

# An Appraisal of Potential Water Salvage in the Lake McMillan Delta Area, Eddy County, New Mexico

---

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2029-E

*Prepared in cooperation with  
the Pecos River Commission*



# An Appraisal of Potential Water Salvage in the Lake McMillan Delta Area, Eddy County, New Mexico

By E. R. COX and J. S. HAVENS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

---

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2029-E

*Prepared in cooperation with  
the Pecos River Commission*



**UNITED STATES DEPARTMENT OF THE INTERIOR**

**ROGERS C. B. MORTON, *Secretary***

**GEOLOGICAL SURVEY**

**V. E. McKelvey, *Director***

---

Library of Congress Cataloging in Publication Data

Cox, Edward Riley, 1927—

An appraisal of potential water salvage in the Lake McMillan delta area.

(Geological Survey Water-Supply Paper 2029—E. Contributions to the hydrology of the United States)

“Prepared in cooperation with the Pecos River Commission.”

Bibliography: p.

- I. Water conservation--New Mexico--Eddy Co. 2. Water conservation--New Mexico--Pecos River watershed. 3. Phreatophytes. I. Havens, J. S., joint author.
- II. Pecos River Commission. III. Title. IV. Series: United States Geological Survey Water-Supply Paper 2029—E. V. Series: Contributions to the hydrology of the United States.

TD224.N7C68 333.9763 74—14740

---

**For sale by the Superintendent of Documents, U. S. Government Printing Office**

**Washington, D. C. 20402 - Price \$1.50 (paper cover)**

**Stock Number 2401-02564**

## CONTENTS

---

	Page
Abstract .....	E1
Introduction .....	1
Distribution and density of phreatophytes .....	3
System of numbering wells in New Mexico .....	4
Climate .....	5
Geology .....	5
Hydrology .....	6
Surface water .....	6
Seepage investigations .....	7
Ground water .....	10
Artesian system .....	10
Nonartesian system .....	10
Relation between surface water and ground water .....	11
Artesia to Rio Peñasco .....	11
Rio Peñasco to Lake McMillan .....	12
Lake McMillan to Major Johnson Springs .....	13
Use of water by phreatophytes .....	13
Potential salvage of water .....	23
Summary and conclusions .....	24
References .....	25

## ILLUSTRATIONS

---

	Page
PLATE	
1. Maps showing areal density of phreatophytes in the Lake McMillan delta area, Eddy County, New Mexico .....	In pocket
2. Geohydrologic maps and sections of the Lake McMillan delta area, Eddy County, New Mexico .....	In pocket
FIGURE	
1. Index map showing area of investigation .....	E2
2. Diagram showing well-numbering system used in New Mexico ...	5
3. Graph showing difference in monthly mean flow of the Pecos River between Artesia and Kaiser Channel gaging stations, 1955-64 ..	9
4. Graph showing yearly transpiration by saltcedar at 100-percent volume density related to average depth to water, Lake McMillan delta area, New Mexico, and Safford Valley, Arizona .....	17

## TABLES

---

	Page
TABLE	
1. Miscellaneous streamflow measurements of the Pecos River between Artesia gaging station and Lake McMillan .....	E8

	Page
TABLE 2. Calculated transpiration, using White's formula, by phreatophytes from ground-water sources, 1957-59 .....	E14
3. Estimated transpiration, using an extension of White's method, by phreatophytes from ground-water sources, 1960, using areal density only .....	16
4. Estimated transpiration by saltcedar, 1960, using 100-percent volume-density estimates .....	18
5. Estimated other water losses, water year 1957 .....	20
6. Estimated other annual water losses, water years 1951-60 .....	21
7. Estimated annual evapotranspiration, using the Blaney-Criddle method .....	22
8. Summary of estimates of water use .....	22

---

**AN APPRAISAL OF POTENTIAL  
WATER SALVAGE IN THE LAKE McMILLAN  
DELTA AREA, EDDY COUNTY,  
NEW MEXICO**

---

By E. R. COX and J. S. HAVENS

---

ABSTRACT

The Lake McMillan delta area is located between Artesia and Lake McMillan on the Pecos River in Eddy County, N. Mex. Alluvium, which is more than 200 feet thick in places, is the principal water-bearing formation and is part of the "shallow aquifer" of the Roswell basin. Recharge to the shallow aquifer is by infiltration from the Pecos River, by irrigation water, by precipitation, and by ground water that moves into the area. Discharge from the shallow aquifer is by wells, by transpiration from phreatophytes, and by evaporation from swampy areas.

Saltcedar growth in the area increased during the study period from about 13,700 acres in 1952 to about 17,100 acres in 1960, a 25-percent increase. Most of this increase was in the areal-density range of zero to 30 percent. The estimated average transpiration of phreatophytes in the Artesia to Lake McMillan reach is about 29,000 acre-feet of water per year from ground-water sources.

In the reach from Artesia to the Rio Peñasco, where the regional water table is above the Pecos River, saltcedar eradication might salvage from 10,000 to 20,000 acre-feet of water per year for use downstream. From the Rio Peñasco to Lake McMillan the river is perched above the water table; therefore, elimination of the saltcedar probably would not increase flow in the river, nor would drains be effective. Clearing in this reach, however, might increase the flow at Major Johnson Springs below Lake McMillan. Floodways through this reach would eliminate some evapotranspiration but might increase the amount of sediment deposited by floodwaters in Lake McMillan.

INTRODUCTION

The potential salvage of water used by phreatophytes along the Pecos River is of direct concern to the Pecos River Commission, in fulfillment of the objectives of the Pecos River Compact (1949).

The purpose of this study is to account for the water in the Pecos River valley between Artesia and Lake McMillan—in particular, to determine the probable amount of water used by saltcedar in the area of the old delta of Lake McMillan and the probable amount of water that might be salvaged by eradication of saltcedar or by construction of floodways through the delta area. Some additional information has been gathered as far south as Major Johnson Springs (fig. 1). Data

E2 CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

presented in this report may be useful in planning projects to salvage water now used by phreatophytes along this reach of the river. This study was made by the U.S. Geological Survey in cooperation with the Pecos River Commission.

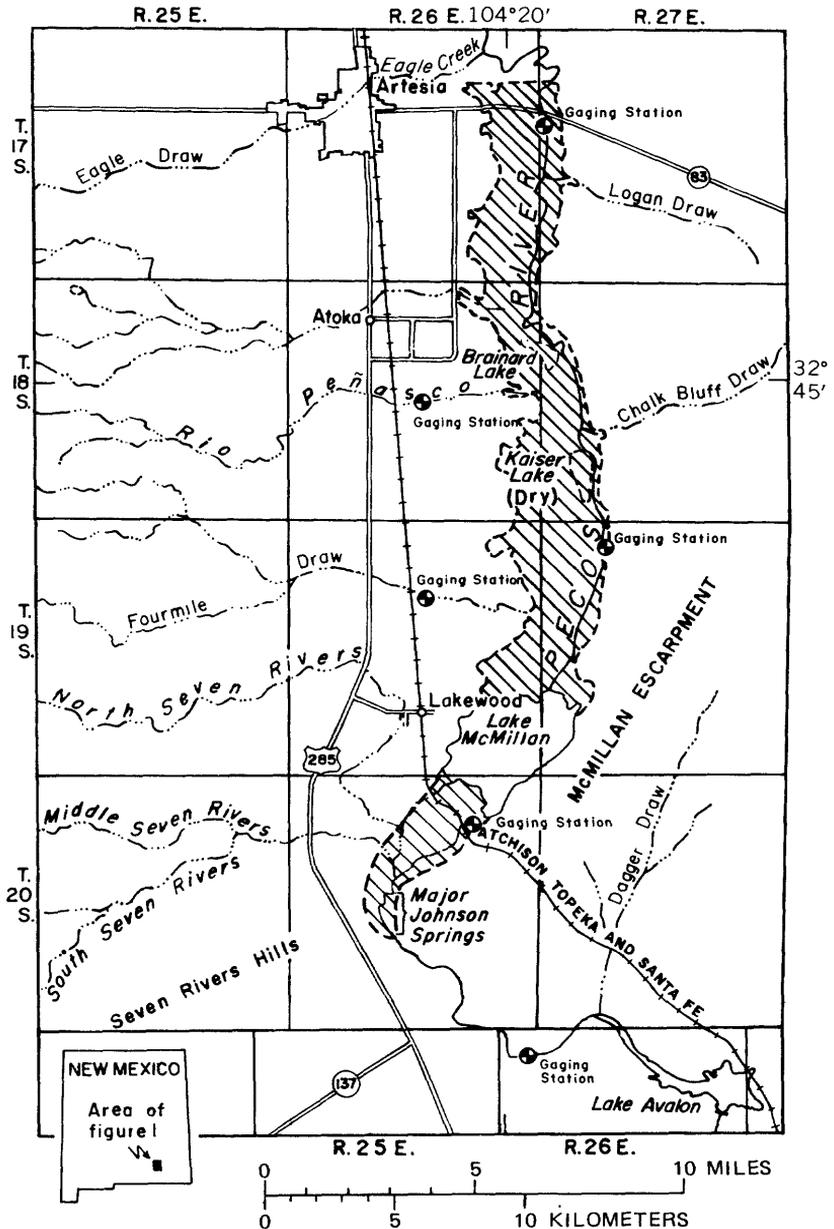


FIGURE 1.—Index map showing area of investigation (patterned).

In 1958 the Pecos River Commission sponsored legislation in the U.S. Congress that resulted in Public Law 85-333, 85th Congress, Senate Joint Resolution 39. This law authorized the construction of a salvage channel, levee, cleared floodway, and spur drains through the Lake McMillan delta reach of the Pecos River. The legislation, however, stipulates that no work shall be commenced on the clearing of the floodway unless provisions have been made to replace any Carlsbad Irrigation District terminal storage that might be lost by the clearing of the floodway. (If the saltcedar, which retards the movement of suspended sediment in the delta during periods of high water, is cleared away, its removal is expected to cause a greatly increased movement of suspended sediment into Lake McMillan, where the sediment would be deposited, thus decreasing the storage capacity of the reservoir.)

Public Law 88-594, Senate Joint Resolution 49, dated September 12, 1964, authorized a continuing program to reduce the nonbeneficial consumption of water (eradication of saltcedar and other phreatophytes) in the Pecos River basin from its headwaters in New Mexico to the town of Girvin, Tex., about 140 miles above its mouth. This law also stated that work could not be started in the Lake McMillan delta area until provision had been made to replace any Carlsbad Irrigation District terminal storage that might be lost by such clearing of vegetation.

Work began in 1967 on the clearing of saltcedar along the reach of the Pecos River between Dexter and Bitter Lake (about 25 to 50 miles northeast of Artesia). However, the clearing of vegetation in the Lake McMillan delta reach of the river has been deferred until provisions have been made to replace any terminal storage in Lake McMillan that may be lost by such action.

The bottom land along the Pecos River between Artesia and Major Johnson Springs is covered by saltcedar and saltgrass. The dense growth of saltcedar transpires large quantities of water that might otherwise be used beneficially. A major feature of this reach of the river is the old delta of Lake McMillan. The delta extends from present-day Lake McMillan to about the mouth of the Rio Peñasco, approximately the middle part of the area studied. The Pecos River flows in conveyance channels throughout much of the reach; the natural channel, for the most part, is choked with saltcedar. The conveyance channels carry about 1,500 ft<sup>3</sup>/s (cubic feet per second); larger flows inundate the saltcedar-infested bottom lands, where part is lost by transpiration.

#### DISTRIBUTION AND DENSITY OF PHREATOPHYTES

Plate 1 shows the distribution and areal density of saltcedar in 1952 and in 1960. Vertical density was not mapped. An examination of these maps shows that most of the saltcedar growth is on the flood plain of the Pecos River and that less dense growth extends up tributaries or canyons.

## E4 CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

From 1952 to 1960 the total acreage infested by saltcedar increased about 25 percent, as shown by the following tabulation:

Areal density (percent)	Area 1952		Areal density (percent)	Area 1960	
	Sq mi	Acres		Sq mi	Acres
0-10	3.6	2,300	0-15	8.7	5,600
10-30	.5	300	15-30	1.1	700
30-50	.7	400	30-50	2.6	1,700
50-70	3.9	2,500	50-70	4.2	2,600
70-90	9.2	5,900	70-90	4.7	3,000
90-100	3.6	2,300	90-100	5.5	3,500
<b>Total</b>	<b>21.5</b>	<b>13,700</b>	<b>Total</b>	<b>26.8</b>	<b>17,100</b>

The two maps on plate 1 are not directly comparable in the lower density values, owing to different density scales, however, much of the increase in saltcedar coverage appears to be in the density range from zero to 30 percent. Most of this increase was on the west side of the Pecos River in the reach from Artesia gaging station to about 2 miles below the Rio Peñasco. In 1952 Brainard and Kaiser Lakes apparently contained water or had no growth of saltcedar; by 1960 these lakes had become dry and were infested by saltcedar growth in the density range from zero to 15 percent, or heavier.

From Artesia gaging station to Lake McMillan, the height and the rocky character of the escarpment east of the Pecos River effectively prevent the spread of saltcedar. Except in the vicinity of the river and in the flood plain, the water table east of the river is too far below the land surface for phreatophytes to become established.

In the old delta of Lake McMillan below the Rio Peñasco, there was little increase of saltcedar. However, some changes—generally to lesser densities—were noted from the 1952 to the 1960 surveys. This may have resulted, in part, from differences in mapping techniques between the 1952 and the 1960 surveys. The 1952 survey was compiled by the U.S. Bureau of Reclamation from stadia survey and aerial photographs; the 1960 survey was made by the U.S. Geological Survey from aerial photographs with spot checks of density (Mower and others, 1964, p. 58-59).

A second possible cause of density change can be attributed to fires in the delta area that occurred between the 1952 and the 1960 surveys.

### SYSTEM OF NUMBERING WELLS IN NEW MEXICO

All wells referred to in this report are identified by a location number assigned by the U.S. Geological Survey and the State Engineer

of New Mexico. The location number is a description of the geographic location of a well, based on the system of public land surveys. It indicates the location of that well to the nearest 10-acre tract, if it can be located that accurately. The location number consists of a series of numbers corresponding to the township, range, section, and tract within a section, in that order, as illustrated in figure 2. If a well has not been located closely enough to be placed within a particular section or tract, a zero is used for that part of the number.

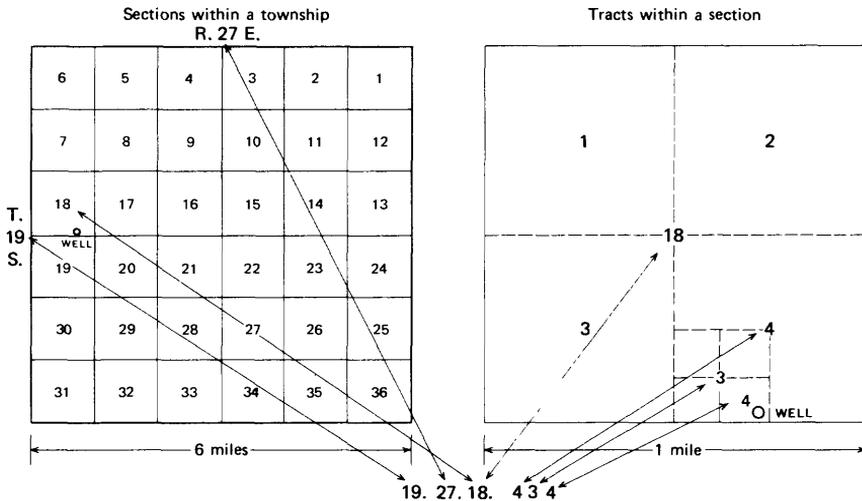


FIGURE 2.—Well numbering system used in New Mexico.

### CLIMATE

The climate of the Lake McMillan delta area is semiarid. The average annual precipitation at Artesia is about 11 inches, most of which occurs during summer thunderstorms. However, for the study period, 1952-60, the rainfall was somewhat below average. About 80 percent of the yearly precipitation occurs during the growing season (May-October). The mean annual temperature at Artesia is 61°F. Daytime summer temperatures in the area may rise above 100°F; winter temperatures frequently drop below 32°F. Evaporation measured from a standard land pan at Lake Avalon is more than 100 inches per year.

### GEOLOGY

The Lake McMillan delta area is in the southern part of the Roswell basin. The Roswell basin extends north and south for a distance of

about 90 miles, from about 68 miles north of Artesia southward to the Seven Rivers Hills. It extends from the bluffs just east of the Pecos River westward about 30 miles to the area of outcrop of the San Andres Limestone, where the water table intersects the bottom of the limestone. The Roswell basin is on the northwest shelf of a large subsurface structural feature, the Delaware basin.

Sedimentary rocks of the Artesia Group of Permian age and alluvium of Holocene age crop out in the Lake McMillan delta area. The Artesia Group consists of the Grayburg, Queen, Seven Rivers, Yates, and Tansill Formations; the Yates and Tansill are absent in the Lake McMillan delta area. The Artesia Group is underlain by the San Andres Limestone of Permian age. The San Andres and Grayburg contain solution openings in limestone, dolomite, and probably gypsum and constitute the main artesian aquifer in the Roswell basin.

Rocks of the Artesia Group that crop out along the east side of the Pecos River in the Lake McMillan delta area (pl. 2A) are, for the most part, gypsum and red silt and clay containing a few thin stringers of dolomite. These rocks are easily eroded and dissolved, and sinkholes and collapse features are numerous in places along the east side of the river, particularly near Lake McMillan.

The alluvium of the Pecos River valley consists of unconsolidated clay, silt, sand, and gravel, and conglomerate cemented with calcium carbonate. In a part of the area the alluvium deposited before construction of McMillan Dam in 1893 can be differentiated from the alluvium deposited after construction of the dam. The alluvium ranges in thickness from zero to more than 200 feet (Morgan, 1938, pl. 1). The post-Lake McMillan alluvium is confined to the area that was covered by Lake McMillan (old delta of Lake McMillan) during the early years of the lake. Since the filling of the upstream part of the lake and the retreat of the lake to its present position, floodwaters have brought sediment to the old delta area; however, virtually all the post-Lake McMillan alluvium was deposited in the upstream part of the lake, where a typical delta was formed. Coarser material was deposited in the upstream part of the delta, and finer material was deposited in the downstream part.

The approximate thickness of the post-Lake McMillan alluvium is shown on plate 2A as the difference in topography between 1915 and 1956. However, inasmuch as sediment was deposited in the delta in the period prior to 1915 and may have filled much of the river channel, the contours representing the thickness of post-Lake McMillan alluvium are the minimum thickness of these sediments.

## HYDROLOGY

### SURFACE WATER

The Pecos River has perennial flow in the reach between Artesia and Lake McMillan. Tributaries in this reach of the Pecos River are inter-

mittent and flow only after heavy rainstorms. The principal tributaries in this reach are the Rio Peñasco and Fourmile Draw, both of which drain areas west of the Pecos River. Chalk Bluff Draw and Logan Draw enter the Pecos River from the east (pl. 2A).

The West Channel (pl. 2A) probably at one time was one of the main-stem channels of the Pecos River, but it is now a tributary of Lake McMillan. During 1956 and part of 1957 water drained from Brainard Lake to Lake McMillan in the West Channel. Floodwater in the Rio Peñasco and Fourmile Draw is intercepted by the West Channel.

The low flow of the Pecos River in the Lake McMillan delta area from about Brainard Lake to Lake McMillan is contained in Kaiser Channel, a conveyance channel constructed by the Carlsbad Irrigation District, aided by the U.S. Bureau of Reclamation, in 1949. Kaiser Channel has since been extended upstream by the same parties. Since 1969 the low flows of the Pecos have been contained in the conveyance channel throughout most of the reach from Artesia to Lake McMillan.

Streamflow records are collected by the U.S. Geological Survey at the following gaging stations (fig. 1): Pecos River near Artesia, Pecos River (Kaiser Channel) near Lakewood, and Pecos River below McMillan Dam, on the main stem; and Rio Peñasco at Dayton and Fourmile Draw near Lakewood, on tributaries. Annual streamflow records have been published by the Survey in water-supply papers through water-year 1960 (U.S. Geological Survey, 1932-60) and in annual data reports since that time (1961-64).

The Artesia and Kaiser Channel gaging stations record the flows in the Pecos River and the release of water to Lake McMillan by the Carlsbad Irrigation District from Alamogordo Reservoir, about 120 miles north of Artesia. Above about 1,500 ft<sup>3</sup>/s, some flow bypasses the Kaiser Channel gaging station. The average flow was 310 ft<sup>3</sup>/s at the Artesia gaging station for the period 1936-64. The difference in measured monthly mean flow (floodflow periods are omitted) between the Artesia and Kaiser Channel gaging stations during 1955-64 is shown in figure 3. A negative figure indicates loss in the reach. These data indicate that the Pecos River loses flow most of the time in the reach between Artesia and Kaiser Channel gaging stations. The average of the mean monthly differences in flow between the Artesia and Kaiser Channel gaging stations as shown in figure 3 was a loss of 2.6 ft<sup>3</sup>/s for 1955-64.

#### SEEPAGE INVESTIGATIONS

Many seepage investigations were made during low-flow periods to determine gains or losses in flow from Artesia to Lake McMillan. The locations of sites where streamflow was measured during seepage investigations between the Artesia gaging station and Lake McMillan are shown on plate 2B. Results of streamflow measurements at these sites are given in table 1.

TABLE 1.—Miscellaneous streamflow measurements of the Pecos River between Artesia gaging station and Lake McMillan, Eddy County, N. Mex.  
 (Streamflow data are in cubic feet per second)

No.	Location	Gain Flow or loss									
Date		8-23-55	9-1-55	11-1-55	3-1-56	4-2-56	5-1-56	6-1-56	9-17-56	10-23-56	11-19-56
1	Artesia gaging station	19.3	3.74	106	76.9	32.4	55.4	37.8	16.3	a24.0	75.4
2	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 24, T. 17 S., R. 26 E.										
3	SE $\frac{1}{4}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 36, T. 17 S., R. 26 E.										
4	NW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 7, T. 18 S., R. 27 E.	25.2	4.68 + 0.94	109 + 3	81.3 + 4.4	32.9 + 0.5	53.7 - 1.7	34.0 - 3.8	15.4 - 0.9	24.8 + 0.8	68.6 - 6.8
5	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 19, T. 18 S., R. 27 E.										
6	Kaiser Channel gaging station	26.4	5.37 + .69	111 + 2	79.8 - 1.5	41.1 + 8.2	59.9 + 6.2	29.2 - 4.8	9.85 - 5.6	23.1 - 1.7	66.3 - 2.3
7	SE $\frac{1}{4}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 18, T. 19 S., R. 27 E.										
8	SE $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 19, T. 19 S., R. 27 E.										
Date		12-18-56	1-17-57	2-14-57	4-15-57	5-17-57	7-1-57	12-17-57	2-20-58	3-1-60	2-19-64
1	Artesia gaging station	72.0	60.1	40.5	40.1	46.4	0.29	70.0	53.9	59.3	b42.2
2	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 24, T. 17 S., R. 26 E.										
3	SE $\frac{1}{4}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 36, T. 17 S., R. 26 E.										
4	NW $\frac{1}{4}$ NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 7, T. 18 S., R. 27 E.	61.6	57.2 - 2.9	40.7 + 0.2	38.0 - 2.1	41.3 - 2.6	0	70.6 + 1.0	50.4 - 4.0	57.5 - 2.5	
5	SE $\frac{1}{4}$ SE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 19, T. 18 S., R. 27 E.										
6	Kaiser Channel gaging station	62.7	56.1 - 1.1	39.3 - 1.4	33.5 - 4.5	35.1 - 1.8	0	64.4 - 3.9	c53.8 + 1.4	56.9 - .6	40.9 + .7
7	SE $\frac{1}{4}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 18, T. 19 S., R. 27 E.										
8	SE $\frac{1}{4}$ NW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 19, T. 19 S., R. 27 E.										

a Not measured. Daily flow.

b Average of two measurements.

c Measured 2-21-58.

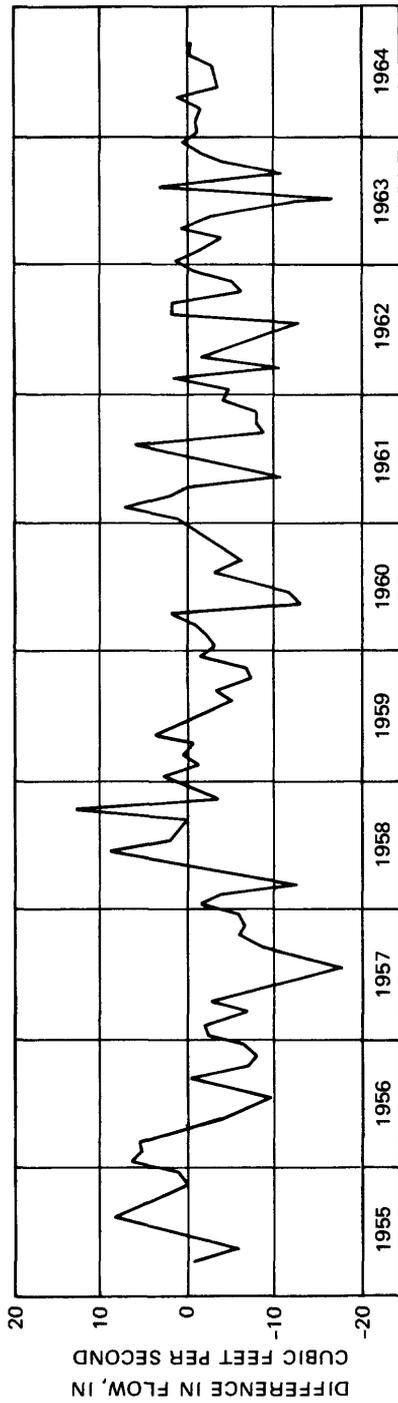


FIGURE 3.—Difference in monthly mean flow of the Pecos River between Artesia and Kaiser Channel gaging stations, 1955-64.

Although the seepage investigations give conflicting results, the Pecos River generally loses flow in the reach between the Artesia gaging station and Lake McMillan (table 1). Many of the apparent gains and losses in the reach are within 5 percent of the measured discharge, the range of error of most discharge measurements. Attempts to measure gains and losses in the range of a few cubic feet per second when flows are larger than about 70 ft<sup>3</sup>/s are likely to result in more erratic gain and loss values than those yielded in the lower flow range.

#### GROUND WATER

The San Andres Limestone, the Grayburg Formation of the Artesia Group, and the alluvium are the principal aquifers in the Roswell basin. In the area of this investigation, in the southern part of the Roswell basin, solution channels in limestone, dolomite, and probably gypsum of the San Andres Limestone and of the Grayburg and Queen Formations of the Artesia Group contain water under artesian pressure in part of the area. The overlying semiconfining bed for this artesian system is silt, clay, and gypsum of the upper part of the Artesia Group (the Seven Rivers Formation and possibly the upper part of the Queen Formation). The alluvium contains water under water-table conditions in unconsolidated gravel, sand, silt, and clay.

#### ARTESIAN SYSTEM

The artesian system in the Lake McMillan delta area is part of a large ground-water reservoir in the San Andres Limestone and the Artesia Group in the Roswell basin. The artesian system is recharged in the limestone uplands in the western part of the basin, and water in the system moves generally eastward toward the Pecos River. In the Lake McMillan delta area, the potentiometric surface of the artesian system sloped generally southeastward about 2 to 5 feet per mile in 1957 (pl. 2C). Water in the artesian system is discharged by wells that tap the aquifer and by upward leakage into the alluvium through the semiconfining beds.

#### NONARTESIAN SYSTEM

The nonartesian aquifer system includes connected permeable zones in the alluvium and part of the Artesia Group. The nonartesian system extends from about 46 miles north of Artesia southward to the Seven Rivers Hills and approximately 5 to 8 miles west of the Pecos River (Mower and others, 1964, p. 27).

Ground water in alluvium in the Roswell basin is recharged by (1) infiltration from streams, (2) infiltration from precipitation, (3) infiltration of irrigation water, (4) upward leakage through the semiconfining beds above the artesian system, and (5) leakage from artesian wells (Mower and others, 1964, p. 33). In the Lake McMillan delta area, the alluvium also is recharged by ground water moving into the system from the north and west.

The water table upstream from Brainard Lake generally slopes toward the Pecos River. From Brainard Lake to Lake McMillan, there is a trough in the water table to the west of the Kaiser Channel, indicating movement of the ground water from the river toward the trough. The ground water moves down the slope of the water table perpendicular to the contours of the water table, as shown on plate 2*D* and 2*E*.

Water in the nonartesian aquifer is discharged by wells, evapotranspiration, local seepage to the Pecos River, and through Major Johnson Springs. Most of the cultivated land in the Lake McMillan delta area is in a strip parallel and adjacent to the bottom land between the Rio Peñasco and Lakewood, between U.S. Highway 285 and the bottom lands north of the Rio Peñasco, and between U.S. Highway 285 and the Pecos River from Lakewood to Major Johnson Springs. A large part of the cultivated land is irrigated from wells that tap the alluvium.

Test holes augured into bottom land between the Rio Peñasco and Lake McMillan show the complexity of the shallow alluvium in that area. The lenticular nature of the beds that comprise the alluvium affects its water-bearing properties. Plate 2*F* shows lithologic sections across the bottom lands between the Rio Peñasco and Lake McMillan. The test holes contained water, which when tapped by drilling was found to be under local artesian pressure caused by differences in permeability of the alluvium.

#### RELATION BETWEEN SURFACE WATER AND GROUND WATER

The Pecos River valley between Artesia and Lake McMillan is divided by the Rio Peñasco into two reaches of nearly equal size. The hydrology of these two reaches is dissimilar, as is the hydrology of the reach between Lake McMillan and Major Johnson Springs. Thus, the relation between surface and ground water in each of these three reaches is discussed separately.

#### ARTESIA TO RIO PEÑASCO

The water table in the shallow aquifer between Artesia and the Rio Peñasco slopes toward the Pecos River to within several hundred feet of the river (pl. 2*D*). The river, therefore, might be expected to gain in flow through this reach because ground water can discharge into the river. Miscellaneous streamflow measurements in this reach, however, do not show appreciable gains. As shown in table 1, the average loss in flow between stations 1 and 4 (pl. 2*B*) is 1.6 ft<sup>3</sup>/s. Streamflow measurements on January 17, 1957, showed a loss of 2.9 ft<sup>3</sup>/s in this reach. During the same month, water-table contours (pl. 2*D*) sloped toward the river. The flow in the river at the Artesia gaging station on January 17, 1957, was about 60 ft<sup>3</sup>/s (table 1); hence, the apparent loss was within 5 percent of the measured flow. This is within the margin of error of most streamflow records. Apparently, the reach of the river between the

Artesia gaging station and the Rio Peñasco neither gains nor loses appreciable flow.

Because the water-table contours show ground water moving toward the river but no gain in flow is measured in this reach, the ground water must be discharged before it reaches the river. A swampy area covered with phreatophytes (mainly saltgrass and saltcedar) extends about a mile west of, and parallel to the river between the Artesia gaging station and the Rio Peñasco (pl. 1). A considerable amount of ground water could be discharged to the atmosphere by evapotranspiration from this swampy area.

The quantity of water moving toward the bottom land from the cultivated area can be estimated from the product of the hydraulic conductivity, in gallons per day per square foot, times the hydraulic gradient, in feet per mile, times the length of the 3,300-foot water-table contour, in miles (pl. 2D), times the saturated thickness of the alluvium, in feet. (Hydraulic conductivity is the amount of water, in gallons per day, moving through 1 square foot of rock or soil at a gradient of 1 ft per ft.) The hydraulic conductivity for the alluvium in a belt between the cultivated area and the bottom lands north of Artesia was estimated at 500 gal/d/ft<sup>2</sup> (gallons per day per square foot) by Mower and others (1964, p. 33). The hydraulic gradient in the alluvium between the Artesia gaging station and the Rio Peñasco is about 15 feet per mile (pl. 2D); the length of the 3,300-foot contour in that area is about 7 miles (pl. 2D). The saturated thickness is about 150 feet because the bottom of the alluvium is at an altitude of 3,150 feet, based on data from Morgan (1938, pl. 1), and the water table is at an altitude of 3,300 feet (pl. 2D). The quantity of water moving perpendicular to the 3,300-foot contour, therefore, is about 7,900,000 gal/d, or about 12 ft<sup>3</sup>/s. This is equivalent to about 8,800 acre-feet of water per year.

This quantity of water moving toward the Pecos River apparently does not discharge into the river, as generally no gain in flow is measured. It is doubtful if much water moves east of the river into the rocks of low permeability in the Artesia Group. Thus, most of the water moving toward the river between Artesia and the Rio Peñasco probably is discharged to the atmosphere by evapotranspiration in the swampy area just west of the river.

#### RIO PEÑASCO TO LAKE McMILLAN

The slope of the water table, as shown by contours on plate 2D, shows that ground water moves eastward and southeastward toward the Pecos River and Lake McMillan in the valley west of the bottom land between the Rio Peñasco and Lake McMillan. Near the river, however, the water table slopes westward and southwestward indicating that water moves from the river to the saltcedar-infested bottom land.

The quantity of water moving from the river into the alluvium in the bottom land is small because miscellaneous streamflow measurements

show only small losses and occasionally small gains (table 1). The average loss in flow of the river between stations 4 and 6 (pl. 2B) during 20 sets of measurements was 0.4 ft<sup>3</sup>/s. The average loss in two sets of measurements at stations 6 and 8 (pl. 2B) was 1.9 ft<sup>3</sup>/s. Thus, the average loss in the reach from the Rio Peñasco to Lake McMillan is 2.3 ft<sup>3</sup>/s, by using data listed in table 1.

Large losses from the river into the alluvium might be expected from the pattern of the water-table contours on plate 2D. The river is perched as much as 12 feet above the water table in the alluvium in the reach between the Kaiser Channel gaging station and Lake McMillan. Probably the river does not lose large quantities of water in this reach because of the presence of relatively impermeable clay in the streambed and in the underlying alluvium (pl. 2F).

#### LAKE McMILLAN TO MAJOR JOHNSON SPRINGS

The water-table contours shown on plate 2D indicate that ground water in the alluvium moves toward the Pecos River in the vicinity of Major Johnson Springs. The Pecos River has no flow between Lake McMillan and Major Johnson Springs except during times when water is released from Lake McMillan or when flood runoff enters the river below Lake McMillan. Part of the flow of Major Johnson Springs is derived from discharge of ground water from the alluvium, and part is derived from a permeable aquifer in the Artesia Group that receives recharge from water leaking into the aquifer from Lake McMillan. That part of the spring flow that is derived from the alluvium averaged 13 ft<sup>3</sup>/s from 1953 through 1959 (Cox, 1967, p. 46). Part of the seepage from the river above Lake McMillan may return to the river through Major Johnson Springs.

#### USE OF WATER BY PHREATOPHYTES

Saltcedar growth of varying density covers most of the Pecos River flood plain between Artesia and Lake McMillan. Some of the more open areas and meadows have thick growths of saltgrass and other plants, with scattered saltcedars. Ground water is lost through phreatophyte transpiration and direct evaporation from swampy areas in this reach.

In 1942 Blaney, Ewing, Morin, and Criddle (1942, p. 230) estimated that annual consumptive use requirements by saltcedar in the Pecos River valley from the Artesia gaging station to Lake McMillan was 5 acre-feet per acre. In this area of 17,000 acres, the annual consumptive use requirement was thus estimated to be about 85,000 acre-feet. Actual use of water from ground-water sources would be considerably less after the contribution from rainfall and optimum ground-water-supply conditions for plant growth are taken into account. When such adjustments are made, an estimate of the annual use of water from ground-water sources probably would be on the order of 50,000 acre-feet.

Saltcedar and other phreatophytes take water from the capillary fringe above the water table, functioning as miniature pumping plants. Thus, observations of water-level fluctuations in nearby wells can be used to determine the quantity of water used by phreatophytes.

White (1932), during a study in the Escalante Valley, Utah, concluded that diurnal fluctuations of ground-water levels reflected the draft upon the water table by phreatophytes. He, therefore, derived the following formula for computing that usage (White, 1932, p. 59-61);

$$q = y (24 r \pm s),$$

in which

$q$  = depth of water withdrawn per day, in feet;

$y$  = specific yield of soil;

$r$  = hourly rate of rise of water table from midnight to 4 a.m., in feet;

$s$  = net rise or fall of water table for 24-hour period, in feet.

White assumed that from midnight to 4 a.m., little or no water was used by phreatophytes and that the slope of the trace of a recorder in a well for this period represented the average rate of recharge of the water table for the 24-hour period. During later studies in the Safford Valley, Ariz., Gatewood and others (1950) determined that saltcedar continued to transpire even during this period and that a correction factor of 1.25 must be applied to the transpiration calculated from White's formula. Mower and others (1964, p. 79) applied this same night-transpiration factor to saltcedar growth in the Roswell basin, and it is used in this report.

In order to use White's approach, six wells were augered in the Lake McMillan delta area and equipped with weekly water-stage recorders. Continuous records were obtained except during periods of mechanical failures or when bad weather or periods of high water made roads impassible, or when wells had to be deepened because of a declining water table. Missing records were estimated or interpolated to follow trends.

Specific yield of soil for each of the wells is shown in table 2.

TABLE 2.—*Calculated transpiration, using White's formula, by phreatophytes from ground-water sources, 1957-59*

Well	Specific yield (percent)	Phreatophyte		Night transpiration factor	1957		1958		1959	
		Type	Areal density (percent)		Transpiration (ft/yr)	Average depth to water (ft)	Transpiration (ft/yr)	Average depth to water (ft)	Transpiration (ft/yr)	Average depth to water (ft)
17.27.7.331	24.3	Saltcedar	70-90	1.25	13.36	5.2	14.56	3.9	6.29	5.3
18.26.12.433	41.5	Saltgrass	.....	1.00	3.70	9.3	3.37	8.0	2.95	7.6
18.26.36.222	27.5	Saltcedar	90-100	1.25	2.72	13.0	1.10	13.4	2.25	13.7
18.27.18.331	40.2	do	50-70	1.25	2.70	9.2	1.08	12.4	1.22	9.6
18.27.30.333	27.5	do	70-90	1.25	.59	13.2	.84	11.7	1.11	12.6
19.27.18.434	29.0	do	30-50	1.25	.58	22.7	7.26	12.3	5.92	14.8

Several modifications and simplifying assumptions were made in applying White's formula to the Lake McMillan delta area:

1. Some factors that affected computed use of water—temperature, relative humidity, precipitation, barometric pressure, and quality of water—were ignored. (See Gatewood and others, 1950, p. 141-146.) Elimination of these factors will not greatly affect the accuracy of the determinations. Average depths to water and areal phreatophyte densities at the wells are given in the chart of estimated usage (table 2). Laboratory determinations of specific yield were made, and have been used in the formula.
2. If zero or negative,  $r$  was not figured. Therefore, water used on these days equals the net fall of the water table for these days.
3. In applying 24-hour net fall or rise,  $s$  was added if the water table had net fall (that is, transpiration was greater than recharge) and was subtracted if the water table had net rise (recharge greater than transpiration).
4. Two methods of calculating  $s$  were used. By the first method, the difference between the depth-to-water reading from midnight to midnight, as shown by the line on the recorder, was used; by the second method, the difference from midnight to midnight as shown by a straight line connecting one daily high to the next was used. The first method was used for most of the records. Use of the second method gave an average change in water level for the day from which the transpiration was calculated.
5. The quantity  $24r \pm s$  was not used if zero or negative.

The water level in well 17.27.7.331, in a thicket of saltcedar having areal density from 70 to 90 percent about 200 feet from the river northwest of the Artesia gaging station, fluctuated in phase with river levels. For this reason, Mower and others (1964, p. 80) concluded that its diurnal fluctuations were not useful in determining transpiration. The calculated transpiration reflected by this well was excessive (table 2) and was not used in further estimates. Such effects may occur in other wells but were not identified.

Well 18.26.12.433 is southeast of Atoka and north of the Rio Peñasco in an open field that is covered by moderately dense saltgrass and sparse (0-15 percent) saltcedar. Transpiration at this well is significantly different from the other wells, and was not used in further calculations. Wells 18.26.36.222, 18.27.18.331, and 18.27.30.333 are south of the Rio Peñasco in saltcedar thickets that range in areal density from 50 to 100 percent. Well 19.27.18.434 is in 30-50 percent saltcedar growth at the lower end of the delta near Lake McMillan.

Calculated transpiration from ground-water sources versus percent areal density for all wells except 17.27.7.331 and 18.26.12.433 were plotted and, although the plotted points are scattered, a line giving the best possible fit represents an average transpiration by saltcedar in the

## E16 CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

Lake McMillan delta area. The following table shows the average transpiration from ground-water sources, taken at the midpoint of the density range, and extrapolated below 30-percent area density:

Areal density (percent) .....	0-15	15-30	30-50	50-70	70-90	90-100
Average transpiration ..(ft/yr)..	0.20	0.45	0.80	1.22	1.73	1.95

The estimated transpiration by saltcedar in 1960 in the Lake McMillan delta area—calculated from figures in the above table, from Artesia to the Rio Peñasco and from the Rio Peñasco to Lake McMillan—is given in table 3. These transpiration values are that part derived from ground water; that part derived from rainfall is excluded.

TABLE 3.—*Estimated transpiration, using an extension of White's method, by phreatophytes from ground-water sources, 1960, using areal density only*

Areal density (percent)	Artesia to Rio Peñasco		Rio Peñasco to Lake McMillan		Total transpiration (acre-ft)
	Area (acres)	Transpiration (acre-ft)	Area (acres)	Transpiration (acre-ft)	
0- 15	3,800	800	1,800	400	1,200
15- 30	300	100	400	200	300
30- 50	300	200	1,400	1,100	1,300
50- 70	300	400	2,300	2,800	3,200
70- 90	800	1,400	2,200	3,800	5,200
90-100	1,800	3,500	1,700	3,300	6,800
Total	7,300	6,400	9,800	11,600	18,000

Another approach used to estimate use of water by phreatophytes is that which relates 100-percent volume density and depth to water to use of water by plants. By assuming an average vertical density, a volume density can be estimated. Mower and others (1964, p. 74) used 75-percent vertical density in 1956, 80 percent in 1957, and 85 percent in 1958. By extrapolation, vertical density would be 90 percent in 1959 and 95 percent in 1960. The midpoint of the areal-density range was taken as an average density. Volume density is the product of areal density times vertical density. The area covered by saltcedar in acres, is then multiplied by volume density (a dimensionless value) to give equivalent acres covered by 100-percent volume density (Gatewood and others, 1950, p. 134-135).

Phreatophytes use less water as depths to water increase. Figure 4 is a plot of transpiration by saltcedar and of depth to water as given by Blaney Ewing, Morin and Criddle (1942, p. 202), Gatewood and others

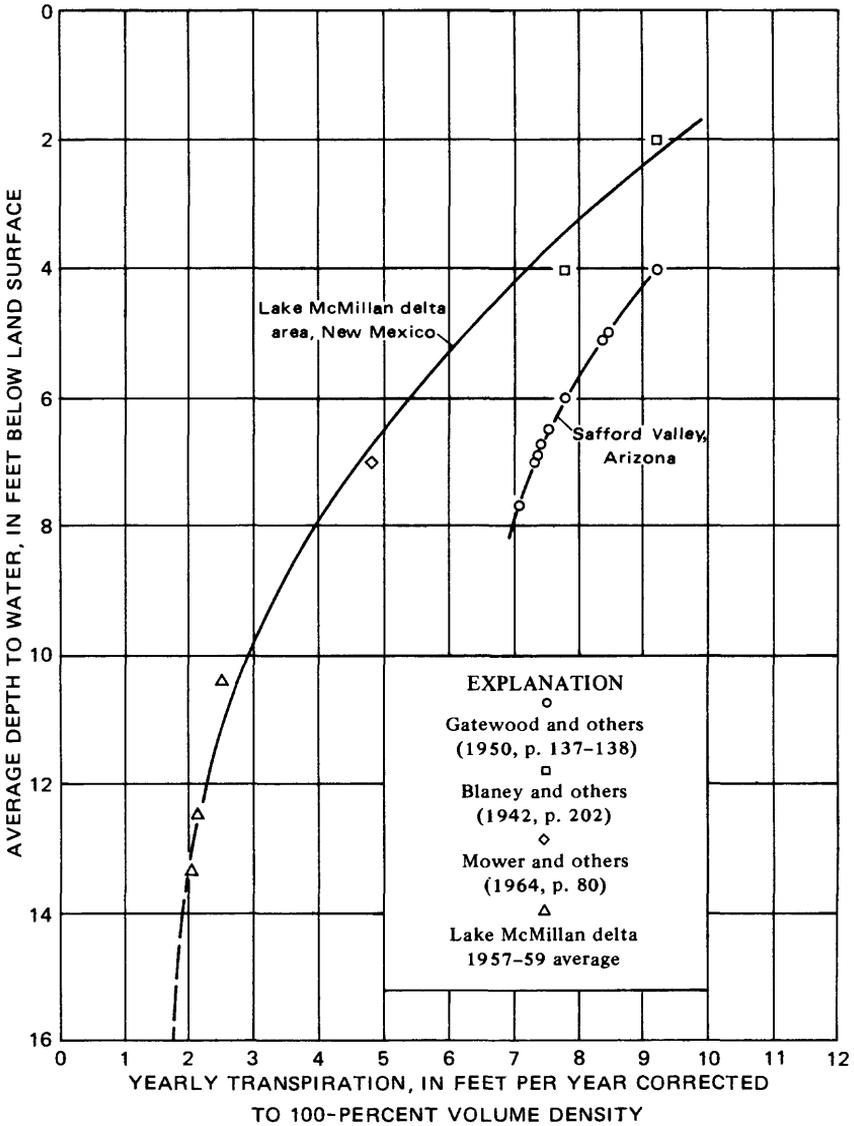


FIGURE 4.—Yearly transpiration by saltcedar at 100-percent volume density related to average depth to water, Lake McMILLAN delta area, New Mexico, and Safford Valley, Arizona.

(1950, p. 137-138), and Mower and others (1964, p. 80), and average transpiration in 1957-59, as computed from wells 18.26.30.222, 18.27.18.331, and 18.27.30.333 in the Lake McMILLAN delta area. All estimates of transpiration have been corrected to 100-percent volume

density. Average depths to water for the Lake McMillan delta wells are given in table 2.

For 1960 the average depth to water in the Lake McMillan delta area is estimated to have been 7 feet in the Artesia to Rio Peñasco reach and 15 feet in the Rio Peñasco to Lake McMillan reach, equivalent to usages of 4.6 feet per year and 1.8 feet per year, respectively.

Table 4 shows volume densities for the Artesia to Rio Peñasco and the Rio Peñasco to Lake McMillan reaches of the Pecos River. Total estimated transpiration from ground-water sources by saltcedar in the Lake McMillan delta area in 1960, as shown in the last column, is 22,600 acre-feet.

TABLE 4.—Estimated transpiration by saltcedar from ground-water sources, 1960, using 100-percent volume-density estimates

Areal density (percent)	Vertical density (percent)	Volume density (percent)	Area (acres)	100-percent volume density (acres)	1960 transpiration (acre-ft)
Artesia to Rio Peñasco <sup>1</sup>					
0- 15	95	7	3,800	300	1,400
15- 30	95	21	300	60	300
30- 50	95	38	300	100	500
50- 70	95	57	300	200	900
70- 90	95	76	800	600	2,800
90-100	95	90	1,800	1,600	7,400
Total for reach .....					13,300
Rio Peñasco to Lake McMillan <sup>2</sup>					
0-15	95	7	1,800	100	200
15- 30	95	21	400	80	100
30- 50	95	38	1,400	500	900
50- 70	95	57	2,300	1,300	2,300
70- 90	95	76	2,200	1,700	3,100
90-100	95	90	1,700	1,500	2,700
Total for reach .....					9,300
Total for Lake McMillan delta area .....					22,600

<sup>1</sup>Transpiration 4.6 ft/yr.

<sup>2</sup>Transpiration 1.8 ft/yr.

Estimated ground-water flow toward the river in the Artesia to Rio Peñasco reach is about 8,800 acre-ft/yr (acre-feet per year), or about 12 ft<sup>3</sup>/s. From 1955-64, average changes in streamflow in this reach were -1.6 ft<sup>3</sup>/s (table 1), a total loss in the reach of about 14 ft<sup>3</sup>/s, or about 10,000 acre-ft/yr. Almost all this loss is traceable to evapotranspiration, and probably the greatest part was transpired by phreatophytes. Evaporation from swampy areas accounts for some loss in this reach.

Comparison of yearly estimates of loss in this reach are (1) by areal density, 6,400 acre-feet; (2) by volume density, 13,300 acre-feet; and (3) by ground-water flow and river loss, 10,000 acre-feet—an average of about 10,000 acre-ft/yr. Depending on the depth to water, the length of growing season, and volume density of saltcedar in this area, loss of water by evapotranspiration from ground-water sources are estimated to be from 10,000 to 20,000 acre-ft/yr. Some of this water might discharge to the river if the saltcedar were eliminated, although evaporation from swampy areas might be increased, and part of the water would be used by other vegetation.

Another approach that is utilized to estimate the use of ground water by saltcedar involves a water balance, or the use of inflow-outflow and storage changes in the study area.

By use of the relationship:  $\text{Inflow} \pm \text{change in storage} - \text{outflow} = \text{water losses}$ , the evapotranspiration from ground-water sources can be estimated if the other evaporative losses or diversions can be separated from the total water losses. (See tables 5 and 6.)

Inflow consists of surface-water inflow at three gaging stations (Pecos River near Artesia, Rio Peñasco at Dayton; and Fourmile Draw near Lakewood), precipitation on the land surface and Lake McMillan, and ground-water inflow in the reach of the river from Artesia gaging station to Major Johnson Springs. The first two parameters can be determined from published records. Ground-water inflow can be estimated by the regional gradient of the water table, average saturated thickness of the aquifer, length of the section estimated, and an estimated transmissivity, as previously explained. Upward leakage from underlying artesian aquifers and return irrigation are included in this amount.

Storage and change in storage in Lake McMillan are available from published U.S. Geological Survey records. Ground-water storage is assumed to be more or less constant; but, because this item is not determined, the results are subject to considerable error.

Surface-water outflow consists of the flow at the gaging station Pecos River at Damsite 3, about 5 miles below Major Johnson Springs, plus an allowance for seepage losses between Major Johnson Springs and Damsite 3 gaging station (4.7 ft<sup>3</sup>/s average loss from seven seepage investigations), plus evaporation losses (equal to precipitation) from the land area investigated (17,140 acres) plus evaporation loss from Lake McMillan.

Water losses were calculated for water year 1957 (Oct. 1956-Sept. 1957), a year of deficient precipitation (3.71 in., or 0.309 ft, for the water year), and for water years 1951-60 (average annual precipitation of 0.758 ft).

Use of this approach to estimate evapotranspiration from groundwater sources in the saltcedar area suggests that the previous es-

E20 CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

TABLE 5.—Water budget showing estimated ground-water losses, in acre-feet, water year 1957

	Average	Total
<b>Inflow:</b>		
Surface water .....	96,300	
Precipitation on land surface (17,140 acres x 0.309 ft) .....	5,300	
Precipitation on Lake McMillan (2,656 acres x 0.309 ft) .....	800	
Ground-water inflow .....	27,200	
<b>Total inflow</b> .....	<b>129,600</b>	<b>129,600</b>
<b>Change (increase, +) in storage in</b>		
Lake McMillan .....	+1,400	+1,400
<b>Outflow: Surface water, total</b> .....	<b>74,300</b>	<b>74,300</b>
<b>Water losses:</b>		
Estimated water losses other than that from ground-water sources:		
	<i>Average</i>	
Seepage loss (Major Johnson Springs to Damsite 3) .....	3,400	
Evaporation from Lake McMillan ....	16,600	
Evapotranspiration from land surface (17,140 acres x 0.309 ft) .....	5,300	
<b>Total losses other than ground-water sources</b> .....	<b>25,300</b>	
Loss by evapotranspiration from ground-water sources (residual), total .....	28,600	
<b>Total water losses</b> .....		<b>53,900</b>
		<b>129,600</b>

timates of 10,000 to 20,000 acre-ft/yr using areal density and 100-percent volume density (tables 3, 4) may be too low.

Another approach to water use by phreatophytes involves the computation of consumptive use of vegetation. A correction to this value to account for effective rainfall will result in water use derived from ground-water sources. Blaney and Criddle (1962, p. 1) suggested using the relationship:

$$U = KF,$$

where

*U* = use of water, in inches;

*K* = empirical seasonal coefficient;

*F* = sum of the monthly factors (*f*) for the season—sum of the products of mean monthly temperature (*t*), in degrees

TABLE 6.—Water budget showing estimated average annual ground-water losses in acre-feet, water years 1951-60

	Average	Total
Inflow:		
Surface water .....	154,000	
Precipitation on land surface (17,140 acres x 0.758 ft) .....	13,000	
Precipitation on Lake McMillan (2,777 acres x 0.758 ft) .....	2,000	
Ground-water inflow .....	27,000	
	<hr/>	
Total inflow .....	196,000	196,000
	<hr/>	<hr/>
Change (decrease, -) in storage in		
Lake McMillan .....	-9,000	-9,000
Outflow: Surface water, total .....	133,000	133,000
Water losses:		
Estimated water losses other than that from ground-water sources:		
Seepage loss (Major	<i>Average</i>	
Johnson Springs to Damsite 3) .....	3,000	
Evaporation from Lake McMillan .....	18,000	
Evapotranspiration from land surface (17,140 acres x 0.309 ft) .....	13,000	
Total losses other than ground-water sources .....	34,000	
Loss by evapotranspiration from ground-water sources (residual), total .....	38,000	
Total water losses .....		72,000
		<hr/>
		196,000

Fahrenheit, and monthly percentage of annual daylight hours ( $p$ ).

The coefficient  $K$  can be determined directly or by extrapolation from estimates by Rantz (1968, p. D11) using an average depth to water of 7 feet for the Artesia to Rio Peñasco reach and 15 feet for the Rio Peñasco to Lake McMillan reach. Factors for saltcedar density correction to the  $K$  value appear in table 7. The value for  $F$  is 64.7 (Blaney and Criddle, 1962, p. 47) for the year; for the saltcedar growing season, May through October, the value is 41.2.

Estimates of water use in the Lake McMillan delta area vary, as shown in table 8.

This range in estimates may define the upper and lower limits of evapotranspiration from ground-water sources. The Blaney-Criddle

E22 CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

TABLE 7.—Estimated annual evapotranspiration from ground-water sources, by use of the Blaney-Criddle method

Areal density . . . . . percent . .	0-15	15-30	30-50	50-70	70-90	90-100
<b>Artesia gaging station to Rio Peñasco</b>						
Growth class <sup>1</sup> . . . . .	Light (0.70)	Light (0.70)	Medium (0.85)	Medium (0.85)	Dense (1.00)	Dense (1.00)
Acres . . . . .(total acres 7,300) . . . . .	3,800	300	300	300	800	1,800
K (adjusted for growth density) . . . . .	0.81	0.81	0.99	0.99	1.16	1.16
K x acres . . . . .(total acres, adjusted, 6,900) . . . . .	3,100	200	300	300	900	2,100
Evapotranspiration <sup>2</sup> . . . . . acre-inches . .						283,000
Evapotranspiration . . . . . acre-feet . .						23,600
Less effective rainfall . . . . . do . . . . .						4,700
Evapotranspiration from ground- water sources . . . . . do . . . . .						18,900
<b>Rio Peñasco to Lake McMillan</b>						
Growth class <sup>1</sup> . . . . .	Light (0.70)	Light (0.70)	Medium (0.85)	Medium (0.85)	Dense (1.00)	Dense (1.00)
Acres . . . . .(total acres 9,800) . . . . .	1,800	400	1,400	2,300	2,200	1,700
K (adjusted for growth density) . . . . .	0.58	0.58	0.71	0.71	0.83	0.83
K x acres . . . . .(total acres, adjusted, 7,000) . . . . .	1,000	200	1,000	1,600	1,800	1,400
Evapotranspiration <sup>2</sup> . . . . . acre-inches . .						287,000
Evapotranspiration . . . . . acre-feet . .						23,900
Less effective rainfall . . . . . do . . . . .						4,800
Evapotranspiration from ground- water sources . . . . . do . . . . .						19,100
Total annual evapotranspiration from both ground-water sources . . . . . do . . . . .						38,000

<sup>1</sup>Rantz (1968, p. D11).

<sup>2</sup>Blaney and Criddle (1962, p. 1, 47).  $U = KF \times \text{acres}$ , where  $F = 41$ , adjusted to May-October average growing season.

TABLE 8.—Summary of estimates of water use  
[Data are in acre-feet]

Method	Evapotranspiration from ground-water sources	Effective rainfall during growing season	Consumptive use	Annual effective rainfall	Total evapotranspiration
Areal density of Phreatophytes in 1960 (table 3) . . . . .	18,000	9,500	27,500	13,000	31,000
Volume density of phreatophytes in 1960 (table 4) . . . . .	23,000	9,500	32,500	13,000	36,000
Inflow-outflow in 1957 (table 5) . . . . .	29,000	4,000	34,000	5,000	34,000
Inflow-outflow, 1951-60 (table 6) . . . . .	38,000	9,500	47,500	13,000	51,000
Blaney-Criddle (table 7) . . . . .	38,000	9,500	47,500	13,000	51,000

method, used extensively for estimation of water consumption by crops, tends to place the figure somewhat higher. The average value of the computations listed in table 8 is about 29,000 acre-feet, a reasonable estimate of annual evapotranspiration derived from ground-water sources in the Lake McMillan delta area.

### POTENTIAL SALVAGE OF WATER

Some of the water now being lost by evapotranspiration might be salvaged if there were a change in the type of vegetation in the delta. For example, if saltgrass could be used to replace saltcedar, there would be a significant reduction in evapotranspiration. For depths to the water table of 7 feet, the evapotranspiration from saltgrass should be only about one-third that from saltcedar, assuming a dense plant growth for both types (Rantz, 1968 p. D11).

Salvage of water in the Pecos River valley between Artesia and Lake McMillan for use downstream could be difficult to accomplish. As mentioned, removal of saltcedar and other nonbeneficial vegetation might change the use of water in this reach. Removal of the nonbeneficial vegetation would cause the water table to rise, particularly in the reach from Artesia to the Rio Peñasco. A higher water table would create a larger swampy area and result in greater evaporation from not only the swampy area but also the soil. Some increased discharge to the river might result from the change in water-table gradients.

Lowering of water levels should be considered to salvage water in the reach between Artesia and the Rio Peñasco. South of the Rio Peñasco, water levels, as mentioned, slope away from the river, and the depth to water is such that lowering water levels would not be effective. However, clearing of nonbeneficial vegetation south of the Rio Peñasco should result in some salvage water that would appear in the river at Major Johnson Springs.

A drain along the west margin of the flood plain would lower water levels and convey the salvaged water to the river. The drain could start near the Artesia gaging station and terminate at the river just south of the Rio Peñasco. The floor of the drain should be at a depth of 10 to 20 feet below the land surface to be most effective.

Another method that could be considered for lowering water levels is the construction and pumping of a line of wells and a pipeline in the reach from the Artesia gaging station to the Rio Peñasco. Pumping wells, spaced at 0.5-mile intervals along a north-south line about 0.5 mile west of the river, should generally lower water levels over the flood plain.

A floodway cleared through the saltcedar, as has been considered by water users in the area, would salvage water now lost, in part, when floods cover the bottom lands. A floodway, however, would allow the suspended sediment now being deposited in the saltcedar bottom land upstream from the lake to reach Lake McMillan during floods.

Perhaps a combination clearing of vegetation and construction of short drains, a few wells, and a floodway would accomplish considerable salvage of water. The design and cost of the most effective system to salvage water was not attempted in this report.

### SUMMARY AND CONCLUSIONS

The shallow water-bearing formation in the Pecos River valley from Artesia to Lake McMillan is alluvium of Holocene age. In places this alluvium, which extends 7 miles to the west and 45 miles north of Artesia, is more than 200 feet thick. Recharge is from precipitation, infiltration from streams, and infiltration of irrigation water. Some water leaks from the underlying artesian aquifer into the alluvium. Other recharge comes from movement of ground water in the alluvium into the area of investigation from the north and west. Discharge is by wells, transpiration by phreatophytes, evaporation from swampy areas, and by spring discharge at Major Johnson Springs.

The interrelation between the Pecos River and water in the alluvium is complex. From the Artesia gaging station to the Rio Peñasco, the alluvial water table slopes toward the river (pl. 2D), and it would normally be expected that the river would gain in this reach. On the basis of the slope of the water table of about 15 feet per mile, average hydraulic conductivity of 500gal/d/ft<sup>2</sup>, average saturated thickness of 150 feet, and a 7-mile total length of saturated section, the quantity of water moving toward the river is about 12 ft<sup>3</sup>/s (about 8,800 acre-ft/yr.) However, miscellaneous streamflow measurements in this reach do not show appreciable gain but, instead, show a possible loss from the river of about 1.6 ft<sup>3</sup>/s (table 1).

From the Rio Peñasco to Lake McMillan, the water table slopes westward, away from the river, indicating loss from the river to the saltcedar-infested bottom lands (pl. 2D). The river is perched as much as 12 feet above the water table in the alluvium. Miscellaneous streamflow measurements (table 1) show only small average losses (about 2.3 ft<sup>3</sup>/s) in this reach. This is within the limits of error in streamflow measurement. Water-table contours shown on plate 2D indicate that losses in this reach should be larger. Relatively impermeable clays in the streambed and in the underlying alluvium probably account for the loss being small.

The thick saltcedar growth covering much of the Pecos River flood plain increased from about 13,700 acres in 1952 to about 17,100 acres in 1960, an increase of about 25 percent.

Based only on areal density and White's method, calculated transpiration at four observation well in saltcedar thickets of various areal densitites indicates that the 1960 transpiration in the reach from Artesia to the Rio Peñasco was about 6,400 acre-feet and in the reach from the Rio Peñasco to Lake McMillan was about 11,600 acre-feet, a

total of about 18,000 acre-feet. If areal densities are converted to 100-percent volume densities, using an estimated 95-percent vertical density, transpiration may be estimated by a depth-to-water relationship (fig. 4). Average depth to water was assumed to be 7 feet in the Artesia to Rio Peñasco reach and 15 feet in the Rio Peñasco to Lake McMillan reach. Based on volume density, 1960 transpiration was about 13,300 acre-feet in the reach from Artesia to the Rio Peñasco and about 9,300 in the reach from the Rio Peñasco to Lake McMillan, a total of about 22,600 acre-feet.

Estimates of annual evapotranspiration from ground-water sources by other methods are: 28,600 acre-feet, using inflow-outflow data for 1957; 38,000 acre-feet, using inflow-outflow data for 1951-60; and 38,000 acre-feet, using calculations based on the Blaney-Criddle method. Estimates, therefore, range from 18,000 to 38,000 acre-feet per year in the Lake McMillan delta area, and average 29,000 acre-feet per year.

Replacement of saltcedar by saltgrass should reduce transpiration rates by about one-third for depths to the water table of about 7 feet. Replacement by other types of vegetation might also be used to reduce transpiration. Salvage of water in the Pecos River valley from Artesia to the Rio Peñasco could be accomplished by clearing of phreatophytes and a combination of drains and wells. South of the Rio Peñasco, salvage of water could be accomplished by clearing phreatophytes, but drains or wells would partly not be effective. Finally, floodwaters now partly lost in the bottom land could be salvaged through construction of a floodway.

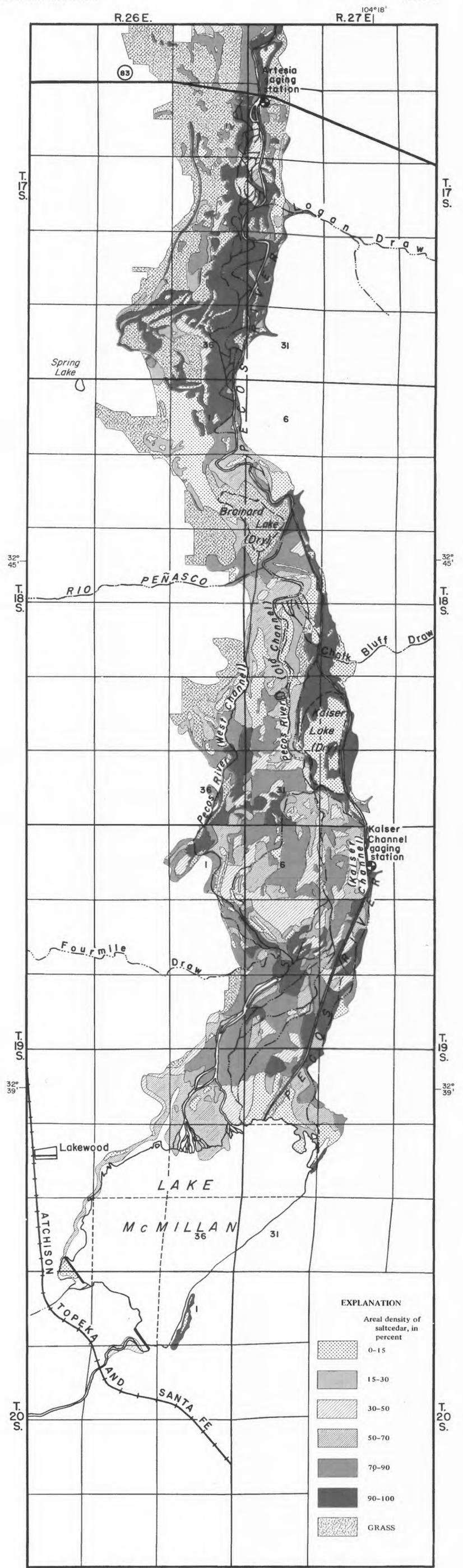
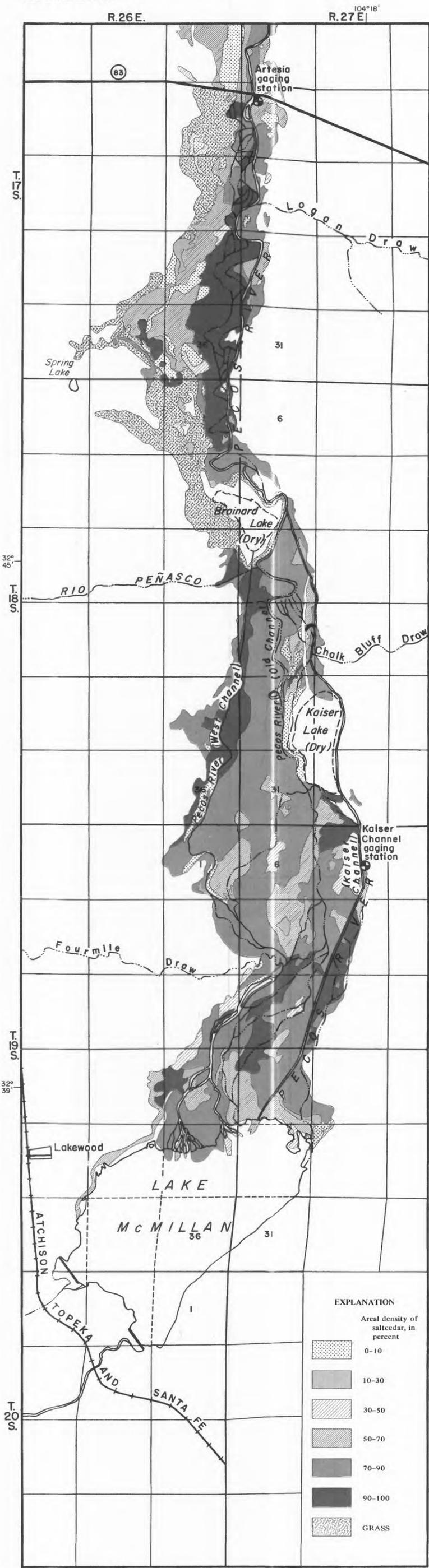
The total amount of water that could be salvaged for use downstream is difficult to estimate. Eradication of saltcedar, control of replacement vegetation, and construction of a floodway, drains, and wells in the reach might salvage 10,000 to 20,000 acre-ft/yr of water.

## REFERENCES

- Blaney, H. F. and Criddle, W. D., 1962, Determining consumptive use and irrigation water requirements: U.S. Agr. Research Service Tech. Bull. 1275, 59 p.
- Blaney, H. F., Ewing, P.A., Morin, K. V., and Criddle, W. D., 1942, Consumptive water use and requirements, Pecos River, New Mexico and Texas; [U.S.] Natl. Resources Planning Board, Pecos River Joint Investigation, in Reports of the participating agencies: Washington, U.S. Govt. Printing Office, pt. 3, sec. 3, p. 170-230.
- Cox, E. R., 1967, Geology and hydrology between Lake McMillan and Carlsbad Springs, Eddy County, New Mexico: U.S. Geol. Survey Water-Supply Paper 1828, 48 p.
- Gatewood, J. S., Robinson, T. W., Colby, B. R., Hem, J. D., and Halpenny, L. C., 1950, Use of water by bottom-land vegetation in lower Stafford Valley, Arizona: U.S. Geol. Survey Water-Supply Paper 1103, 210 p.
- Morgan, A. M., 1938, Geology and shallow-water resources of the Roswell artesian basin, New Mexico: New Mexico State Engineer 12th-13th Bienn. Repts., 1934-38, p. 155-249. (Also published as New Mexico State Engineer Office Bull. 5.)
- Mower, R. W., Hood, J. W., Cushman, R. L., Borton, R. L., and Galloway, S. E., 1964, An

## E26 CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

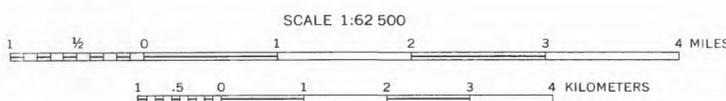
- appraisal of potential ground-water salvage along the Pecos River between Acme and Artesia, New Mexico: U.S. Geol. Survey Water-Supply Paper 1659, 98 p.
- Pecos River Compact, 1949, U.S. 81st Cong., 1st sess., S. Doc. 109, Public Law 91.
- Rantz, S. E., 1968, A suggested method for estimating evapotranspiration by native phreatophytes: U.S. Geol. Survey Prof. Paper 600-D, p. D10-D12.
- U.S. Geological Survey, 1932-60 (published annually), Surface water supply of the United States in 1930-60; Part 8, Western Gulf of Mexico Basins: U.S. Geol. Survey Water-Supply Papers 703, 718, 733, 748, 763, 788, 808, 828, 858, 878, 898, 928, 958, 978, 1008, 1038, 1058, 1088, 1118, 1148, 1178, 1212, 1242, 1282, 1342, 1392, 1442, 1512, 1562, 1632, and 1712.
- 1961-64, (published annually), Surface water records of New Mexico: Albuquerque, N. Mex., Water Resources Division.
- White, W. N., 1932, A method of estimating ground-water supplies based on discharge by plants and evaporation from soil—Results of investigations in Escalante Valley, Utah: U.S. Geol. Survey Water-Supply Paper 659-A, p. 1-105.



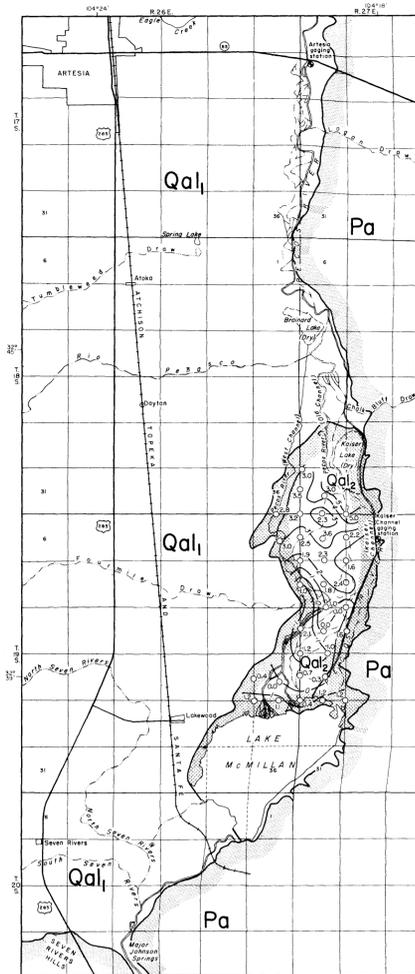
Base compiled from U.S. Geological Survey  
1:24,000, Lake McMillan North,  
Lake McMillan South, 1955,  
and Spring Lake, 1955

Survey by U.S. Bureau of Reclamation 1952.  
Redrafted with modifications by John S. Havens.

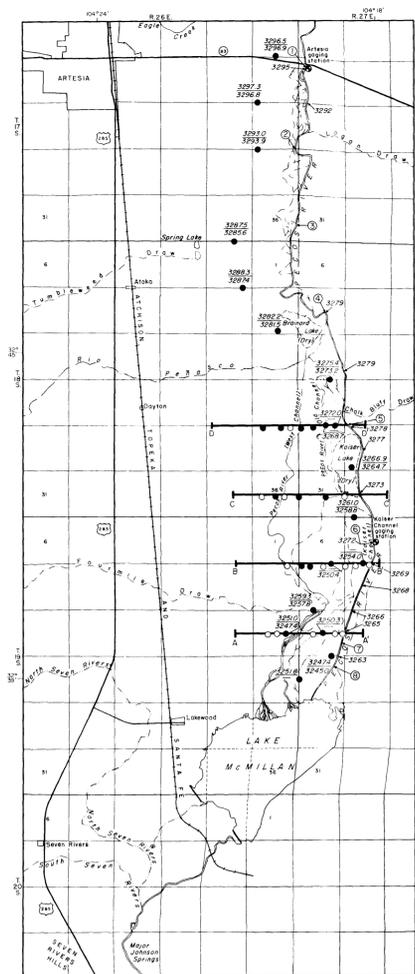
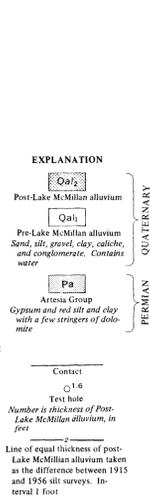
Survey by A. C. Doyle, 1960. Redrafted  
with modifications by John S. Havens.



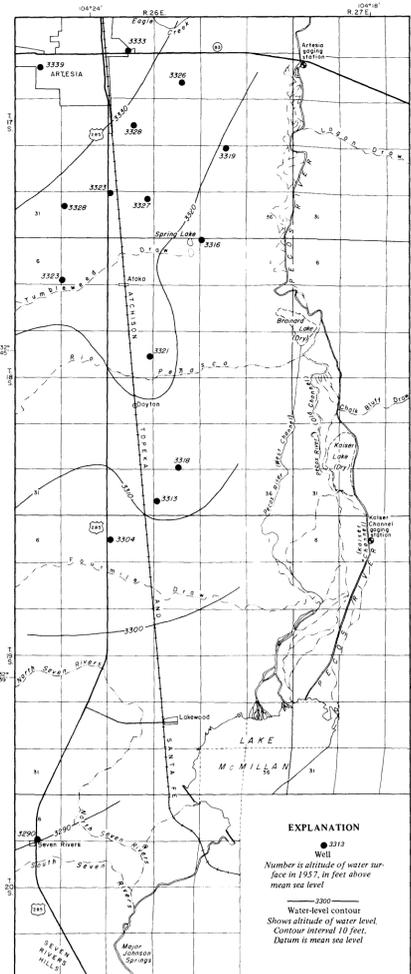
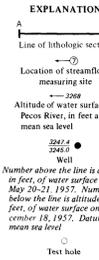
**MAPS SHOWING AREAL DENSITY OF PHREATOPHYTES IN THE LAKE McMILLAN DELTA AREA,  
EDDY COUNTY, NEW MEXICO**



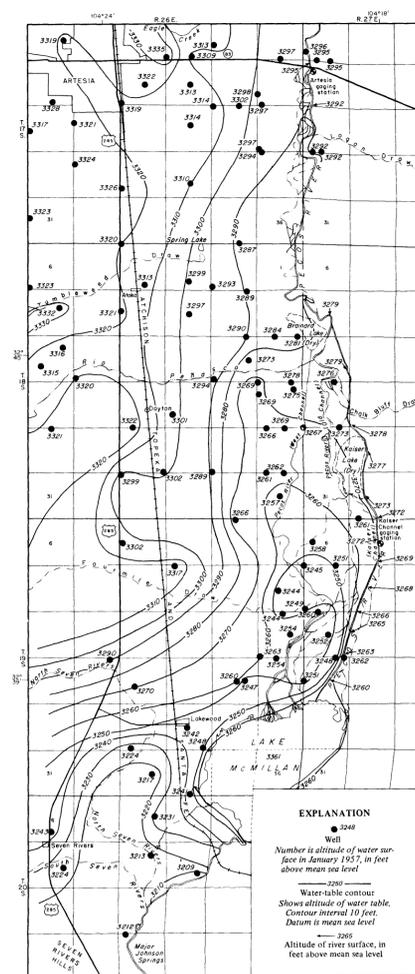
A. GEOLOGIC MAP SHOWING THICKNESS OF POST-LAKE McMILLAN ALLUVIUM



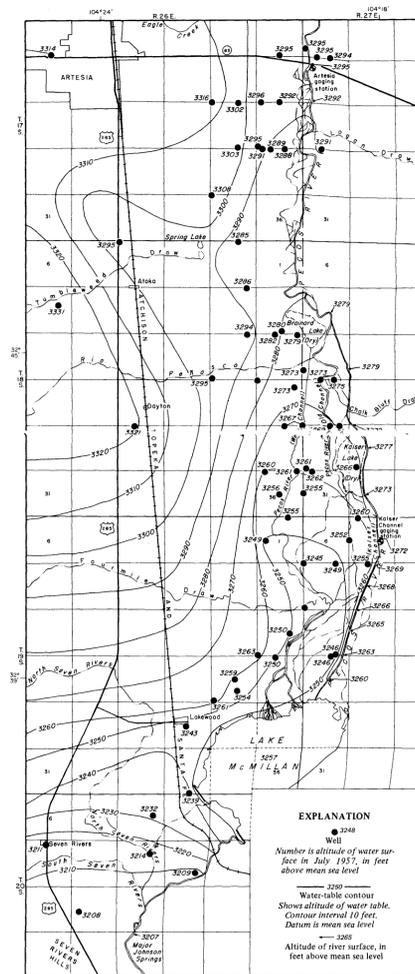
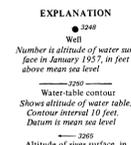
B. STREAMFLOW MEASURING SITES AND LOCATIONS OF LITHOLOGIC SECTIONS



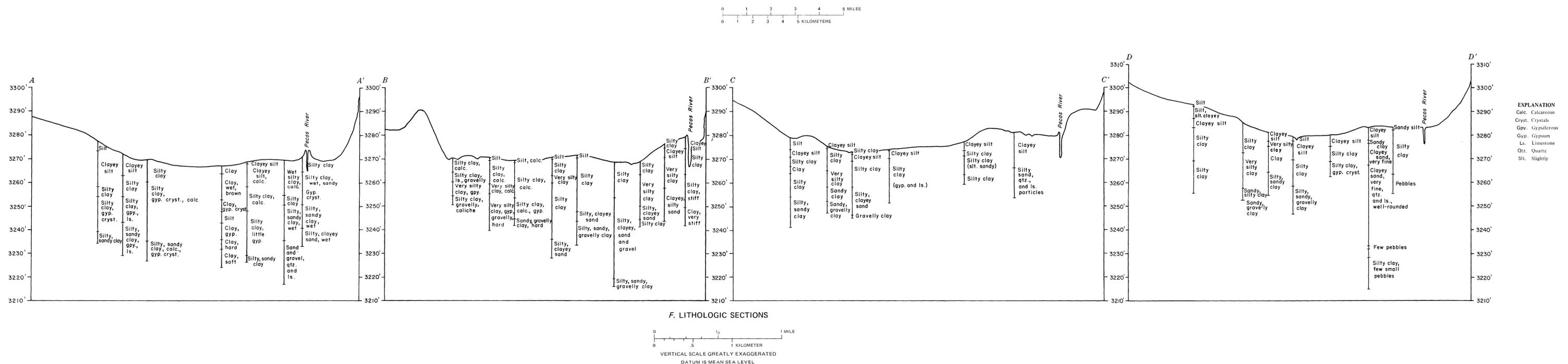
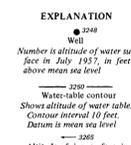
C. POTENTIOMETRIC CONTOUR MAP OF ARTESIAN SYSTEM, 1957



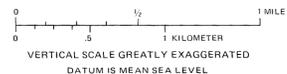
D. WATER-TABLE CONTOUR MAP, JANUARY 1957



E. WATER-TABLE CONTOUR MAP, JULY 1957



F. LITHOLOGIC SECTIONS



GEOHYDROLOGIC MAPS AND SECTIONS OF THE LAKE McMILLAN DELTA AREA, EDDY COUNTY, NEW MEXICO