BASE FLOW GEOHYDROLOGY IN THE PECOS RIVER BETWEEN ACME AND ARTESIA, NEW MEXICO

by

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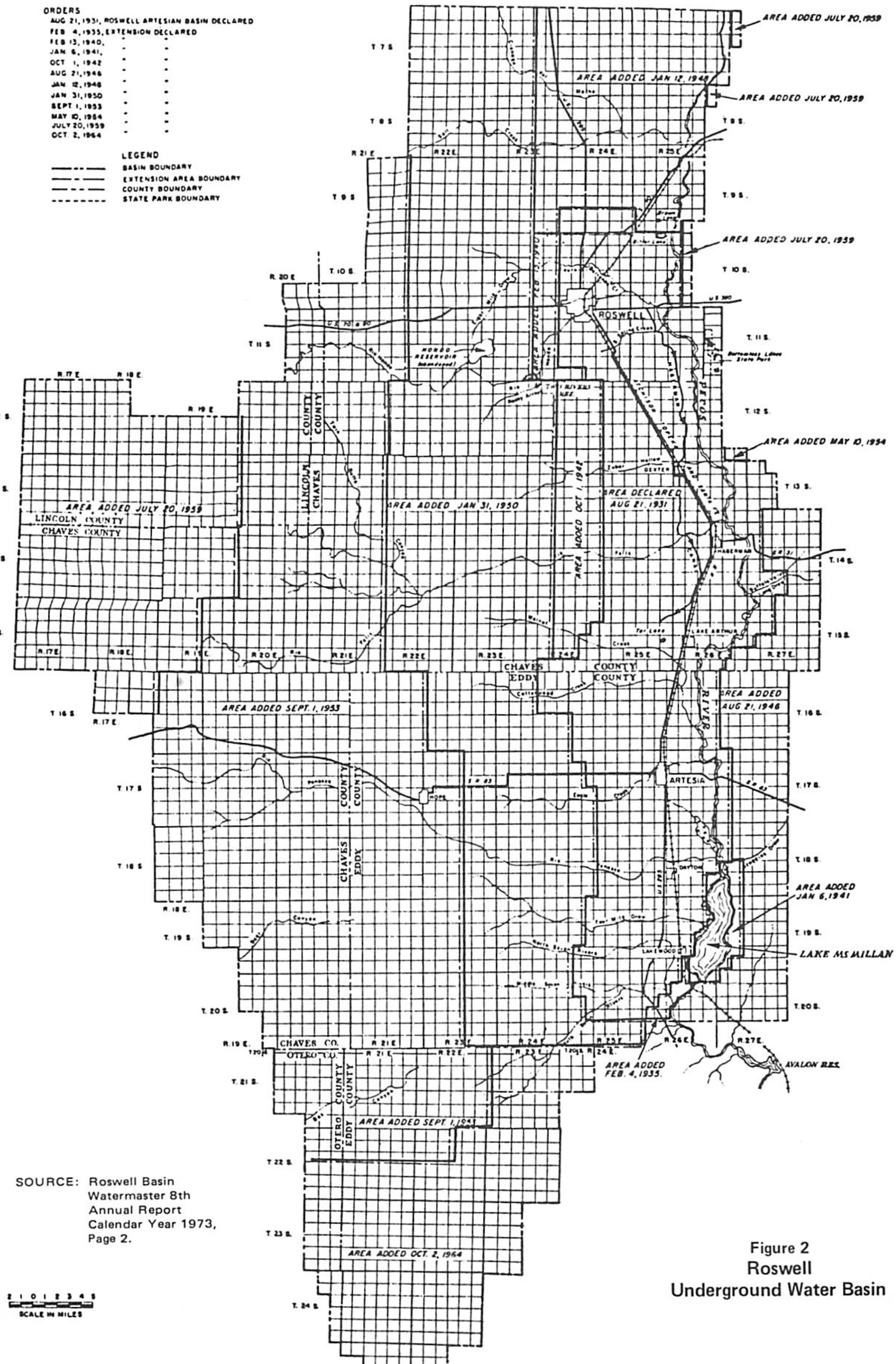
INTRODUCTION

The purpose of this study is to document the depletion of ground water as a result of man's activities and, if possible, prove that these activities have caused a decrease in the base flow gain to the Pecos River between the Acme and Artesia gages. It is anticipated that the findings of this study will be used in the TEXAS VS. NEW MEXICO United States No. 65 Original lawsuit which is scheduled for trial beginning February 27, 1978

Special acknowledgement is extended to Mr. Zack Dean and Mr. George E. Welder for their assistance and cooperation which contributed toward the successful completion of this investigation and to a better understanding of the ground-water resources of the Roswell Artesian Basin.

Figure 1 delineates the Roswell Artesian Hydrologic Basin, located in parts of Chaves, DeBaca, Eddy, Guadalupe, Lincoln, Otero, and Torrance Counties, New Mexico. The basin is adjacent to and west of the Pecos River and includes an area in excess of 7,000 square miles. The administrative boundary of the Roswell Underground Water Basin, as declared by the New Mexico State Engineer, is shown on Figure 2.

Within the basin, the climate is semi-arid and it is characterized by abundant sunshine and large temperature contrasts. The mean annual temperature is 59°F. Most of the precipitation occurs during May through September (Rabinowitz, et al., 1977, p. 5).



SOURCE: Roswell Basin Watermaster 8th Annual Report Calendar Year 1973, Page 2.

Figure 2
Roswell
Underground Water Basin

In 1968, approximately 140,000 acres were being irrigated. Irrigated lands, for the most part, are located on alluvial deposits where alfalfa, cotton, and sorghums are grown (Rabinowitz, et al., 1977, p. 5).

GEOHYDROLOGY OF THE ROSWELL ARTESIAN BASIN

General Hydrology and Geology

The ground-water flow system in the Roswell Artesian Basin consists of three hydrologically related geologic units, from the bottom to top: a deep confined aquifer of the San Andres Formation, a semi-confined aquifer referred herein as the Chalk Bluff Formation, and a shallow unconfined Quaternary Alluvium aquifer (Figures 1 and 3).

The San Andres Formation of Permian age underlies the entire basin and is in geologic contact with the approximate western half of the Quaternary Alluvium; thence eastward with the Chalk Bluff Formation (Figure 3). It consists dominantly of limestone and dolomitic limestone which includes minor amounts of dolomite, gypsum, anhydrite, sandstone, and shale. The San Andres is exposed at the surface west of the western boundary of the alluvium, dips to the east-southeast, is approximately 1200 feet thick, and is about 650 feet below the surface in the vicinity of the Pecos River near Roswell. Throughout the basin, and especially in the northern portion, the San Andres Formation has highly developed solution cavities caused primarily by the dissolution of the gypsum and anhydrite. Recharge to the formation is aided to a large extent by three complex zones of flexure, fracture, and faulting which trend across the basin in northeasterly directions. These features are the Border Hills, Sixmile Hill, and Y-O Structures (Figure 1). Large quantities of water enter the aquifer where the tributaries to the Pecos River traverse these structures. The San Andres aquifer is under water table conditions in its outcrop area west of the alluvium and under artesian conditions beneath the alluvium and Chalk Bluff Formation. As an aquifer, the San Andres has an effective porosity of approximately one (1) percent, transmissibility may be from a few thousand to 2.5×10^6 gpd/ft., and artesian storage may range from about 2×10^{-4} to 1×10^{-2}. Irrigation wells completed in the aquifer produce from a permeable zone that generally ranges in thickness from 100 to 300 feet in the eastern part of the basin. The San Andres and the Chalk Bluff aquifers, which appear to function as a single hydrologic unit, are the major aquifers in the Roswell Artesian Basin (Rabinowitz, et al., 1977; Welder, 1973; and Fielder and Nye, 1933).

Hydrologically, the principal significance of the Chalk Bluff Formation in the basin is that shales within it confine the underlying San Andres and create artesian conditions. The Chalk Bluff comprises of heterogeneous clastic and evaporite rocks primarily of beds of red shale, gypsum, anhydrite, and salt combined with fine-grained sandstone, thin beds of limestone, and dolomitic limestone. Southward, these lithologic characteristics of the rocks give way to form mostly limestones. The confining shales are not completely impermeable but leak at rates governed by the thickness of the bed, its vertical permeability, and the artesian pressure in the underlying San Andres.

The shallow unconfined Quaternary Alluvium aquifer overlies the San Andres and Chalk Bluff Formations and is composed of unconsolidated deposits of clay, sand, gravel, conglomerate, and sandstone laid down by the Pecos River. The alluvium ranges in width from 8 to 25 miles and its maximum thickness is about 300 feet. The most important ground-water boundary, for the purposes of this investigation, is the western edge of the shallow unconfined alluvium aquifer (Figures 1 and 3), which marks the line dividing the recharge area of the deep confined aquifer (San Andres Formation) from its downdip artesian zone. The specific yield of the alluvium is probably on the order of 0.15 to 0.20 (Welder, 1973; and Hood, et al., 1960).

Ground-Water Development

Development from the San Andres deep artesian aquifer of the Roswell Artesian Basin began in 1891 (Pecos River Compact Commission, 1949, p. 2). Based on the number of existing wells for the period 1905-1925 (Fielder and Nye, 1933, p. 225) pumpage from the deep aquifer appears to be on the order of 140,000 acre-feet per annum for the previously stated period. Subsequent to 1925, ground-water withdrawals increased to the year 1946 when pumpage exceeded 340,000 acre-feet. By the latter part of the nineteen thirties, development began in the shallow alluvium aquifer. During the period 1937 to 1976, this alluvial aquifer sustained less than one-half of the total annual pumpage. After 1947, ground-water withdrawals generally increased to the year 1965 when pumpage was approximately 460,000 acre-feet. Following this peak pumpage in 1965, withdrawals decreased to a low of 339,000 acre-feet and then gradually increased again to 441,000 acre-feet in 1976. Development of the aquifer system in the Roswell Artesian Basin is shown in Figure 4 in terms of the annual ground-water withdrawals.

Recharge, Ground-Water Movement, and Discharge

Natural recharge to the ground-water flow system in the basin comes from precipitation on the outcrops of the aquifers. Additionally, recharge results from infiltration of surface water flowing along the Pecos River and its tributaries such as the Rio Hondo, Rio Felix, and Cottonwood Creek. The recharge area of the deep artesian aquifer (San Andres Formation) is delineated on Figure 1. A water-budget idealized graphical model of the Roswell Artesian Basin portraying the hydrologic flow system, and more importantly, the base flow gain along the Pecos River between the Acme and Artesia gages, is given on Figure 4. This model is fundamental to the understanding of the objectives of this investigation.

During the construction of this graphical water-budget model from the information available, it was necessary to make certain assumptions which will unfold in the following discussion. Assumptions are quite normal when establishing procedural steps to analyze a hydrologic system.

The San Andres deep artesian aquifer has an effective recharge area of approximately 5,800 square miles (Figure 1). Within this area there are many openings, such as; fault zones, sinkholes, and solution channels (Rabinowitz, et al., 1977; and Mower, 1964). The mean annual precipitation of less than 10 inches may vary throughout the basin depending upon the year and the susceptibility of the land surface to recharge also varies; therefore, the recharge may fluctuate accordingly from area to area. However, as a whole, the average natural recharge to the deep artesian aquifer has been determined to be on the order of 235,000 acre-feet per year (U.S. Bureau of Reclamation, 1976, p. 76).

For the shallow alluvium aquifer, the average natural recharge was found to be approximately 30,000 acre-feet per year (U.S. Bureau of Reclamation, 1976, p. 76). This is about 15 percent of the total natural recharge to the system which would total to be approximately 265,000 acre-feet.

The average natural recharge to the aquifer system was probably less during the years prior to 1947 because storage in the aquifers was near its full capacity; thus the water available for recharge was rejected. This is indicated by the relatively high base flows in the Pecos River during this period (Figure 4). Additionally, it is reasonable to infer that base flows were also higher in the tributary streams (Rio Hondo, Rio Felix, and Cottonwood Creek), even though this data is not available, than they were after 1947 (Figure 5). If this were true, then infiltration of surface water along the streams was also less prior to 1947.

Of the total amount of ground water withdrawn from the aquifer system, it has been estimated that from 20 to 30 percent returns to the aquifers' storage (Mower, 1960, p. 53 and p. 55). This may occur when irrigating crops and/or as transit losses along the transmission canals. For the purpose of this investigative analysis, it was estimated that 25 percent of the pumpage returned to the aquifer system; and this primarily to the shallow unconfined aquifer in response to pumpage.

Following the infiltration of precipitation and surface water to the deep artesian aquifer, the ground water moves in the aquifer toward areas of discharge (Figures 1 and 3). This movement can be relatively rapid (Rabinowitz, et al., 1977, p. 37), and discharge occurs as pumpage or as natural discharge (base flow) into the Pecos River from the shallow aquifer or directly from the deep artesian aquifer through fractures and solution openings in many areas (Welder, 1973). A small amount of saline water from the deep aquifer also moves upward into the Pecos River east of the bad water line in the Roswell area (Figure 3).

Changes in Water Levels

Systematic measurement of water levels in water wells producing from the aquifer system is simply a means of determining the quantity of ground water in storage in the reservoir. Water levels in the deep artesian and shallow alluvial aquifers have declined because the ground-water pumpage exceeds the natural recharge to the aquifer system. Water has been removed from the aquifer system storage (Figure 4).

As a result, the effects of this overdraft has caused, most importantly, a decrease in the base flow of the Pecos River (Figure 4) as well as increased pumping lifts and encroachment of saline water (Busch and Hudson, 1967).

SALT CEDAR GROWTH AND WATER USE

Salt cedar was first observed in the Acme-Artesia reach of the Pecos River in about 1912 (Mower, et al., 1964, p. 3). It spread gradually through the reach and had covered about 2,470 acres by 1939. Subsequent growth, principally within the confines of the main stem of the Pecos River, was very rapid (Figures 4 and 6). In 1946 approximately 8,406 acres were present; in 1950 10,335 acres were present; and by 1967 on the order of 21,510 acres were present (Pecos River Commission, 1955, Exhibit 4 and J. A. Bradley, personal communication, July 3, 1975). Until about 1950, the Commission referred to the density of salt cedar growth in the reach as light to medium. By 1958, however density in most tracts had increased to medium to dense (J. A. Bradley, personal communication, July 3, 1975).

Mr. Bradley (above) reports that in 1967, operations to clear the salt cedar were begun. By 1969 a total of 21,510 acres were cleared primarily between the Acme and Artesia gages. For comparative purpose of this investigation, salt cedar uses from ground water were estimated at about 2 acre-feet of water per acre annually and that the grasses which replaced much of the cleared salt cedar used about one acre-foot per acre. Therefore savings resulting from the clearing are estimated at one acre-foot per acre per year. These estimates are based primarily on the density of growth as reported by Bradley (1975), Mower (1964), and the Pecos River Commission (1955). The estimated salt cedar use and savings and their relationship to other groundwater use are shown on Figure 4. Use by those phreatophytes whose roots actually enter the stream channel were considered as surface water losses for the purpose of Figure 4. Other related surface water losses include base flow evaporation from streams and wet sandbars and were estimated at 6,500 acre-feet per year by Welder (1973, p. 39).

PRECIPITATION-BASE FLOW STUDIES

Method of Analysis

An average of precipitation records at Roswell, Artesia, Carlsbad, and Whitetail were used as the index precipitation (Dean, undated tables). On the theory that base flow discharge from the basin lags somewhat behind precipitation, the above index precipitation for four (4) years prior to, and the year coincident with the discharge were weighted as follows: the fourth year prior was given a weight of one, the third year a weight of two, the second year a weight of three, the year prior a weight of four, and the coincident year a weight of two (Pecos River Compact Commission, 1949, p. 48).

Data points shown by Figure 7 were then recomputed and verified following the procedure and data described in the report of the Engineering Advisory Committee to the Pecos River Compact Commission (Pecos River Compact Commission, 1949, p. 48).

Following this, the Tipton-Kalmbach, Inc. annual base flow (Pecos River Commission, 1960-Review of Basic Data) for the year 1937 through 1946 were weighted using a progressive two year average for the period 1938 through 1946 (Pecos River Compact Commission, 1949, p. 48). The two year progressive average base flows were next plotted against the weighted precipitation derived by the 1947 Engineering Advisory Committee for the period 1938-1946 (Figure 8) (Pecos River Compact Commission, 1949, p. 48). Since the data plots using the two methods described above, gave essentially the same relationship, it is believed that Figure 7 accurately describes the "1947 Condition" relationship of precipitation and base flow gain.

Precipitation data for the weather stations at Roswell, Whitetail, Artesia, and Carlsbad were then tabulated for the year 1947 through 1976 (U.S. Department of Commerce, 1954 and 1949-1977) to supplement the precipitation data tabulated by the 1947 Engineering Advisory Committee. Missing precipitation during the years 1947 through 1976 was estimated by comparison with data at nearby stations. The tabulated precipitation data for the years 1947 through 1976 were next weighted as previously described in the first paragraph of this section. The weighted precipitation was then related to Figure 7 to estimate the annual "1947 Condition" base flow for the years 1947 through 1976. Data derived was then combined with that previously developed by the 1947 Engineering Advisory Committee 1905-1946 to give Figure 8.

Figure 9 shows the comparison between estimated "1947 Condition" base flow gain between Acme and Artesia and the estimated historic base flow for 1905-1976. Data for the historic base flow gain for the period 1905-1918 is from the Engineering Advisory Committee (Pecos River Compact Commission, 1949, pp. 51-52), for the years 1919-1956, is from the study by Tipton and Kalmbach, Inc.(Pecos River Commission, 1960) and for the years from 1957 through 1976, is from G. E. Welder of the U.S. Geological Survey office in Albuquerque, New Mexico. Also shown are the annual and cumulative differences between estimated historic base flow gain and the "1947 Condition" base flow gain developed by the 1947 Engineering Advisory Committee. The cumulative differences for the period 1905-1946 as shown on Table 1 amounts to 504,900 acre-feet as compared to 688,700 acre-feet for the period 1947 through 1976 (Table 2). A comparison of the estimated historic base flow gain between that used by the 1947 Engineering Advisory Committee and the estimated "1947 Condition" base flow gain for the period 1905-1946 (not shown on the illustration) amounts to a reduction in ground-water inflow in the amount of 692,100 acre-feet.

Results

Results of precipitation-base flow studies indicate the following. Substitution of two year average base flows from Tipton and Kalmbach, Inc. for

Table 1.--Annual and Cumulative Differences Between Estimated Historical [1/] and Estimated 1947 Condition Base-Flow Gain [1/] (Acme and Artesia Gages) 1905-1946, in 1,000's of Acre-Feet

Year	Historical Base-Flow Gain	Estimated Base-Flow Gain	Difference
1905	124.9	61.6	63.3
1906	88.3	66.0	22.3
1907	80.2	64.5	15.7
1908	41.3	61.8	-20.5
1909	62.6	56.4	6.2
1910	73.7	50.5	23.2
1911	79.6	49.5	30.1
1912	60.7	52.9	7.8
1913	72.5	54.6	17.9
1914	76.8	57.5	19.3
1915	91.5	60.9	30.6
1916	71.1	61.8	9.3
1917	61.5	58.2	3.3
1918	67.1	52.4	14.7
1919	84.4	52.5	31.9
1920	75.2	55.0	20.2
1921	67.5	55.4	12.1
1922	60.3	53.9	6.4
1923	57.7	52.5	5.2
1924	70.0	51.7	18.3
1925	60.3	49.5	10.8
1926	74.9	50.8	24.1
1927	61.1	52.1	9.0

Table 1.--Annual and Cumulative Differences Between Estimated Historical [1/] and Estimated 1947 Condition Base-Flow Gain [1/] (Acme and Artesia Gages) 1905-1946, in 1,000's of Acre-Feet--Continued

Year	Historical Base-Flow Gain	Estimated Base-Flow Gain	Difference
1928	64.7	50.6	14.1
1929	72.4	52.5	19.9
1930	63.1	52.6	10.5
1931	71.8	53.4	18.4
1932	88.3	57.9	30.4
1933	66.7	57.9	8.8
1934	46.1	52.8	-6.7
1935	59.7	50.4	9.3
1936	57.9	50.4	7.5
1937	78.9	52.2	26.7
1938	54.4	55.7	-1.3
1939	46.1	52.0	-5.9
1940	46.4	48.4	-2.0
1941	101.3	91.7	9.6
1942	110.9	108.4	2.5
1943	59.8	66.5	-6.7
1944	61.5	65.4	-3.9
1945	48.2	48.4	-0.2
1946	51.7	59.0	-7.3
		Cumulative Total	504.9

1/Figure 9

Table 2.--Tabulations of Differences in Historical Base Flow (Acme and Artesia Gages) and Predicted Base Flows Using the Precipitation-Base Flow Correlation (Figure 7), 1947-1976, in 1,000's of Acre-Feet

Year	Historical Base Flow	Predicted Base Flow	Difference
1947	43.0	49.0	6.0
1948	42.9	48.5	5.6
1949	49.7	50.3	0.6
1950	39.6	53.5	13.9
1951	37.0	53.2	16.2
1952	34.3	51.0	16.7
1953	31.6	49.1	17.5
1954	43.5	48.3	4.8
1955	38.0	48.6	10.6
1956	32.0	48.2	16.2
1957	31.8	47.8	16.0
1958	36.6	50.0	13.4
1959	29.0	52.2	23.2
1960	34.0	53.3	19.3
1961	33.5	53.5	20.0
1962	26.4	52.2	25.8
1963	22.8	51.4	28.6
1964	15.3	49.1	33.8
1965	16.3	48.1	31.8
1966	20.6	49.1	28.5
1967	16.6	49.4	32.8
1968	18.9	50.7	31.8
1969	20.7	52.7	32.0
1970	19.2	51.7	32.5
1971	16.1	50.4	34.3

Table 2.--Tabulations of Differences in Historical Base Flow (Acme and Artesia Gages) and Predicted Base Flows Using the Precipitation-Base Flow Correlation (Figure 7), 1947-1976, in 1000's of Acre-Feet--Continued

Year	Historical Base Flow	Predicted Base Flow		Difference
1972	18.2	51.4		33.2
1973	17.6	52.8		35.2
1974	22.1	55.3		33.2
1975	20.6	58.0		37.4
1976	16.2	54.0		37.8
			Total	688.7

1947 Engineering Advisory Committee base flows gives essentially the same relationship as shown by Figure 7. Comparison of the base flow gain using the correlation (Figure 7) for the period 1947 through 1976 indicates that the actual base flow gain between Acme and Artesia gages is much less than the predicted "1947 Condition" base flows.

WATER LEVEL - BASE FLOW STUDIES

Method of Analysis

Two separate analyses were made to evaluate the water level - base flow relationship on the Pecos River between the Acme and Artesia gages. In the first analysis, the mean annual water levels in the Orchard Park well and the base flow gain between the two gages were plotted using Tipton-Kalmbach, Inc. data for the period 1926-1956 (Pecos River Commission, 1960) and U. S. Geological Survey data for the period 1957-1976 (Welder, 1977, person communication). The results of plotting these data are shown on Figure 10. In the second analysis, the mean annual water levels in the Orchard Park well and the base flow gain between the two gages were also plotted using the base flow data contained in Senate Document 109 (Pecos River Compact Commission, 1949) for the period 1926-1946. Figure 11 shows the results using these data.

Results

The water-level fluctuations in the Orchard Park well correlate very well with the base flow gain plot between the Acme and Artesia gages on the Pecos River for the period of 1926 to 1976 (Figure 10).

Only minor differences in the correlation are noted when water levels in the Orchard Park well and the base flow gain relationships for the period 1926-1946 are correlated and compared using the two sets of base flow data described in the Method of Analysis section above (Figures 10 and 11).

When comparing the data after 1954, the correlation of heads and base flow (Figure 10) is excellent and there are no apparent shifts in the data points, with time, parallel to the base-flow axis. Since there was clearing of the salt cedar during the period 1967-1969 without a subsequent shift in the data

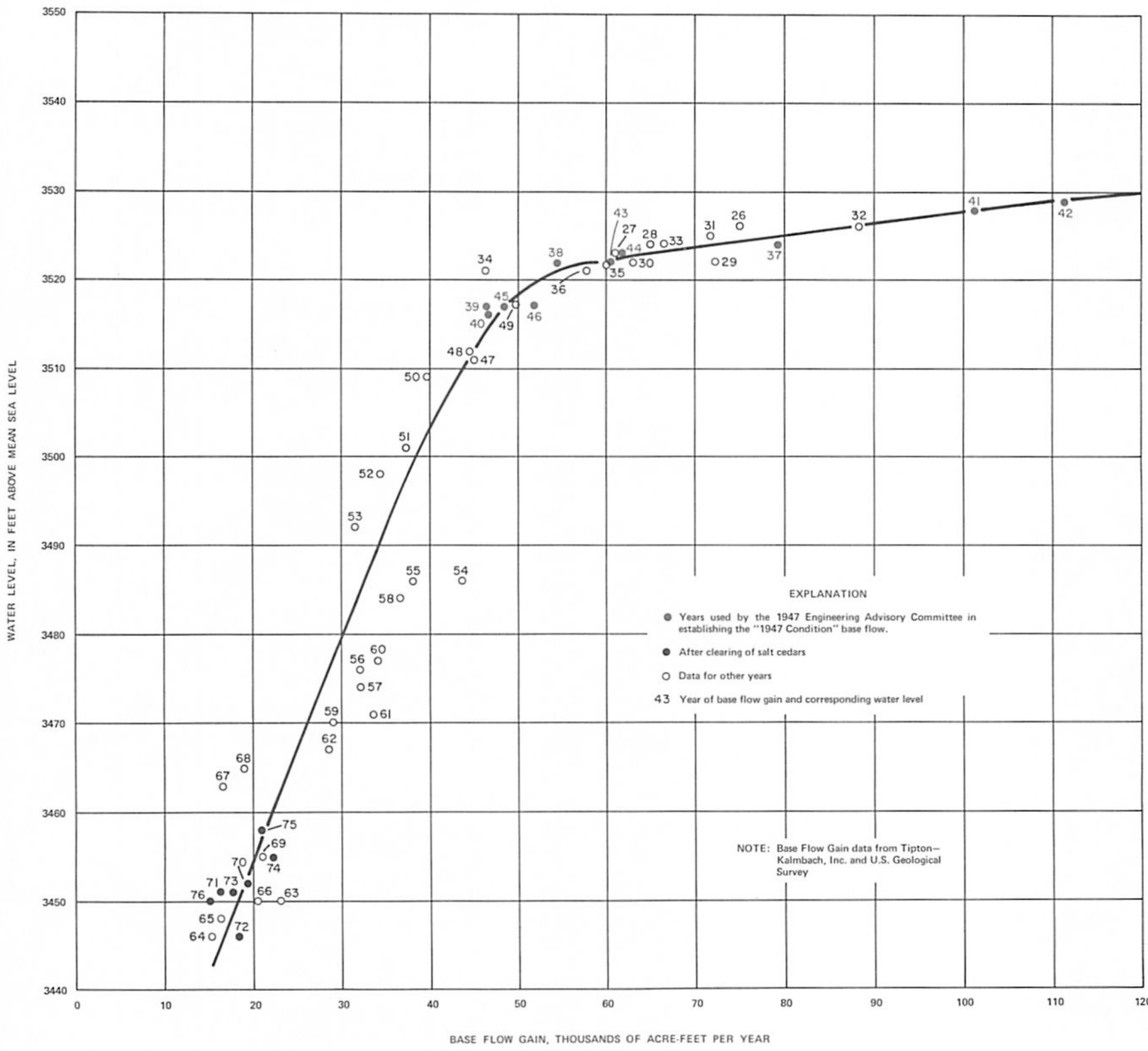


Figure 10

Correlation of Water Levels in the Orchard Park Well and the Base Flow Gain Between the Acme and Artesia Gages, 1926-1976

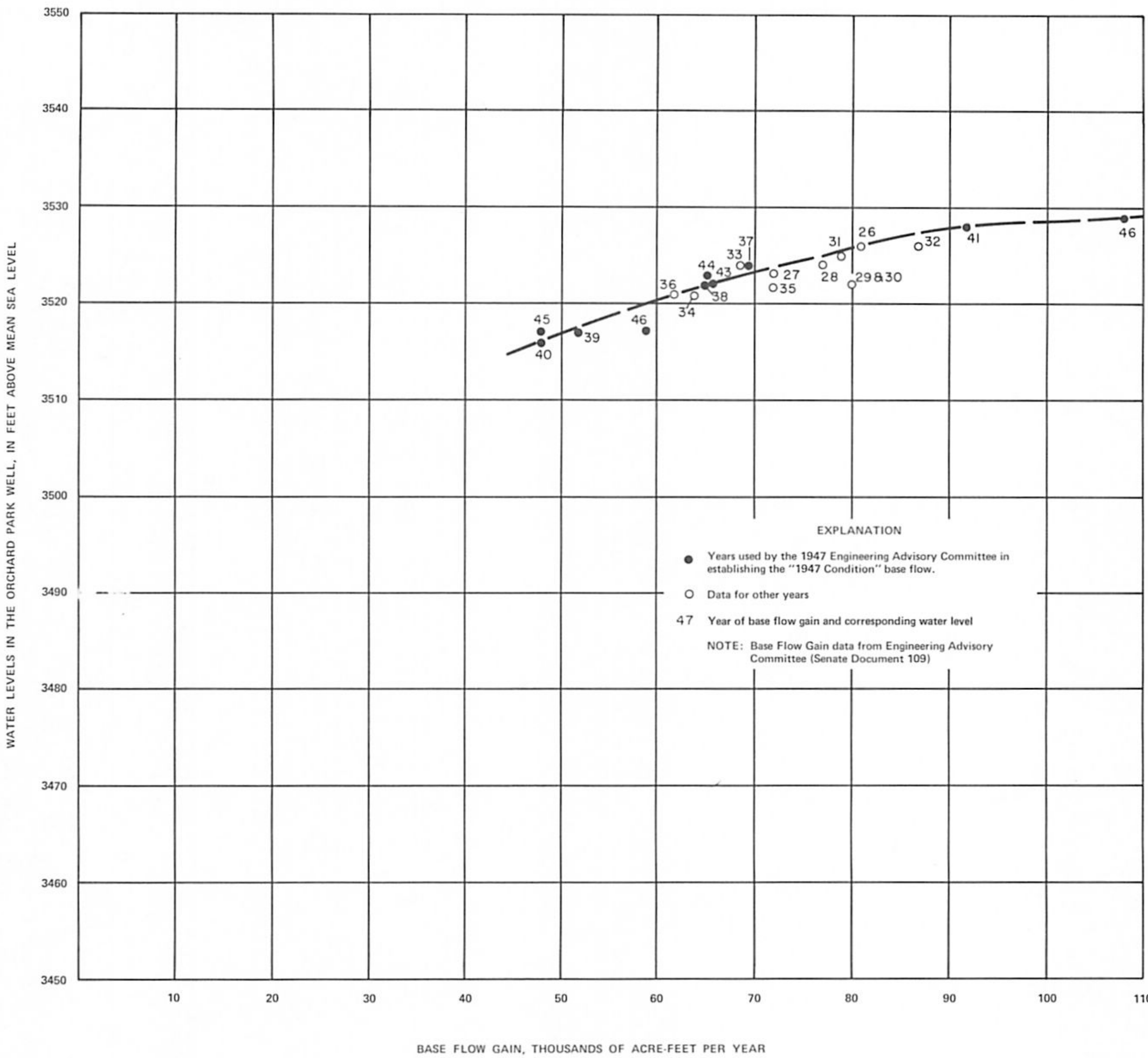


Figure 11

Correlation of Water Levels in the Orchard Park Well and the Base Flow Gain Between the Acme and Artesia Gages,1926 - 1946 points parallel to the base-flow axis after the clearing, it is indicated that phreatophytic water use or savings from clearing had little effect on the ground-water system.

PUMPAGE-BASE FLOW STUDIES

Method of Analysis

Figure 4 was constructed as a generalized graphical model of the Roswell Artesian Basin to show the relationship between base flow gain (Acme to Artesia reach) and withdrawals from ground-water aquifers in the area. Annual pumpage for the period 1905-1924 was estimated from Fielder and Nye (1933, Figure 32, p. 225). Annual pumpage figures for the period 1925-1976 were taken from Mower (1960, p. 72); Brim (1975, p. 13); and Welder (oral communication, November, 1977). Figure 4 lists the various authors and the respective pumpage periods which are applicable to each. Base flow gain data came from the Pecos River Compact Commission (1949, p. 51); the Pecos River Commission (1960, Table A-8-1); and Welder (1973, Table 2., p. 42). A breakdown of the various time periods involved is given on Figure 4.

Figure 12 was constructed by plotting estimated annual pumpage (from both artesian and water-table aquifers) against annual base flow gain in the Acme-Artesia reach of the Pecos River for the years 1919 through 1976. Data were taken from the same sources as used in Figure 4.

Results

The above discussed work indicates a definite correlation between increased pumpage and decreased base flow gain between the Acme and Artesia gages. Two correlations (1919-1965 and 1966-1976) are shown on Figure 12. Due to a marked reduction in pumpage after 1964, the periods 1919-1965 and 1966-1976 correlated differently. This apparent reduction of pumpage after 1964 caused the correlation of data points to shift. During the subsequent increase in pumpage, the data generally follows the same type of curve as did the data for the period 1919-1965.

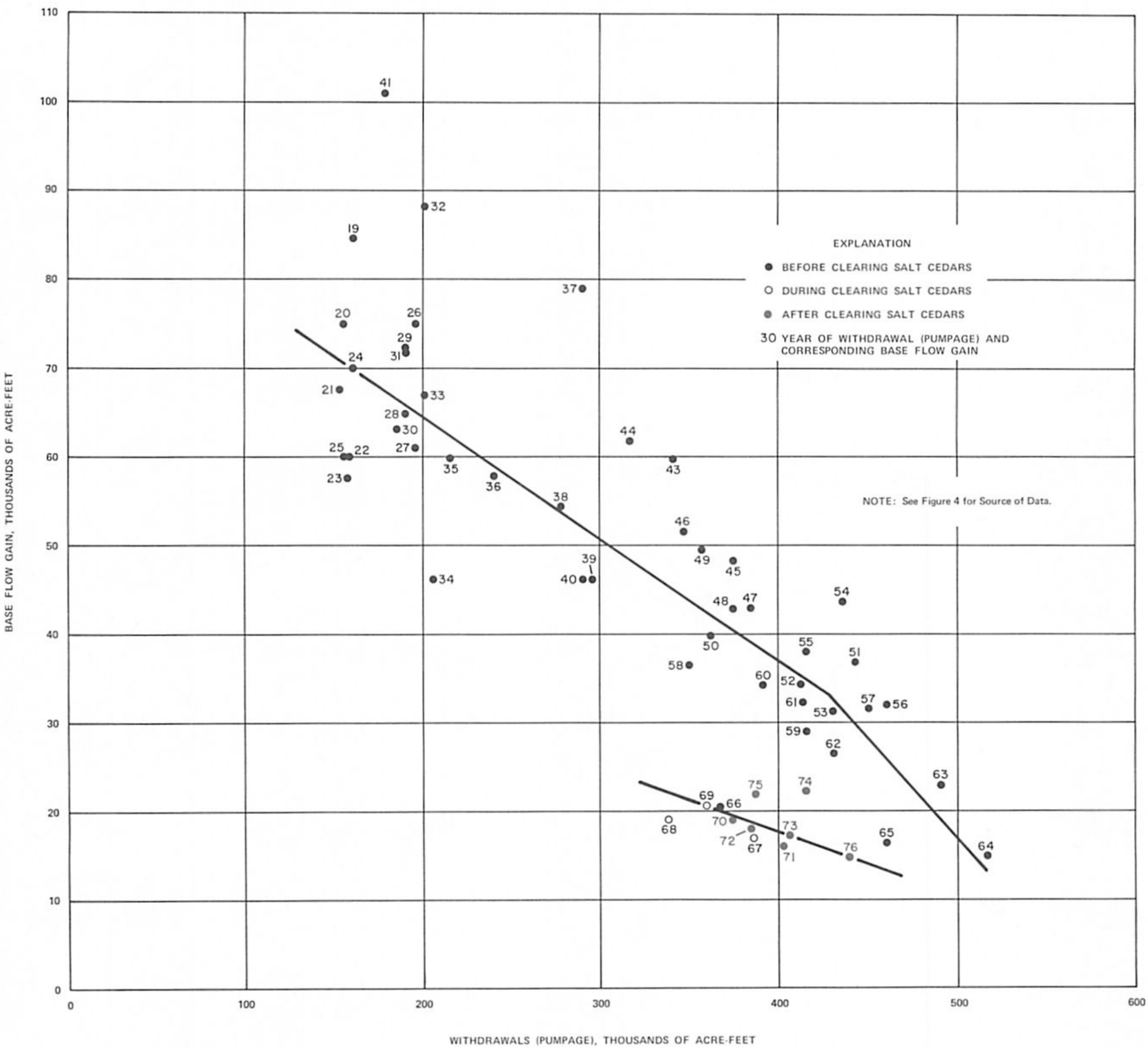


Figure 12

Correlation of Ground-Water Withdrawals (Pumpage) and Base Flow Gain Between Acme and Artesia Gages, 1919-1976

CONCLUSIONS

Base flow gain between the Acme and Artesia gages in the Pecos River appears to have reduced somewhat during the period 1905-1939. Base flows were high during 1940 and 1941 and they have declined steadily during the period from 1942-1976 (Figure 4). The primary cause of reduced base flow gain in the Acme-Artesia reach of the Pecos River is the result of loss of head in the aquifer system (both deep and shallow aquifers) due to pumpage which has removed varying amounts of water from storage during the period 1937-1976 (Figures 4, 10, and 12). The rapid decline in base flow, starting in the early nineteen forties, correlates well with the large ground-water withdrawals during the period 1942-1976 (Figure 4).

Surface flows in the Rio Hondo, Rio Felix, and Cottonwood Creek have decreased (starting in the nineteen forties). The decline in surface flows correlates well with the large ground-water withdrawals and declining water levels during the period 1942-1976; thus indicating increased ground-water recharge due to increased infiltration (Figures 4 and 5). In Rio Hondo, Rio Felix, and Cottonwood Creek, average surface flows after 1946 have decreased by more than 50 percent when considered collectively (Figure 5). Precipitation does not show the same relationship after 1946 (Figure 5).

The average of base flows used by the 1947 Engineering Advisory Committee and the Tipton-Kalmbach data for the period 1938 through 1946 is 67,800 and 66,000 acre-feet per year, respectively. Therefore, the "1947 Condition" analysis used by the 1947 Engineering Advisory Committee (Figure 7) is valid and the use of either data set results in only minor differences in the correlation.

Using Figure 7 to estimate the "1947 Condition" base flow for the period 1947-1976 (Figure 8) and comparing this with the estimated historical base flow for the same period, the total ground-water deficit during this time is approximately 688,700 acre-feet (Figure 9 and Table 2). This is, for the most part, due to ground-water mining.

Table 1 shows the annual differences between the "1947 Condition" and estimated historical base flow for the period 1905 through 1946. The cumulative difference amounts to 504,900 acre-feet for the period.

The spread of salt cedar during the 1940's-1966 and the subsequent clearing during the period 1967-1969 appears to have only minimal effects on the geo-hydrologic system for the reasons which follow. First, ground-water withdrawals (pumpage) are at least ten to twelve times greater than estimated salt cedar use (Figure 4). The relationship showing water levels in the Orchard Park well vs. base flow gain (Figure 10) for the period 1950-1976 indicates no measurable effects in base flow due to the spread, clearing, and removal of salt cedars. And finally, the relationship showing pumpage vs. base flow gain for the period 1966-1976 (Figure 12) illustrates that pumpage was the dominate factor causing the reduction of base flow and that the effects of the salt cedars are negligible as previously shown on Figure 10.

Estimates of overdraft on the Roswell Artesian Basin have been placed at between 120,000 to 170,000 acre-feet per year (U.S. Bureau of Reclamation, 1976, p. 77). These continued overdrafts will have adverse effects on water movement from the deep artesian to the shallow aquifer, on the Pecos River, and on the rate of salt-water encroachment into the fresh water areas of the deep artesian aquifer. These effects are better illustrated by quoting directly from a New Mexico Planning document (U. S. Bureau of Reclamation, 1976, pp. 77 and 78) as follows:

"The continuing general decline of head in the artesian aquifer has caused saline water, which formerly discharged naturally to the Pecos River, to encroach into the freshwater portion of the aquifer east and north of Roswell.

If present conditions of use and recharge continue, it can be expected that the natural discharge that appears as base inflow to the river will cease. The loss of this discharge will adversely affect the supply available to the river pumping plants in the Acme-Artesia reach, the Carlsbad Irrigation District, and other downstream surface water users, as well as cut off the natural escape route for salts from the basin."

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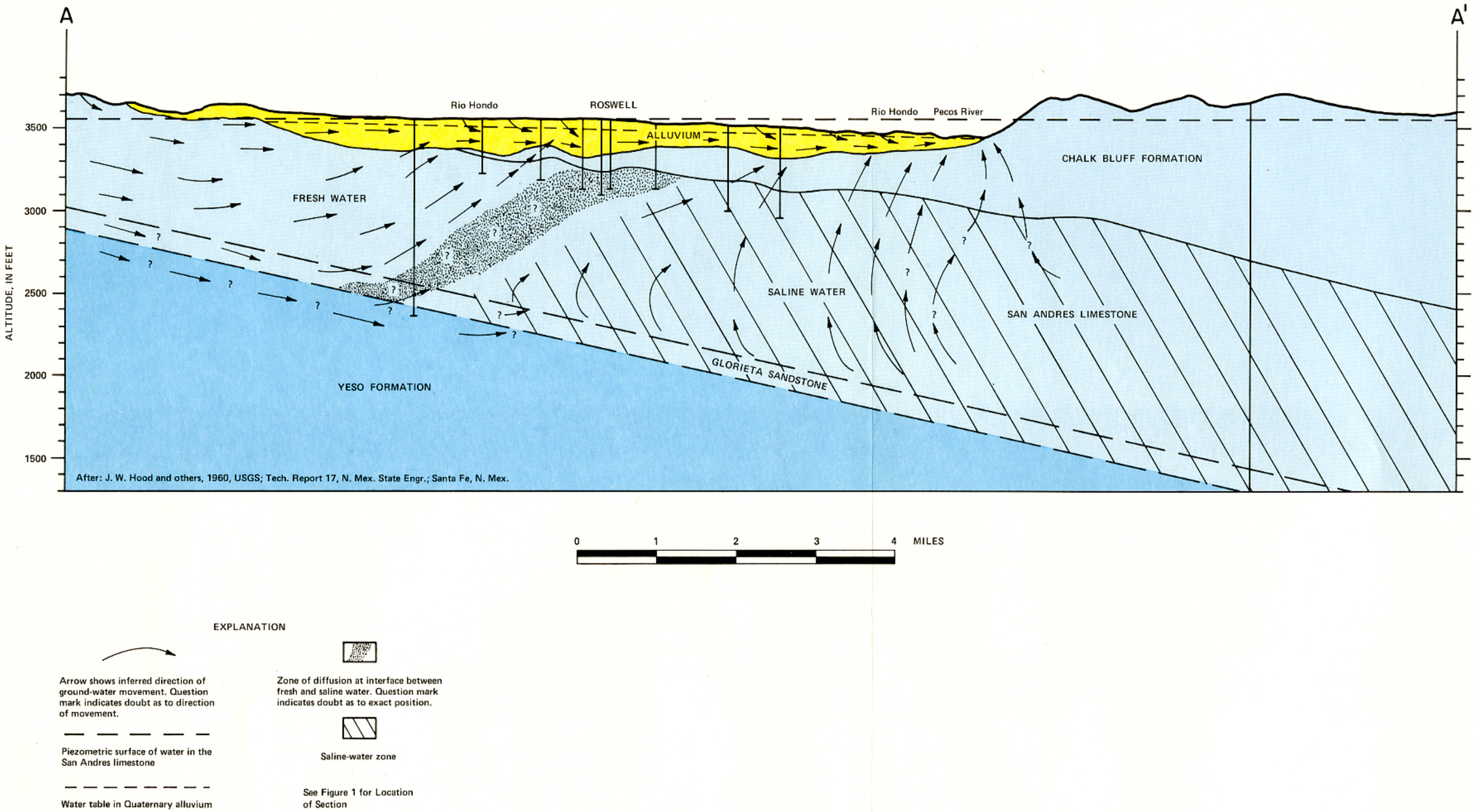

Figure 3

Diagram Showing Geologic Section, the Probable Pattern of Circulation of Ground Water, and the Interface Between Fresh and Saline Water in the San Andres Limestone at the Latitude of Roswell, Chaves County, New Mexico

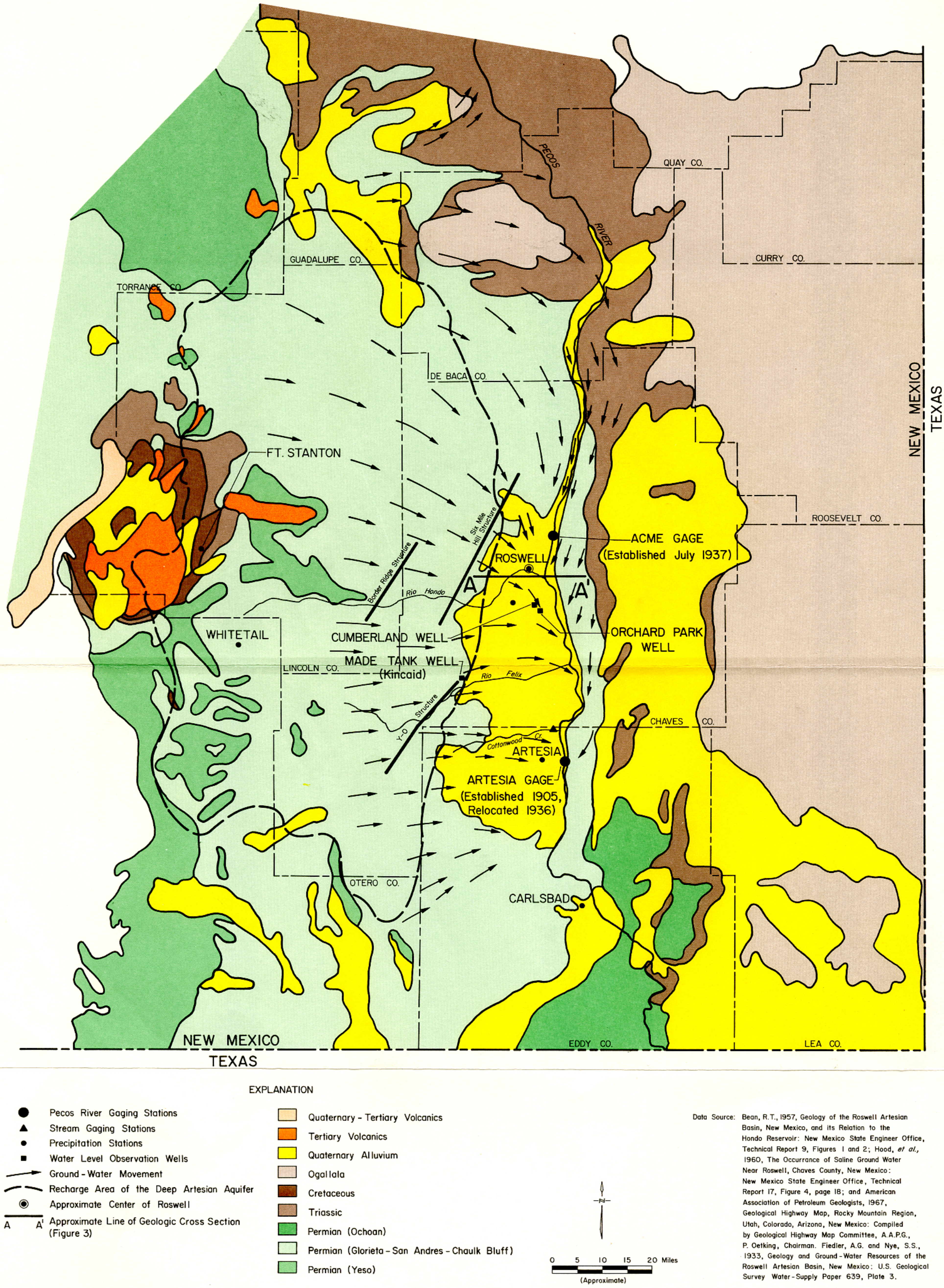

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Figure 1

Generalized Geologic Map of the Roswell Region Showing Ground-Water Movement and the Approximate Total Recharge Area of the Deep Artesian Aquifer

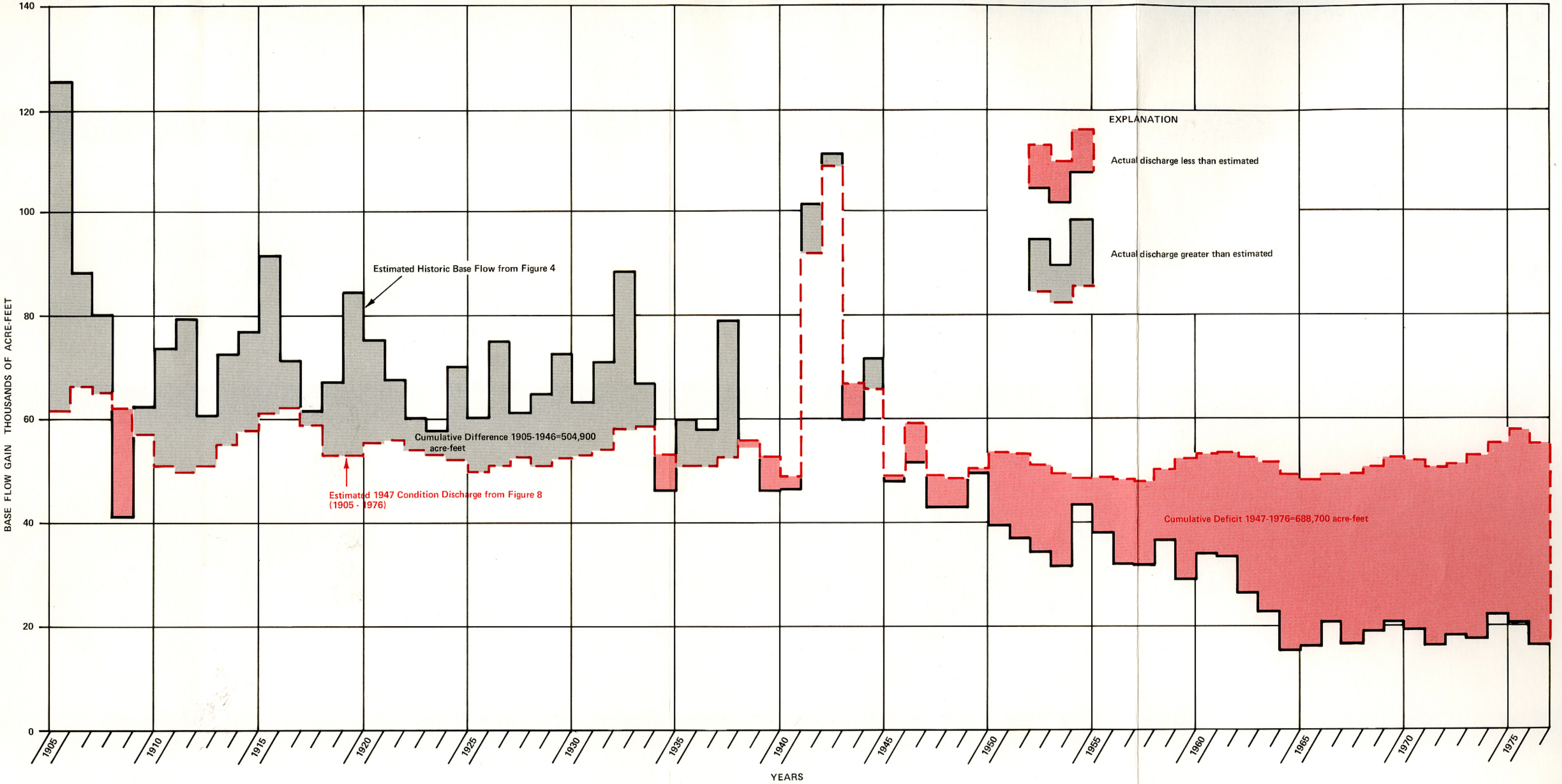
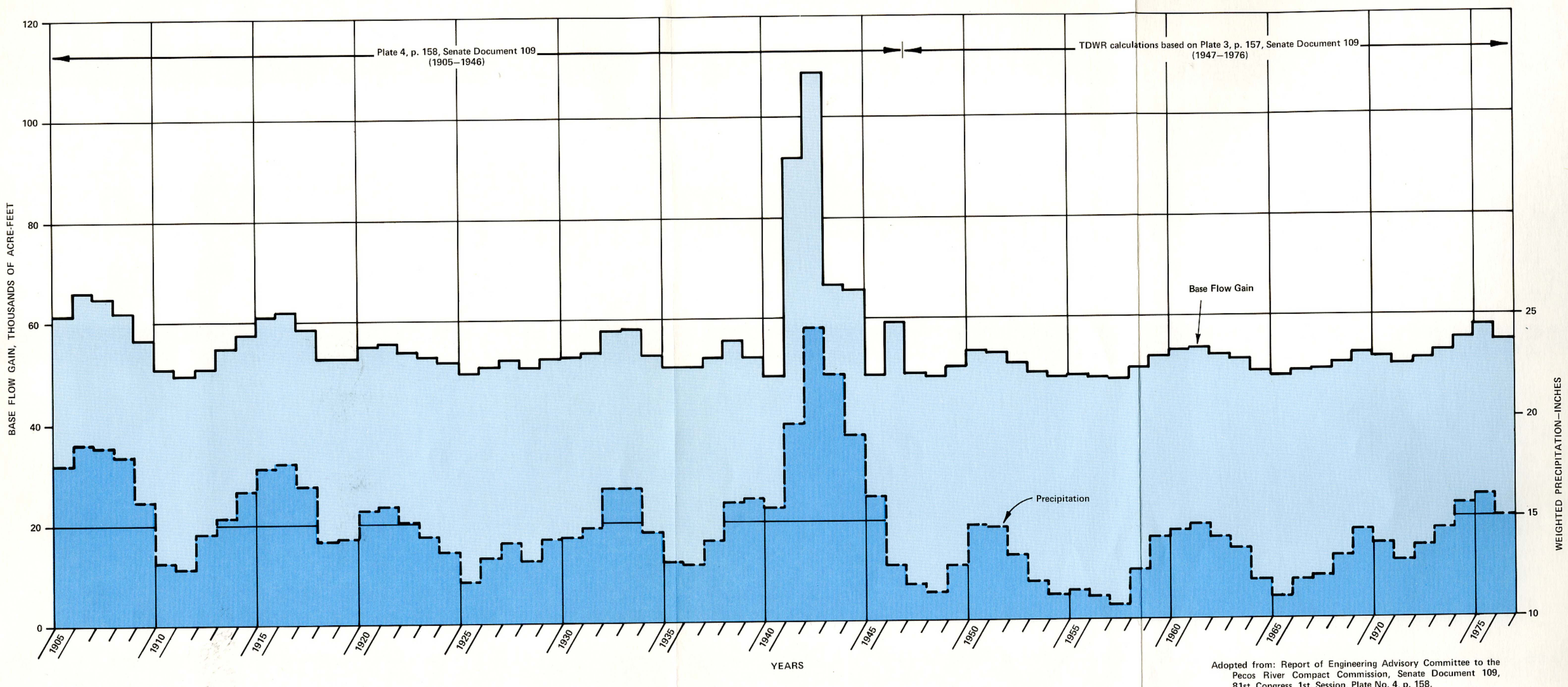


Figure 9

Base Flow Gain Acme To Artesia Gages



Adopted from: Report of Engineering Advisory Committee to the Pecos River Compact Commission, Senate Document 109, 81st. Congress, 1st. Session, Plate No. 4, p. 158.

Figure 8

Predicted Base Flow Gain Between Acme and Artesia Gages Using the Weighted Five Year Precipitation and Base Flows (Figure 7) and Historical Precipitation For the Period 1905 Through 1976

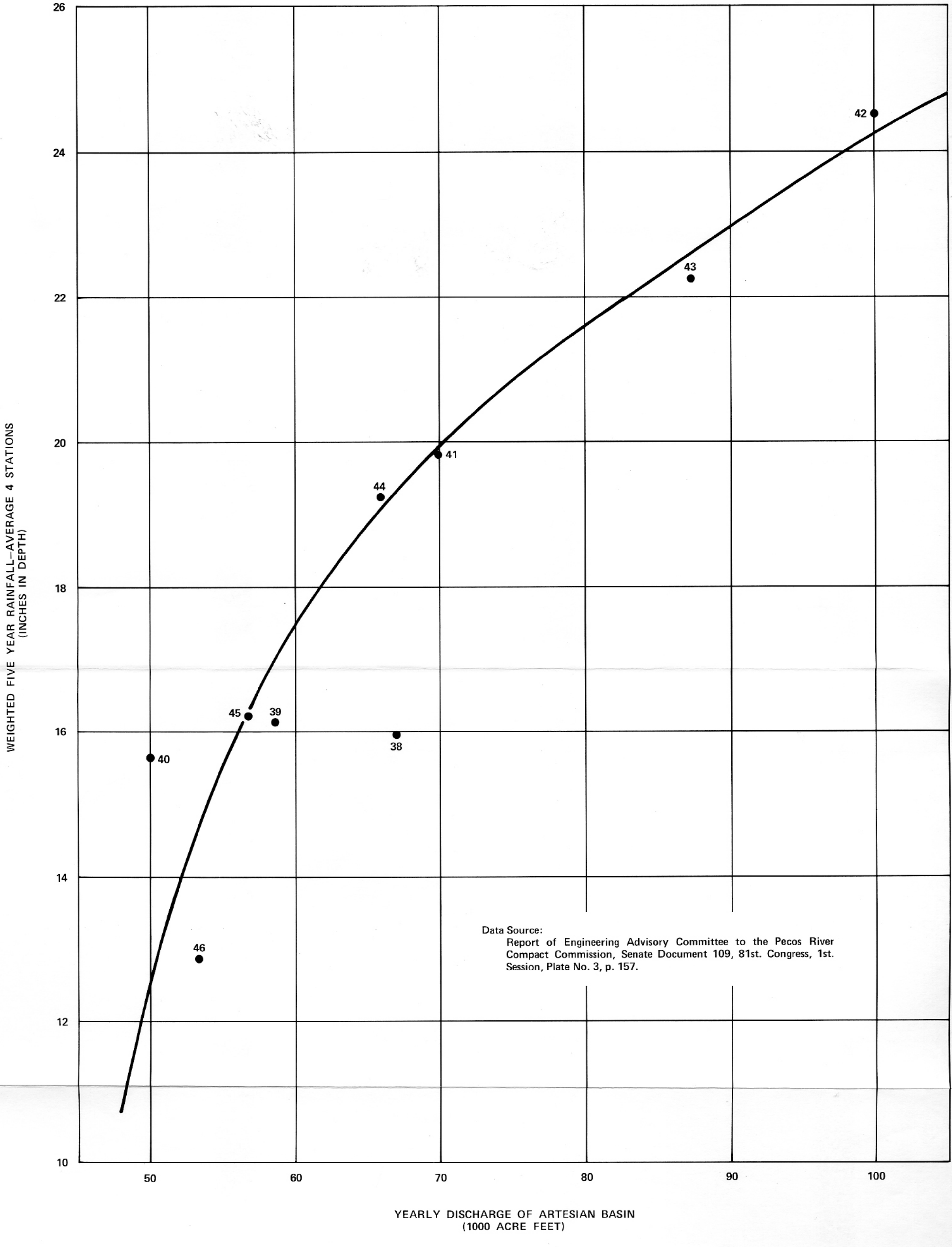


Figure 7

Correlation of Weighted Precipitation (Roswell, Artesia, Carlsbad, and Whitetail Gages) and Base Flow Gain (Discharge) Between the Acme and Artesia Gages on the Pecos River, New Mexico, 1938-1946

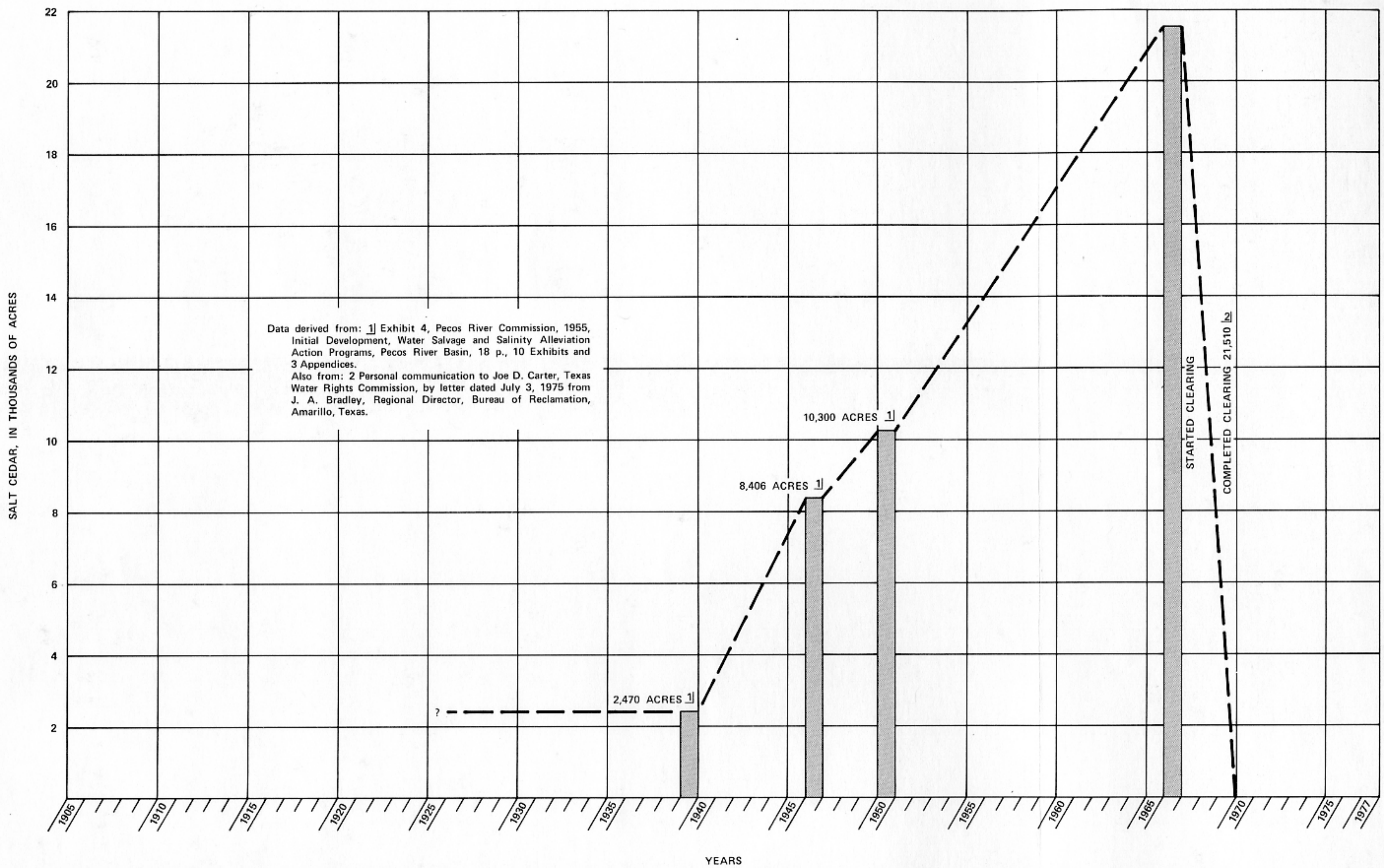
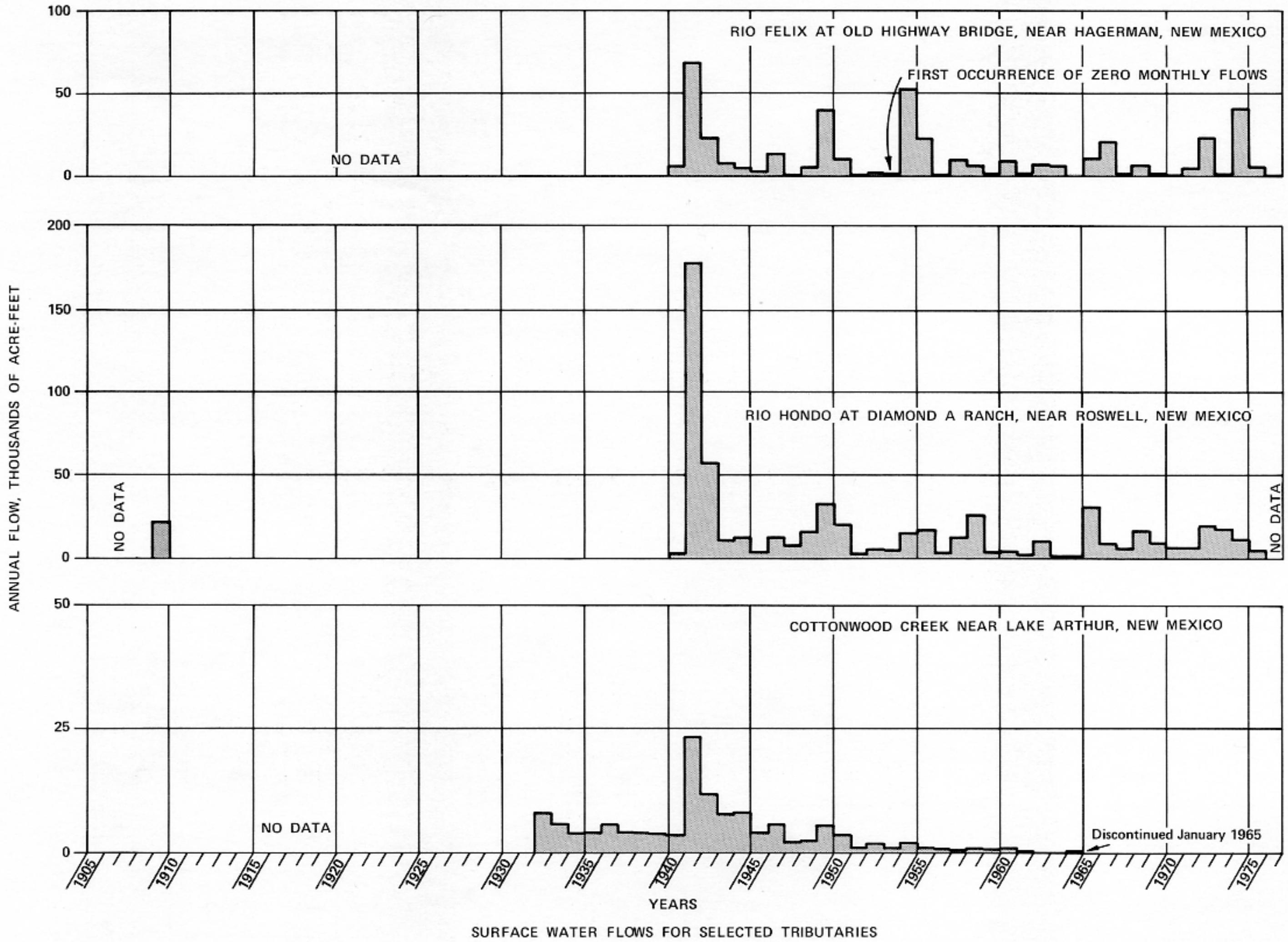
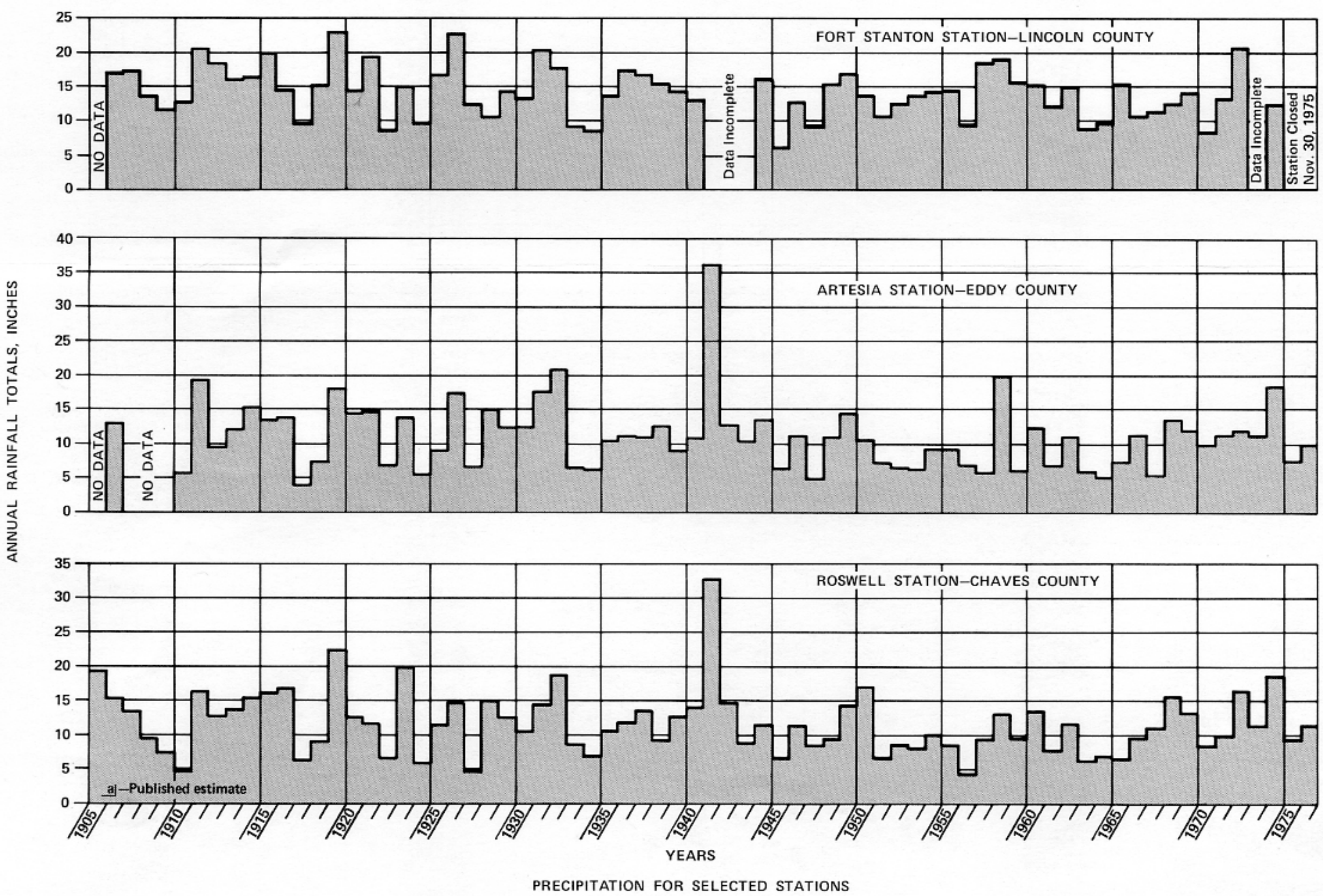


Figure 6

The Spread and Elimination of Salt Cedar Between Acme and Artesia Gages, New Mexico





Source of Data:

PRECIPITATION

State of New Mexico State Engineer Office, 1956, Climatological summary New Mexico precipitation 1849-1954: New Mexico Interstate Stream Commission and the Weather Bureau, U.S. Dept. of Commerce, Tech. Rept. No. 6, pp. 95, 96, 136, and 202.

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Missing data secured from records of TDWR Weather Modification and Technology Division.

SURFACE WATER FLOWS

Cottonwood Creek and Rio Felix

Records through 1971: Pecos River Commission, 1972, Preliminary Compilation of Pecos River Reservoir and Stream flow records: Inflow-Outflow Subcommittee to the Engineering Advisory Committee, Pecos River Commission, miscellaneous unpublished data.

1972-1976: U.S. Geol. Survey, Water resources data for New Mexico, annual reports for 1972 through 1976.

Rio Hondo

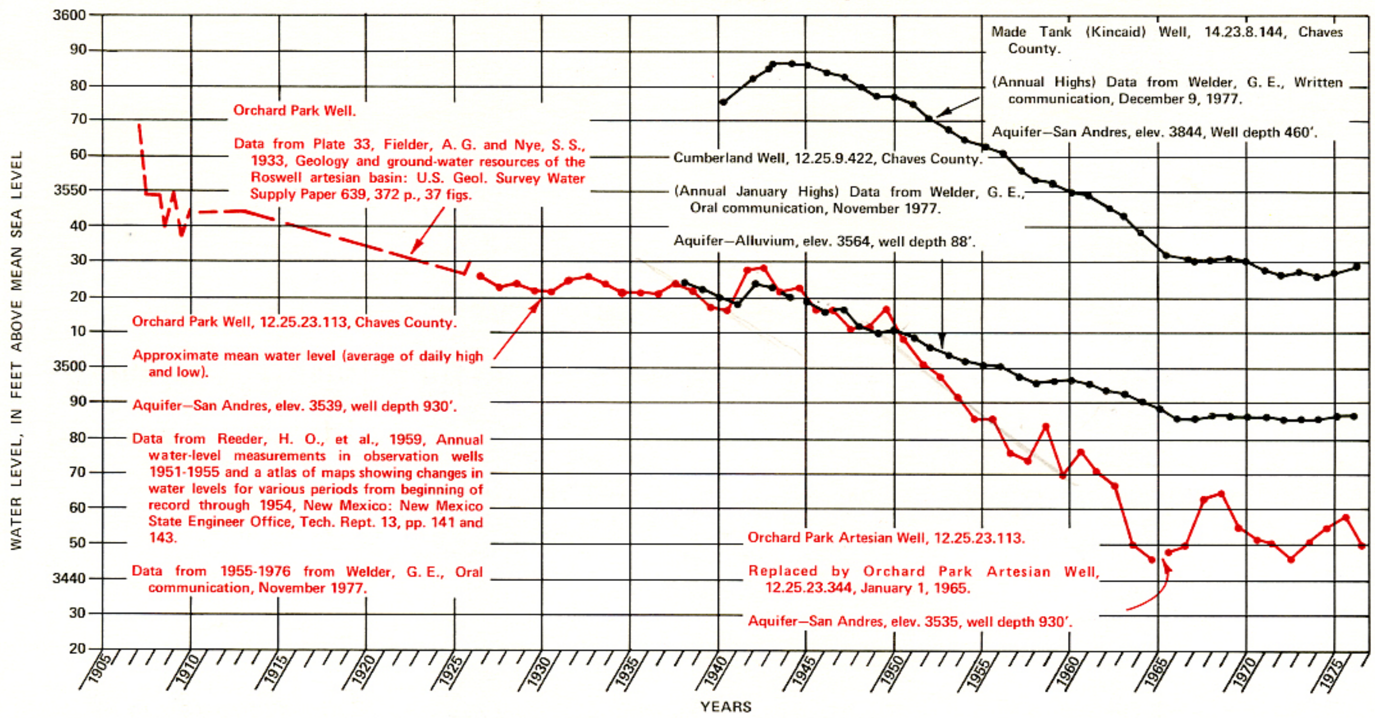
May 1908—April 1909: p. 196, U.S. National Resources Planning Board, 1942, Regional planning, part X—the Pecos River joint investigation in the Pecos River Basin in New Mexico and Texas—summary, analysis, and findings 206 p.

1940-1969: From publications of U.S. Geol. Survey entitled, "Compilation of Records of Surface Waters of the United States" for specified years and from the following Water-Supply Papers and page numbers, respectively: 1312, pp. 535-537; 1732, p. 489; 1923, pp. 610-612; and 2123 pp. 708-710.

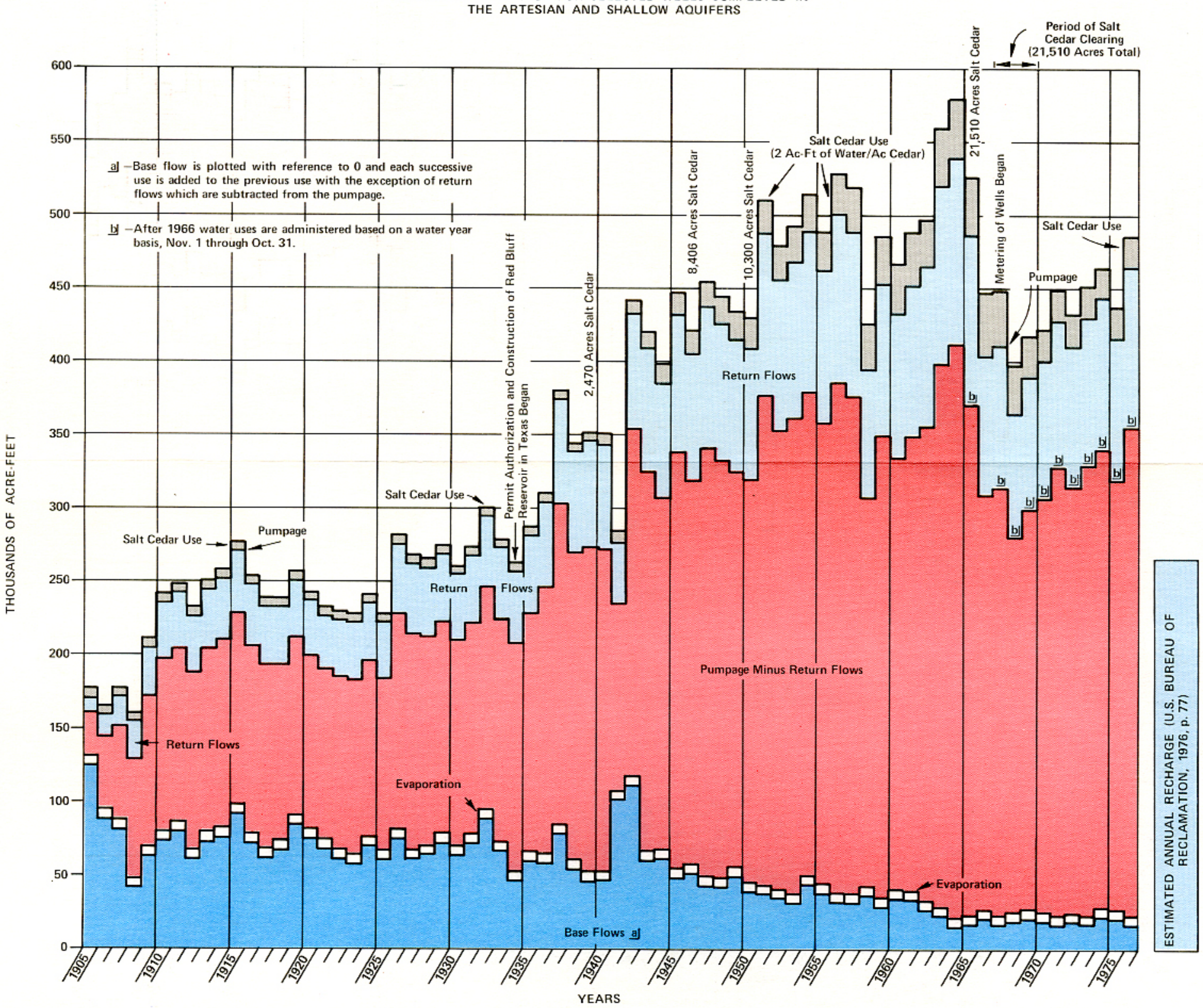
1970-1976: U.S. Geol. Survey, Water resources data for New Mexico, annual reports for 1970 through 1976.

Figure 5

Surface Water Flows for Selected Tributaries and Precipitation for Selected Stations in the Roswell Region, New Mexico, 1905 Through 1976



WATER-LEVEL CHANGE FOR SELECTED WELLS COMPLETED IN THE ARTESIAN AND SHALLOW AQUIFERS



Source of Data for Idealized Graphical Model:

BASE FLOW

1905-1918: Pecos River Compact Commission, 1949, Compact entered into by the States of New Mexico and Texas, relating to waters of the Pecos River–together with the report of the Engineering Advisory Committee to the Pecos River Compact Commission: presented by Mr. O'Mahoney, August 19 (Legislative day June 2), 1949, U.S. 81st Congress, 1st Session, Senate Document 109, Public Law 91, p. 51.

1919-1956: Pecos River Commission, 1960, Report on review of basic data to the Engineering Advisory Committee, Table A-8-1.

1957-1976: Table 2, p.42, Welder, G. E., 1973, Base flow in the Acme-Artesia reach of the Pecos River, New Mexico, 1957-1971: U.S. Geol. Survey open-file rept., 50 p. With updates 1972 through 1976.

PUMPAGE

1905-1924: From Figure 32, p. 225, Fielder, A. G., and Nye, S. S., 1933, Geology and ground-water resources of the Roswell artesian basin, New Mexico: U.S. Geol. Survey Water-Supply Paper 639, 372 p., 37 figs.

1925 and 1938-1957: Table 11, p. 72, Mower, R. W., 1960, Pumpage in the Roswell basin, Chaves and Eddy Counties, New Mexico: U.S. Geol. Survey open-file rept., 88 p.

1926-1937 and 1958-1966: Welder, G. E., Oral communication, November 1977.

1967-1976: From p. 13, Brim, G. W., 1975, Roswell Basin Watermaster 10th annual report calendar year 1975: New Mexico State Engineer Office, 16 p.

EVAPORATION

From p. 39, Welder, G. E., 1973, Base flow in the Acme-Artesia reach of the Pecos River, New Mexico, 1957-1971: U.S. Geological Survey open-file rept., 50 p.

RETURN FLOW

Used 25%, 5% for transit losses and 20% for deep perculation based on data on pp. 53 and 55, Mower, R. W., 1960, Pumpage in the Roswell basin, Chaves and Eddy Counties, New Mexico: U.S. Geol. open-file rept., 88 p.

SALT CEDAR USE

Assumed 2 Ac-Ft/Ac water use and used acreage data from Exhibit 4, Pecos River Commission, 1955, Initial development, water salvage and salinity alleviation action programs, Pecos River Basin: 18 p., 10 exhibits, and 3 appendices. Additional data by personal communication to Joe D. Carter, chairman, Texas Water Rights Commission, by letter dated July 3, 1975 from J. A. Bradley, U.S. Bureau of Reclamation, Amarillo, Texas.

Figure 4

Idealized Graphical Model of the Roswell Artesian Basin Showing the Approximate Ground-Water Use, Recharge, Base Flow Gain (Acme to Artesia), and Water-Level Change for Selected Wells Completed in the Artesian and Shallow Aquifers in the Roswell Region, New Mexico, 1905 Through 1976