecos River
ROSWELL
Hagerman
Dexter
ARTESIA
LAKE McMILLAN RESERVOIR
Hope
EDDY CO
CHAVES CO
LINCOLN CO
Atchison Topeka and Santa Fe R.R.
Rio Hondo
Rio Felix
Rio Penasco
Fourmile Draw
Eagle Creek
Walnut Creek
Johnson Draw
Thirteenmile Draw
Eightmile Draw
Fivemile Draw
Arroyo del Macho
Salt Creek
Blackwater Draw
Berrendo Creek
North Spring River
South Spring
Orchard Park
Zuni Draw
Greenfield Draw
Mame Well Draw
Twin Butte Canyon
Monument Canyon
Crooked Canyon
Seven Rivers
Major Johnson Springs
River Hills
285
70
380
48
31
13
82
3250
3300
3350
3400
3450
3500

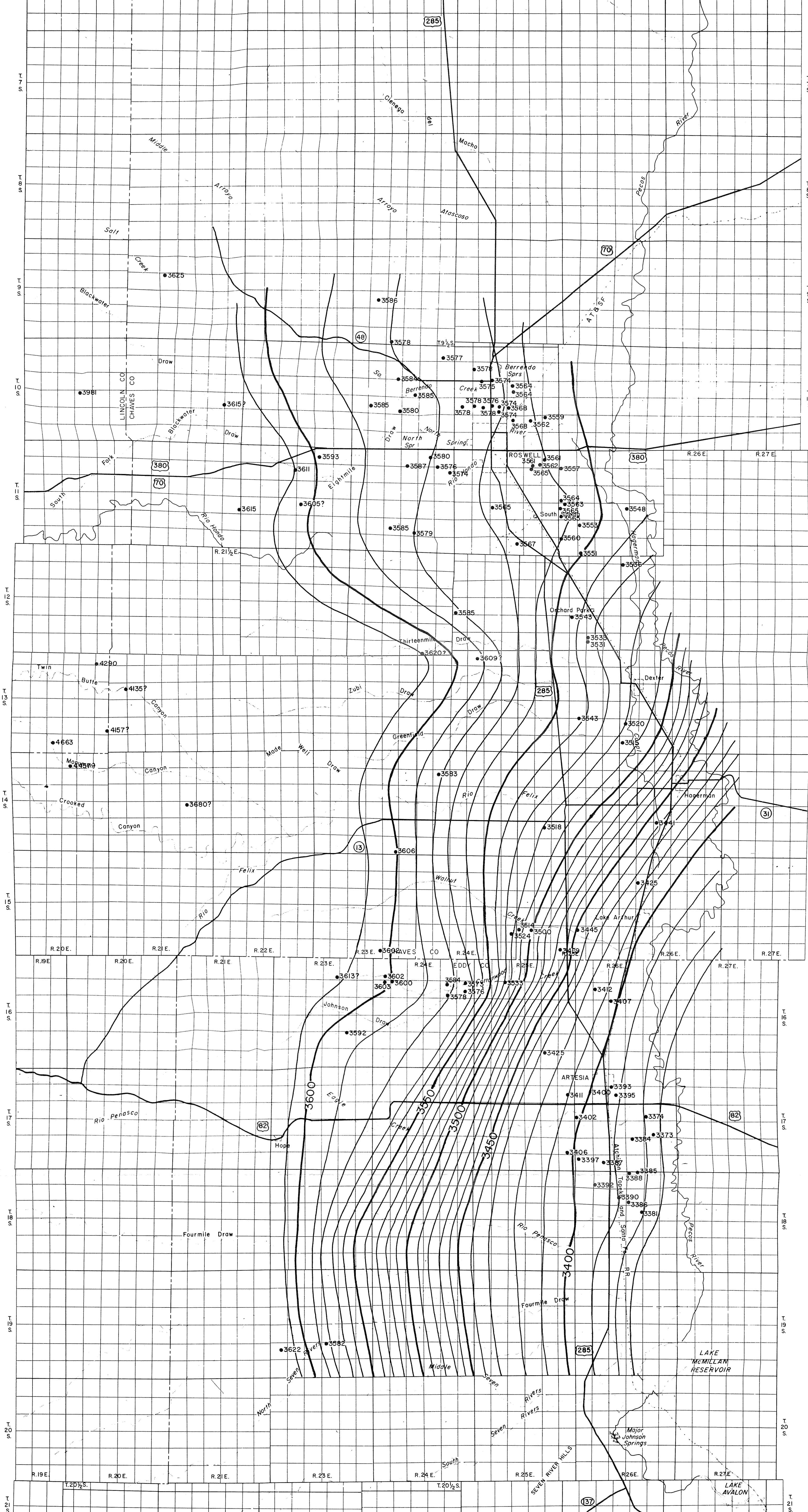


FIGURE D-10. -- POTENTIOMETRIC-SURFACE CONTOURS IN THE PRINCIPAL CONFINED AQUIFER, JANUARY 1926.

(All control shown. Potentiometric surface elevations from U.S.G.S.)

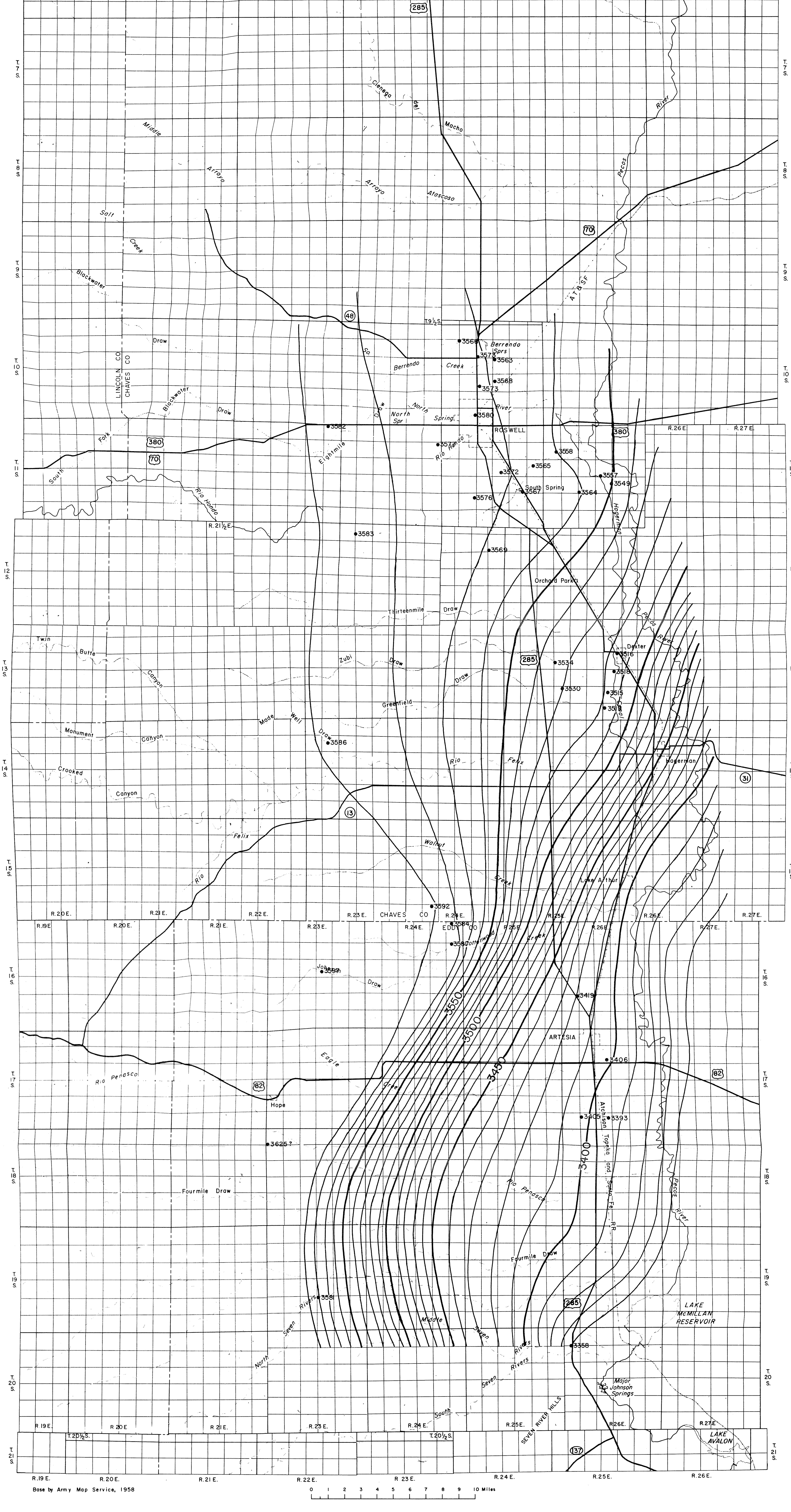


FIGURE D-11. --POTENTIOMETRIC-SURFACE CONTOURS IN THE PRINCIPAL CONFINED AQUIFER, JANUARY 1944.

(All control shown. Potentiometric surface elevations from U.S.G.S.)

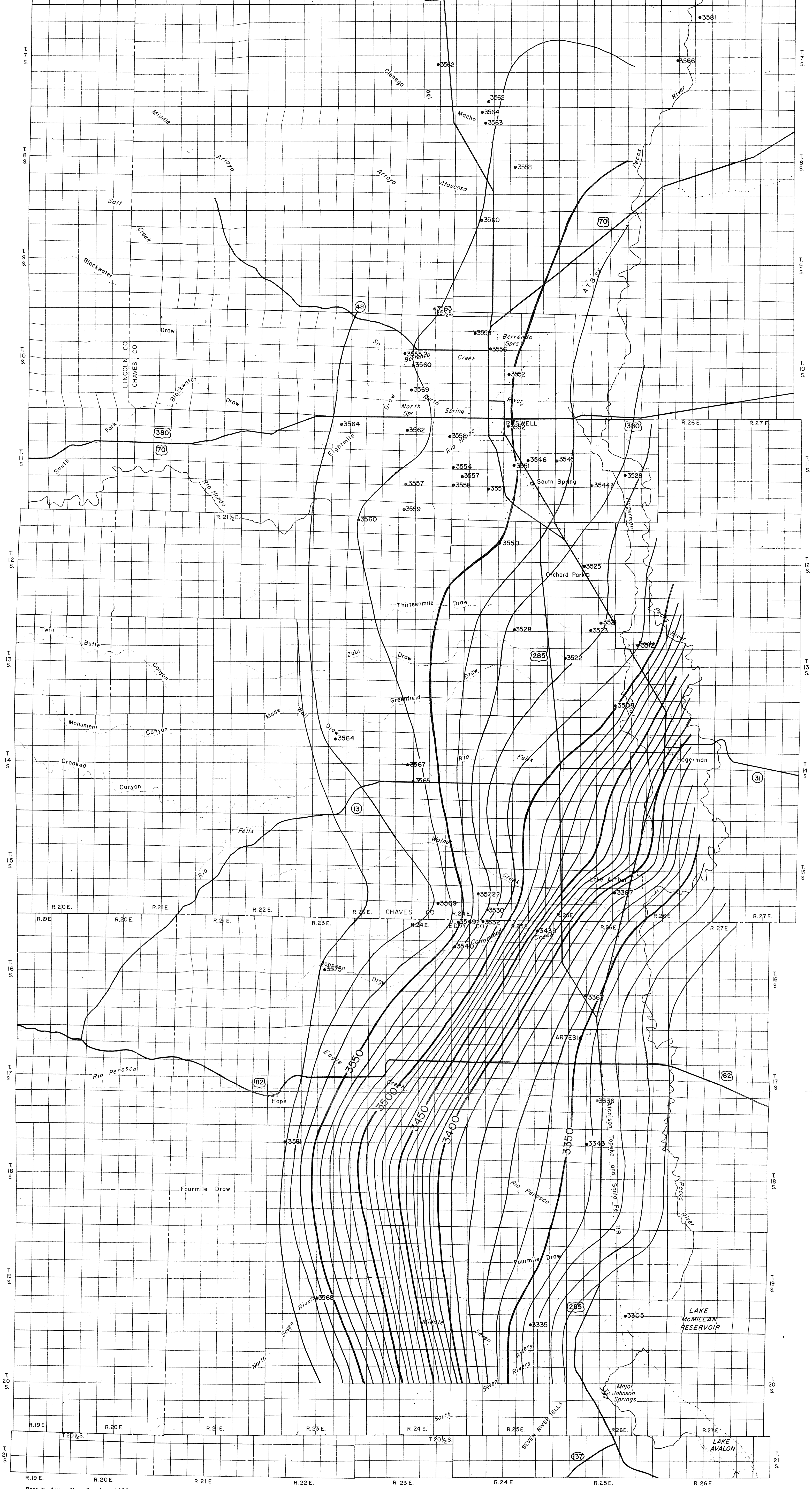
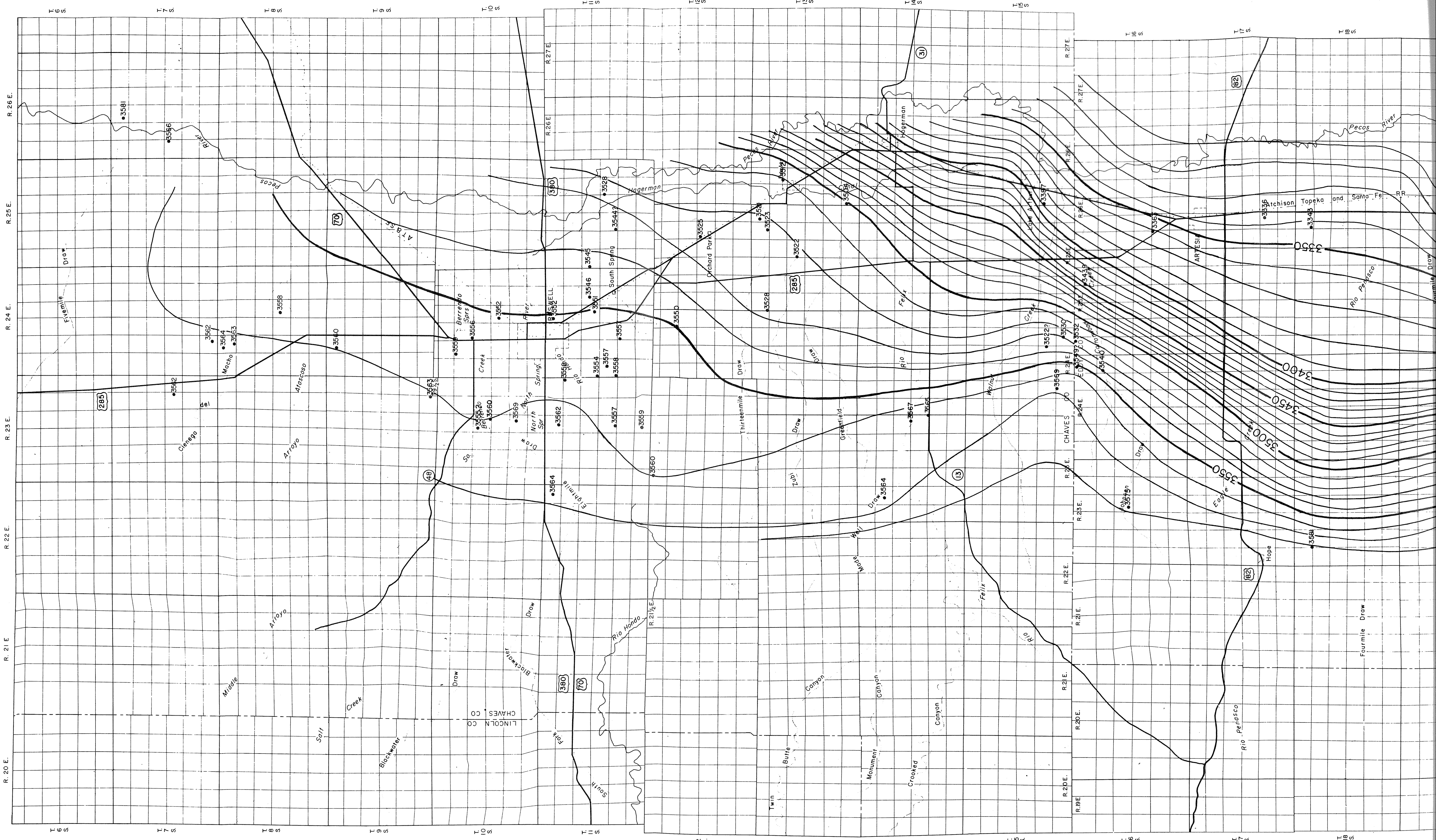


FIGURE D-12. --POTENTIOMETRIC-SURFACE CONTOURS IN THE PRINCIPAL CONFINED AQUIFER, JANUARY 1954.

(All control shown. Potentiometric surface elevations from U.S.G.S.)



R. 26 E.
R. 25 E.
R. 24 E.
R. 23 E.
R. 22 E.
R. 21 E.
R. 20 E.
R. 27 E.
T 6 S.
T 7 S.
T 8 S.
T 9 S.
T 10 S.
T 11 S.
T 12 S.
T 13 S.
T 14 S.
T 15 S.
T 16 S.
T 17 S.
T 18 S.
Pecos River
Hagerman
ROSWELL
ARTESIA
Hope
Orchard Park
Atchison Topeka and Santa Fe RR
Fivemile Draw
Rio Hondo
Rio Felix
Rio Penasco
Fourmile Draw
Thirteenmile Draw
Eightmile
Blackwater
Salt Creek
Twin Butte Canyon
Monument Canyon
Crooked Canyon
LINCOLN CO
CHAVES CO
EDDY CO
285
380
70
82
48
13
31
3350
3400
3450
3500
3550

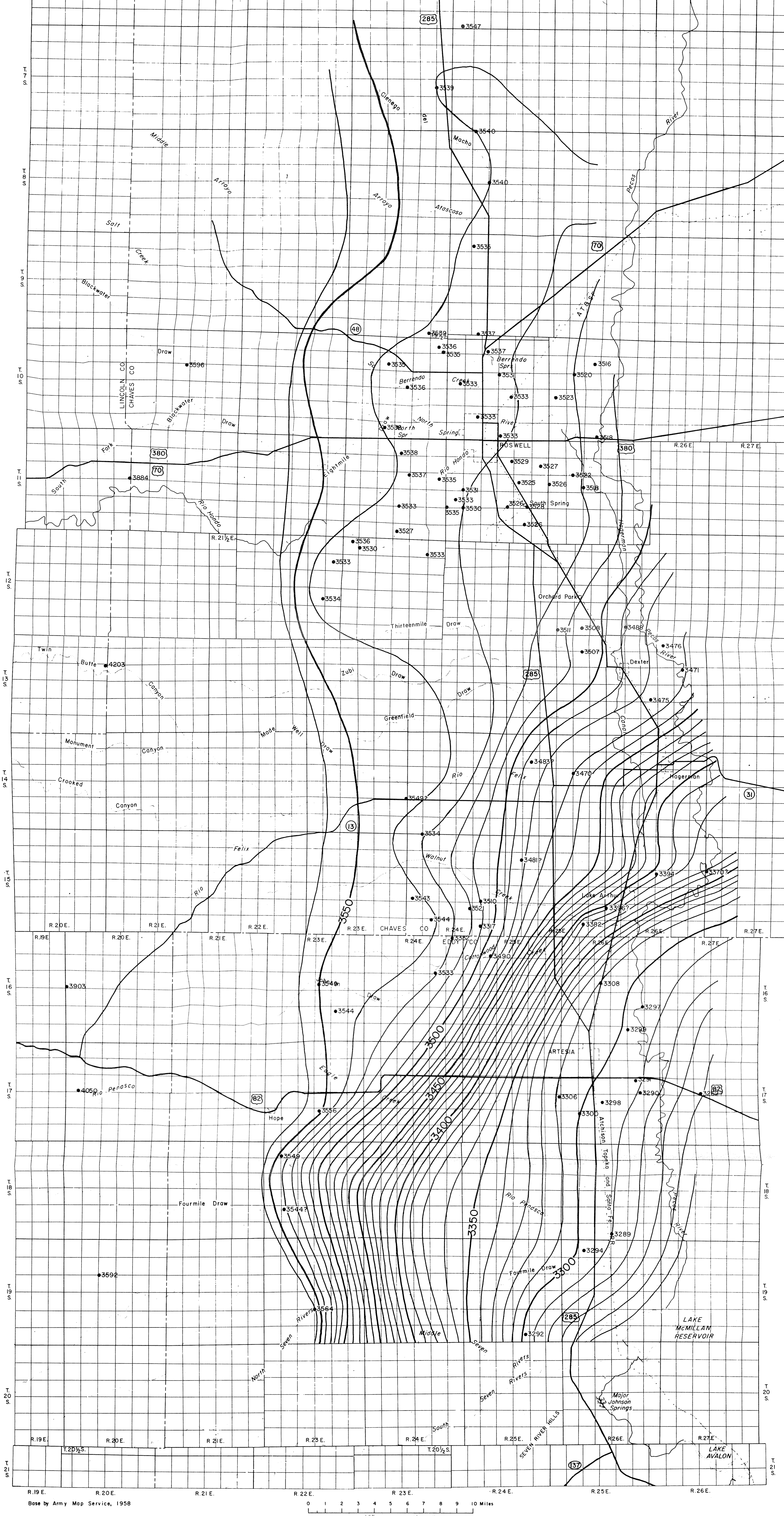


FIGURE D-13. -- POTENTIOMETRIC-SURFACE CONTOURS IN THE PRINCIPAL CONFINED AQUIFER, JANUARY 1964.

(All control shown. Potentiometric surface elevations from U.S.G.S.)

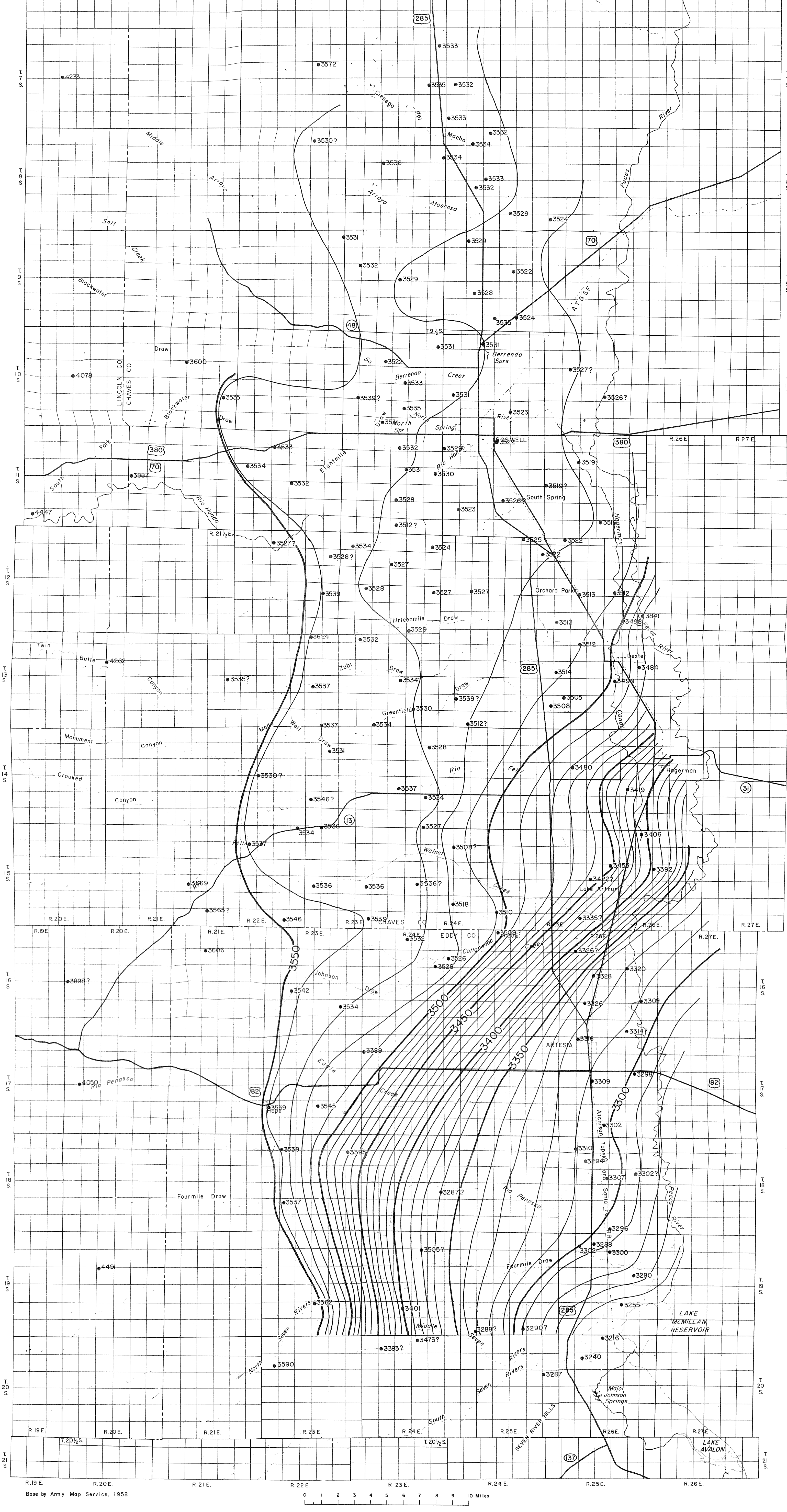


FIGURE D-14. --POTENTIOMETRIC-SURFACE CONTOURS IN THE PRINCIPAL CONFINED AQUIFER, JANUARY 1969.

(All control shown. Potentiometric surface elevations from U.S.G.S.)

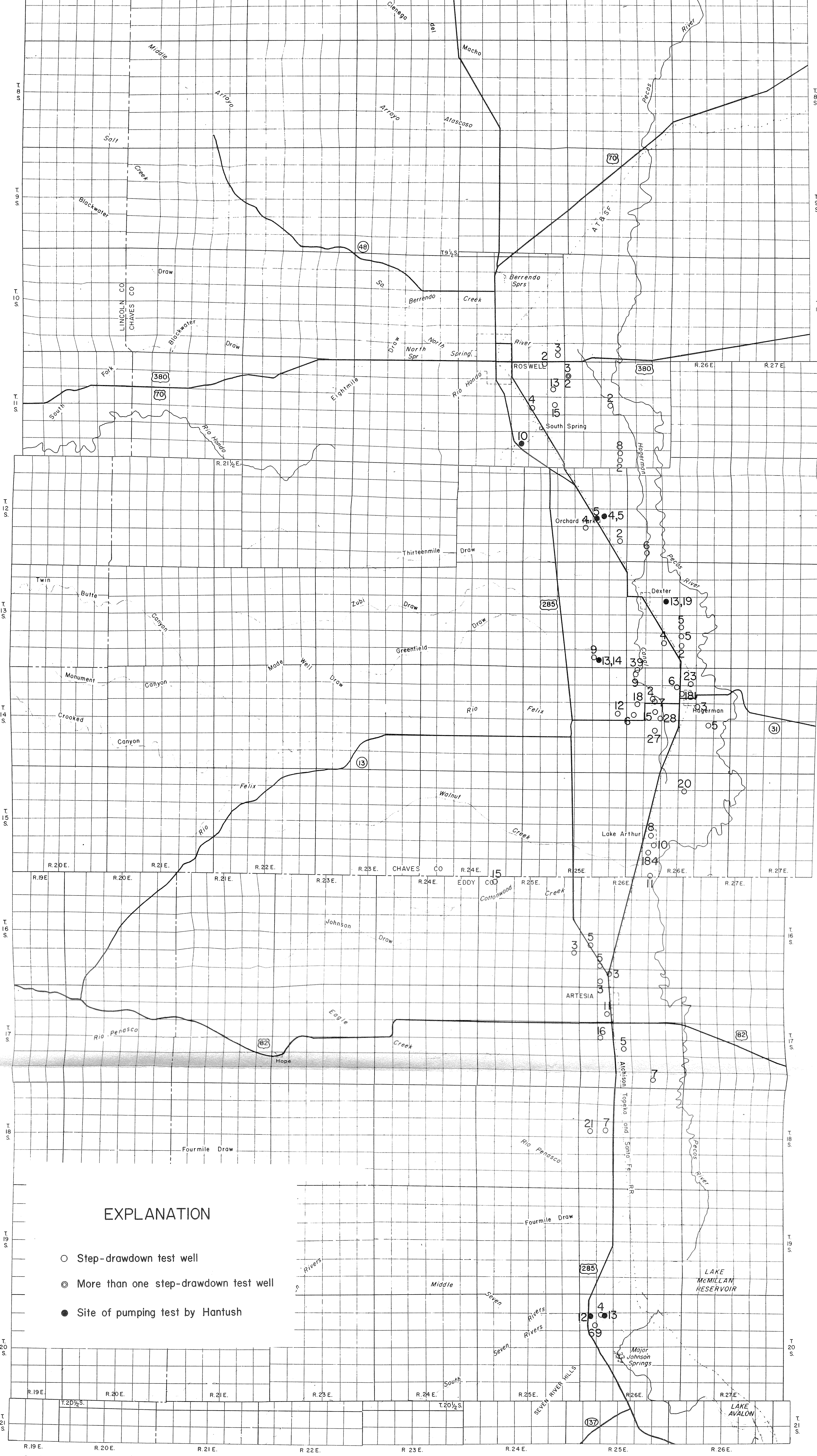
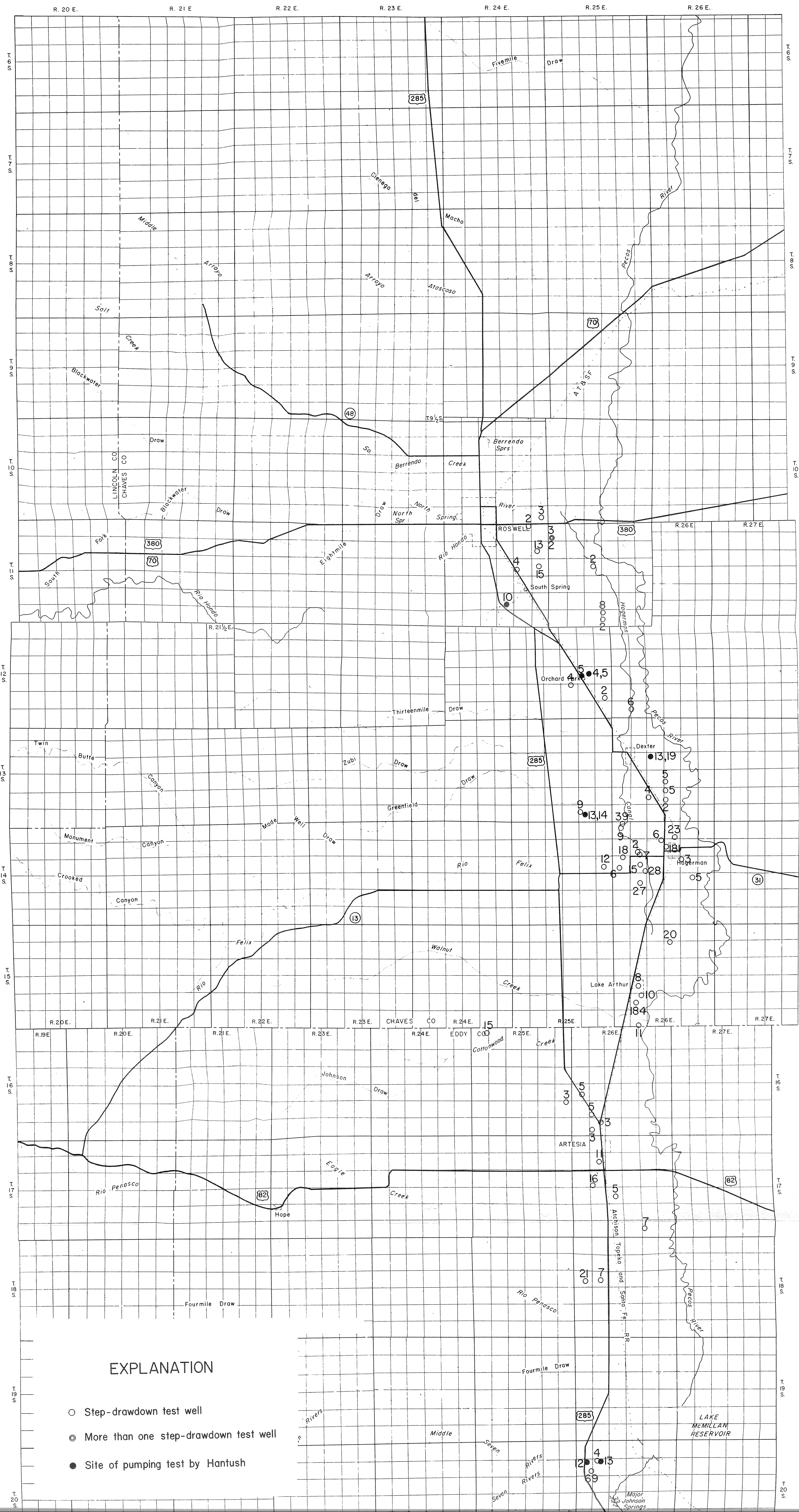


FIGURE D-15.--ESTIMATED TRANSMISSIVITIES IN THOUSANDS OF FT^2/DAY (FROM STEP DRAWDOWN TESTS IN THE SHALLOW AQUIFER).


R. 20 E.
R. 21 E
R. 22 E.
R. 23 E.
R. 24 E.
R. 25 E.
R. 26 E.
R. 27 E.
T. 6 S.
T. 7 S.
T. 8 S.
T. 9 S.
T. 10 S.
T. 11 S.
T. 12 S.
T. 13 S.
T. 14 S.
T. 15 S.
T. 16 S.
T. 17 S.
T. 18 S.
T. 19 S.
T. 20 S.
ROSWELL
Orchard Park
Dexter
Hagerman
Lake Arthur
ARTESIA
Hope
South Spring
Berrendo Sprs
LINCOLN CO
CHAVES CO
EDDY CO
Pecos River
Rio Hondo
Rio Felix
Rio Penasco
Atchison Topeka and Santa Fe RR
LAKE McMILLAN RESERVOIR
Major Johnson Springs
EXPLANATION
Step-drawdown test well
More than one step-drawdown test well
Site of pumping test by Hantush

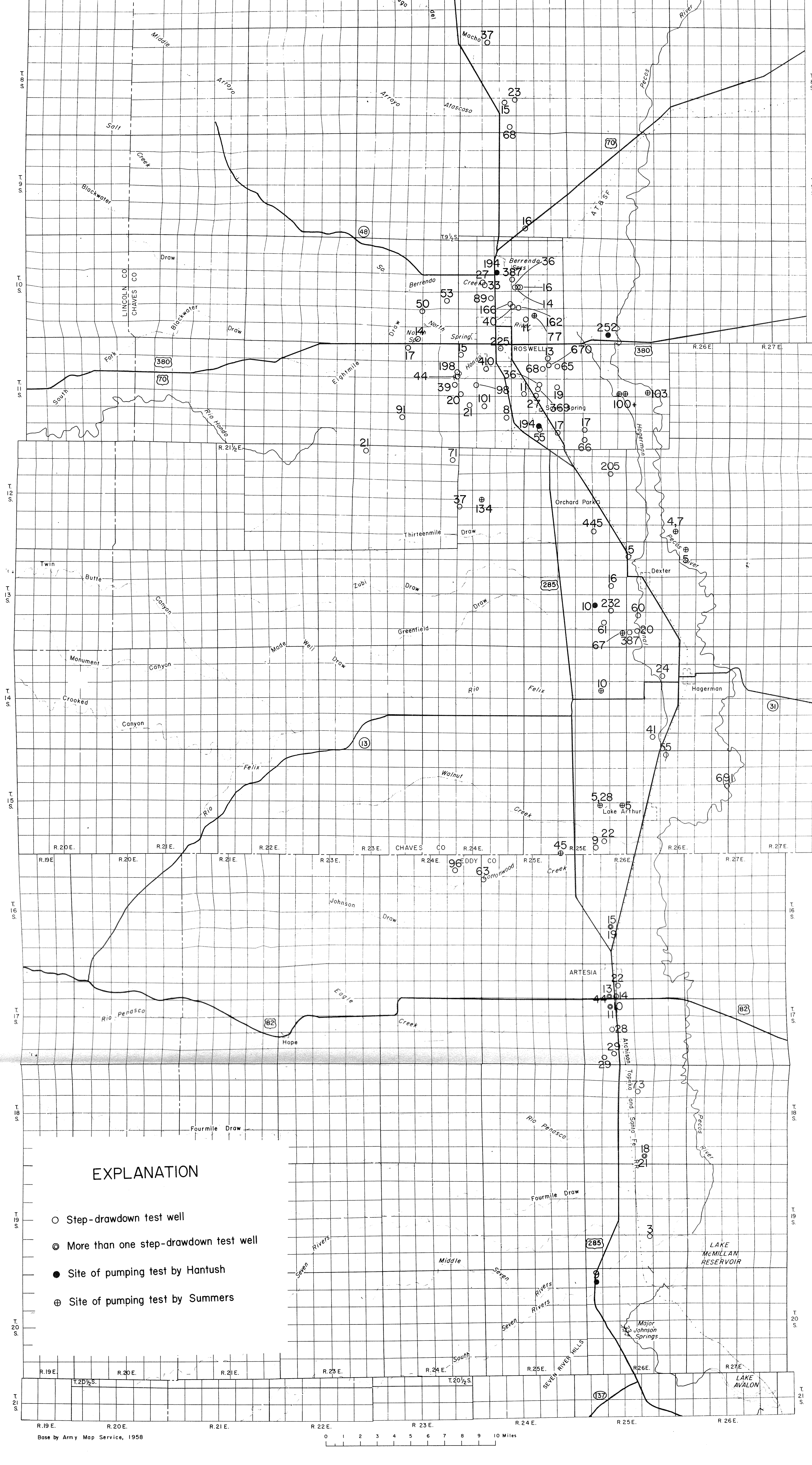
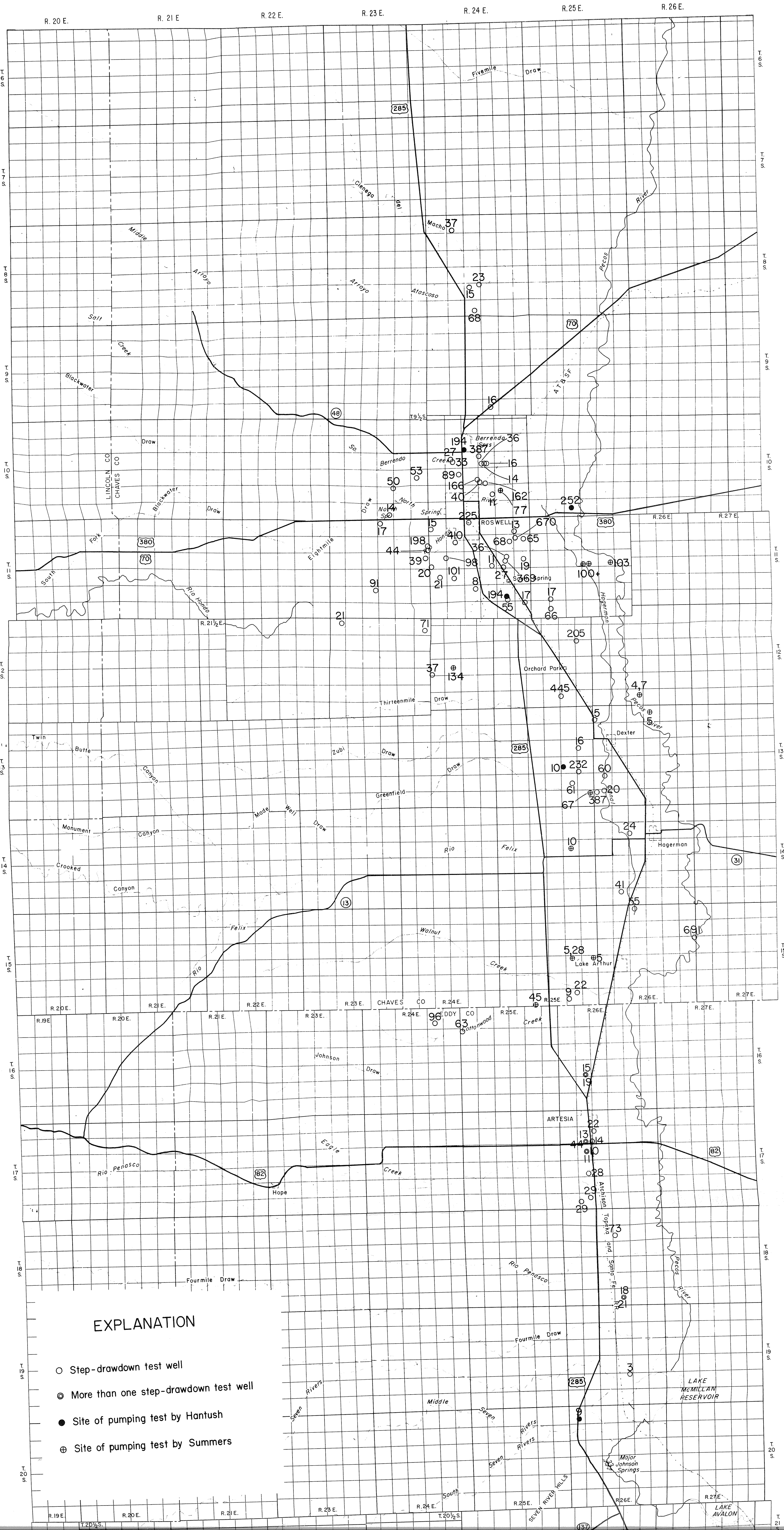


FIGURE D-16.--ESTIMATED TRANSMISSIVITIES IN THOUSANDS OF FT^2/DAY (FROM STEP DRAWDOWN TESTS IN THE PRINCIPAL CONFINED AQUIFER).


EXPLANATION
Step-drawdown test well
More than one step-drawdown test well
Site of pumping test by Hantush
Site of pumping test by Summers
ROSWELL
ARTESIA
Dexter
Hagerman
Hope
Lake Arthur
Orchard Park
LAKE McMILLAN RESERVOIR
LAKE AVALON
Major Johnson Springs
SEVEN RIVER HILLS
Pecos River
Rio Hondo
Rio Felix
Rio Penasco
Berrendo Creek
North Spring River
South Spring
Fivemile Draw
Eightmile Draw
Thirteenmile Draw
Fourmile Draw
Blackwater Draw
Salt Creek
Walnut Creek
Eagle Creek
Cottonwood Creek
Johnson Draw
Greenfield Draw
Zubi Draw
Made Well Draw
Twin Butte Canyon
Monument Canyon
Crooked Canyon
Atchison Topeka and Santa Fe
LINCOLN CO
CHAVES CO
EDDY CO

This thesis is accepted on behalf of the faculty of the Institute by the following committee:

Date: 26 May 1969