Report 317

Evaluation of Ground-Water Resources in Parts of Loving, Pecos, Reeves, Ward, and Winkler Counties, Texas

January 1990

Texas Water Development Board

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by
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ABSTRACT

The evaluation of ground-water resources of a part of the Trans-Pecos region of West Texas includes all or parts of Loving, Pecos, Reeves, Ward, and Winkler Counties. This report is in response to the 1985 passage of House Bill 2 by the Sixty-ninth Texas Legislature, which called for the identification and study of areas in the State that are experiencing or expected to experience, within the next 20 years, critical underground water problems. The study area has a semi-arid climate that is characterized by low rainfall and high rate of evaporation. Agricultural and petroleum industries dominate the economy.

Water needs for the area are supplied almost entirely from the Cenozoic Pecos Alluvium aquifer with lessor amounts pumped from underlying units which include the Capitan Limestone, Rustler, Dockum Group, and the Edwards-Trinity (Plateau) aquifers. The Cenozoic Pecos Alluvium, which consists of up to 1,500 feet of alluvial fill, occurs in two hydrologically separate basins, the Pecos Trough and the Monument Draw Trough.

Average annual effective recharge to the Cenozoic Pecos Alluvium aquifer in the study area is calculated to be 67,800 acre-feet and is derived principally from precipitation and irrigation return flow. Water-level declines in excess of 200 feet have historically occurred in south-central Reeves and north-west Pecos Counties, but have moderated since the mid 1970's. Elsewhere only moderate declines have occurred.

The chemical quality of water in the Cenozoic Pecos Alluvium is highly variable, differing naturally with location and depth. Water from the aquifer is generally hard to very hard and contains dissolved-solids concentrations ranging from less than 300 milligrams per liter to more than 5,000. Sulfate and chloride are the two most prominent constituents. Quality deterioration in parts of the study area has resulted from petroleum activities and irrigation practices.

In 1985, the total pumpage of ground water within the study area was 117,430 acre-feet, of which 73 percent was used for agricultural irrigation. This amount is expected to increase to over 161,000 acre-feet annually by the year 2010. Current and projected water demands are in excess of the estimated annual recharge rate and by the year 2010, 13 percent of the usable-quality water currently held in storage in the aquifer is projected to have been withdrawn, with approximately 7.3 million acre-feet remaining. This quantity should be adequate to meet projected needs through the year 2010, although continued deterioration of the chemical quality could limit the use of some of this water.

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INTRODUCTION

Purpose

In 1985, the Sixty-ninth Texas Legislature recognized that certain areas of the State were experiencing or were expected to experience, within the next 20 years, critical ground-water problems. House Bill 2 was enacted which, in part, directed the Texas Department of Water Resources to identify the critical ground-water areas, conduct studies in those areas, and submit its findings and recommendations on whether a ground-water conservation district should be established in the respective areas to address the ground-water problems (Subchapter C, Chapter 52, Texas Water Code).

This study in the area of Loving, Pecos, Reeves, Ward, and Winkler Counties was conducted to address the problems of overdraft and quality deterioration with respect to the Cenozoic Pecos Alluvium aquifer (previously referred to as the Cenozoic Alluvium aquifer), which is the primary aquifer in the area. A discussion of underlying aquifers is also included.

Location and Extent

The study area is located in the northern part of the Trans-Pecos region of West Texas, which is in the Great Plains physiographic province, and falls within the Rio Grande basin. The boundary of the area is defined by the areal extent of the Cenozoic Pecos Alluvium in parts of Loving, Pecos, Reeves, Ward, and Winkler Counties (Figure 1) and includes the population centers of Kermit, Monahans, Pecos, and several smaller communities.

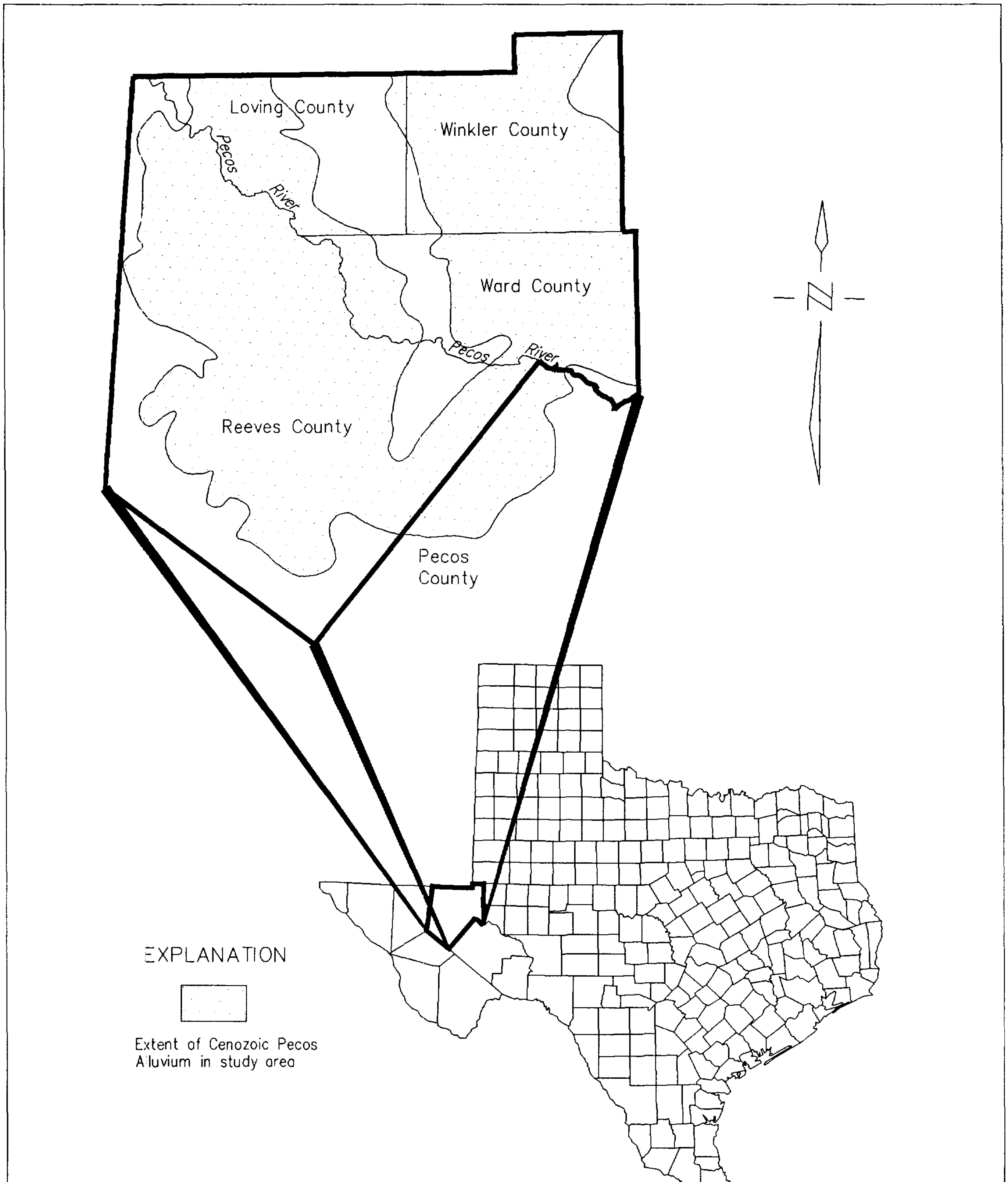


Figure 1

LOCATION OF STUDY AREA

Geographic Setting

Topography and Drainage

The study area consists of uplands that gently slope toward the Pecos River and merge with terraces or lowlands that border the river. The uplands, which are mantled by caliche and thin sandy soils, are sparsely vegetated with semi-desert shrubs and grasses and are devoted largely to ranching. The river terraces are mantled by fine- to medium-textured gypsiferous soils that historically were extensively cultivated (White, 1971).

A band of migrating sand dunes occurs in northeastern Ward and eastern Winkler Counties. The dunes rise as much as 50 feet above the surrounding land surface and represent an important area of recharge because of the lack of vegetation and high permeability of the sand.

Surface drainage is most apparent in Reeves County where ephemeral streams that head in the Rustler Hills and Davis Mountains to the west and south, drain toward the Pecos River. Flow in these normally dry streams rarely reaches the river, but rather sinks into channel beds or spreads out over broad valleys.

The Pecos River, the primary drainage in the region, enters from New Mexico to the northwest and flows southeastward through the center of the study area. Drainage north and east of the Pecos River is mostly closed with runoff collecting in swales, sinks, and playas.

Economy

The economy of the region is based primarily on the production of oil and gas, raising of beef cattle, and irrigated farm production, all of which are heavily dependent on ground water. The first commercially produced oil was discovered in the area in 1925 in Loving County. However, historians report of the occurrence of a heavy asphalt type oil, possibly accumulating in small seeps on the surface, north of Toyah in the late 1800's. Total crude production as of January 1, 1987 in Loving, Reeves, Ward, and Winkler Counties was 1.76 billion barrels, 92 percent of which was produced from Ward and Winkler Counties. Total crude production in this four-county area in 1986 was 19.3 million barrels (Railroad Commission of Texas, 1986).

Agriculture, including ranching and farming, is also a major industry in the region, generating a total annual income of approximately 30.7 million dollars in 1985 (Texas Department of Agriculture and U.S. Department of Agriculture, 1985). Irrigated farming is presently restricted mostly to the Toyah basin area of Reeves County and the Coyanosa area of northwest Pecos County.

Climate

The semi-arid climate in the region is characterized by a wide range in temperature, low rainfall, and high rate of evaporation, as recorded by the National Weather Service. Temperatures sometimes drop below freezing when cold fronts pass through the region during winter months, while rising to break 100 degrees Fahrenheit periodically during the summer.

The average annual precipitation increases from 9 to 13 inches eastward across the study area, much of which falls during thunderstorms between May and October. As a result, large differences in rainfall occur within relatively small geographic areas. Average annual gross lake surface evaporation is approximately 80 inches, an amount more than six times the average annual precipitation in the same region (Larkin and Bomar, 1983).

Previous Investigations

Several ground-water investigations have been published by the Texas Water Development Board and its predecessor agencies that address the geohydrology of the study area. Those reports most pertinent are, by county: Pecos (Armstrong and McMillion, 1961); Reeves (Knowles and Lang, 1947; Ogilbeee, Wesselman, and Irelan, 1962; and Perkins, Buckner, and Henry, 1972); Ward (White, 1971); and Winkler (Garza and Wesselman, 1959). A reconnaissance report by Brown and others (1965), provides a generalized evaluation of the ground-water conditions in the Rio Grande basin in Texas, which includes all of the study area. Richey and others (1985) prepared a U.S. Geological Survey water-resources investigation report that describes the geohydrology of the Delaware Basin in Texas and New Mexico. Publications pertinent to the geology and hydrology of the aquifers in the study area are listed in the selected references of this report.

Geologic mapping in the study area is best presented on the Fort Stockton, Hobbs, Pecos, and Van Horn-El Paso Geologic Atlas Sheets published by the University of Texas, Bureau of Economic Geology. The base map for this report was adapted from these sheets.

The Texas Water Development Board has maintained a water-level and chemical-quality monitoring network within the study area since 1939. The network consists of 129 annual water-level observation wells and 1,616 chemical analyses of water samples taken from 898 wells.

Acknowledgements

The author wishes to thank the numerous individuals who cooperated in providing information on the aquifer in their area, and to the many property owners who allowed access to their wells to measure water levels and sample for chemical quality. Additionally, special thanks are given to a group of individuals who served on an advisory committee that was formed by the Board to provide a medium through which those most affected by the conditions of the aquifer in the study area could contribute to the study. The committee consisted of a small number of concerned and knowledgeable citizens who represent public supply, irrigation, and industrial users of ground water in the study area.

GEOHYDROLOGY

Regional Structure

The most prominent regional geologic structures under the study area are the Delaware Basin and the Central Basin Platform (Figure 2). A southward-trending structural high, the Central Basin Platform divides the Permian Basin of West Texas into two smaller basins, the Delaware Basin on the west and Midland Basin on the east. A large barrier reef complex known as the Capitan occurs along the margin of the Delaware Basin.

During the Cenozoic Era, a thick sequence of alluvial deposits accumulated in two large slumpage depressions (Figures 2, 3, and 5). These depressions are herein referred to as the Monument Draw Trough, which developed along the eastern margin of the Delaware Basin, and the Pecos Trough, which occupies the south-central part of the Basin. The troughs were formed by dissolution and removal of evaporites in the underlying Ochoan Series, which resulted in the collapse of the Rustler Formation and younger rocks into the voids (Maley and Huffington, 1953). Water saturated alluvial fill in these troughs is classified as the Cenozoic Pecos Alluvium.

Stratigraphy and Water-Bearing Properties

Geologic units in the study area that contain ground water range in age from early Paleozoic to Recent. Paleozoic formations of Ordovician, Silurian, Devonian, and some of Permian age generally contain water that is produced as a by-product of oil production. Limited data suggests that water in some of these formations ranges in quality from moderately saline to brine, with some water containing concentrations of dissolved solids from two to seven times that of ocean water (Guyton and Associates, 1958; and White, 1971).

The following section will address those aquifers that are of particular importance in the study area. Water-bearing properties of these and of others that contain water of very poor quality, or none at all, are summarized in Table 1, while Figure 4 shows the areal extent of those aquifers that are most commonly used. In the description of the water-bearing properties, the chemical quality of the water is classified according to the following:

Description	Dissolved-Solids Content (Milligrams Per Liter)
Fresh	Less than 1,000
Slightly Saline	1,000 to 3,000
Moderately Saline	3,000 to 10,000
Very Saline	10,000 to 35,000
Brine	More than 35,000

and yields of wells are described according to the following rating:

Description	Yield (Gallons Per Minute)
Small	Less than 50
Moderate	50 to 500
Large	More than 500

Capitan Limestone Aquifer

The Capitan Reef Complex consists of the Capitan Reef and associated reefs and limestones which were deposited around the perimeter of the Delaware Basin during Permian time. The reef complex is composed of approximately 2,000 feet of massive, vuggy to cavernous limestone and dolomite, bedded limestone, and reef talus. In the study area, the reef occurs in a 6 to 10 mile wide, south-southeast trending belt, extending from New Mexico through western Winkler, central Ward, and western Pecos Counties (Figure 4). Depth to the top of the reef ranges from 2,400 to 3,600 feet (Guyton and Associates, 1958). The Capitan Reef Complex yields small to large quantities of moderately to very saline water to wells in the study area that primarily have been used for secondary recovery of oil in Ward and Winkler Counties (Richey and others, 1985).

Rustler Aquifer

The Rustler Formation underlies the entire study area and consists of 200 to 500 feet of anhydrite and dolomite with a basal zone of sandstone and shale. Slightly to moderately saline water occurs in the formation in most of Reeves and western Loving, Ward, and Pecos Counties (Figure 4) and has mostly been used for irrigation and livestock supply. Elsewhere, the formation produces very saline to brine quality water that is used primarily for secondary oil recovery. Water in the aquifer occurs under artesian conditions, except in the outcrop in the Rustler Hills to the west and in collapsed zones in the two troughs.

Dockum Group Aquifer

The Dockum Group of Triassic age consists of upper and lower shaley units and a middle water-bearing sandstone unit often referred to as the "Santa Rosa." Small to moderate quantities of fresh to moderately saline water are produced from the sandstone in Winkler, Ward, eastern Loving, and eastern Reeves Counties, primarily where the aquifer is relatively shallow (Figure 4). In parts of Pecos, Reeves, Ward, and Winkler Counties, where the sandstone is hydraulically connected to the Cenozoic Pecos Alluvium, the combination has been referred to as the Allurosa aquifer.

Edwards-Trinity (Plateau) Aquifer

The Edwards-Trinity (Plateau) aquifer underlies the Cenozoic Pecos Alluvium in the study area in the southwest half of Reeves County and a portion of the Coyanosa area in northwest Pecos County (Figure 4). The aquifer is composed of water-bearing lower Cretaceous sands and limestones that are hydraulically connected to the overlying alluvium. Wells completed in the aquifer produce small to moderate quantities of fresh to moderately saline water, which is generally similar to that of the overlying alluvium. The poorest quality water in the aquifer, with dissolved solids in excess of 3,000 milligrams per liter (mg/l), occurs in the southwestern part of Reeves County where the aquifer receives recharge from the sulfate-rich Rustler aquifer. Water from the Edwards-Trinity (Plateau) aquifer is mostly used for irrigation, with a lesser amount used for industrial purposes in western Reeves County.

Table 1. Geologic Units and Their Water-Bearing Characteristics

Era	System	Series or Group	Stratigraphic Unit	Character of Rocks	Water-Bearing Characteristics *
Cenozoic	Quaternary		Cenozoic Pecos Alluvium	Unconsolidated to partially consolidated sand, silt, gravel, clay, and caliche.	Yeilds small to large amounts of fresh to moderately saline water to wells.
	Tertiary		Volcanic Rocks	Tuff, ash, lava, breccia, with some sandstone, conglomerate, and limestone.	Yeilds small amounts of fresh water to wells and springs in southern Reeves County.
Mesozoic	Cretaceous	Gulf	undifferentiated	Flaggy limestone interbedded with shale.	Not known to yield water to wells in the study area.
		Comanche: Washita Fredericksburg	undifferentiated	Limestone with interbedded marl, shale, and sandstone.	The Edwards-Trinity (Plateau) aquifer yields small to moderate amounts of fresh to moderately saline water to wells in southern Reeves and western Pecos Counties.
		Comanche: Trinity	undifferentiated	Sandstone, limestone, and conglomerate.	
	Triassic	Dockum	undifferentiated	Red shale and siltstone separated by a reddish brown to greenish gray sandstone.	Yields small to moderate amounts of fresh to moderately saline water to wells mostly in Winkler County.
Paleozoic	Permian	Ochoan	Dewey Lake Red Beds	Red siltstone and shale.	Not known to yield water to wells in the study area.
			Rustler Formation	Dolomite, anhydrite, sandstone, conglomerate, and variegated shale.	Yields small to large amounts of slightly to moderately saline water to livestock and irrigation wells.
			Salado Formation	Mostly halite, with anhydrite and some dolomite.	Not known to yield water to wells in the study area.
			Castile Formation	Mostly calcareous anhydrite, with halite and associated salts and some limestone.	
		Guadalupian	Capitan Reef Complex	Porous limestone and dolomite, bedded limestone, and reef talus.	Yields small to large amounts of moderately to very saline water to industrial and irrigation wells that, in some areas, flow.
	Devonian Silurian Ordovician		undifferentiated	Marine carbonates.	Yields very saline to brine water as a byproduct from oil wells.

** Yields of wells:* *small--less than 50 gallons per minute (gal/min); moderate-- 50 to 500 gal/min; large--more than 500 gal/min.*
Chemical Quality of Water: *fresh--less than 1,000 milligrams per liter (mg/l) ; slightly saline--1,000 to 3,000 mg /l; moderately saline--3,000 to 10,000 mg/l ; very saline--10,000 to 35,000 mg/l ; brine--more than 35,000 mg/l.*

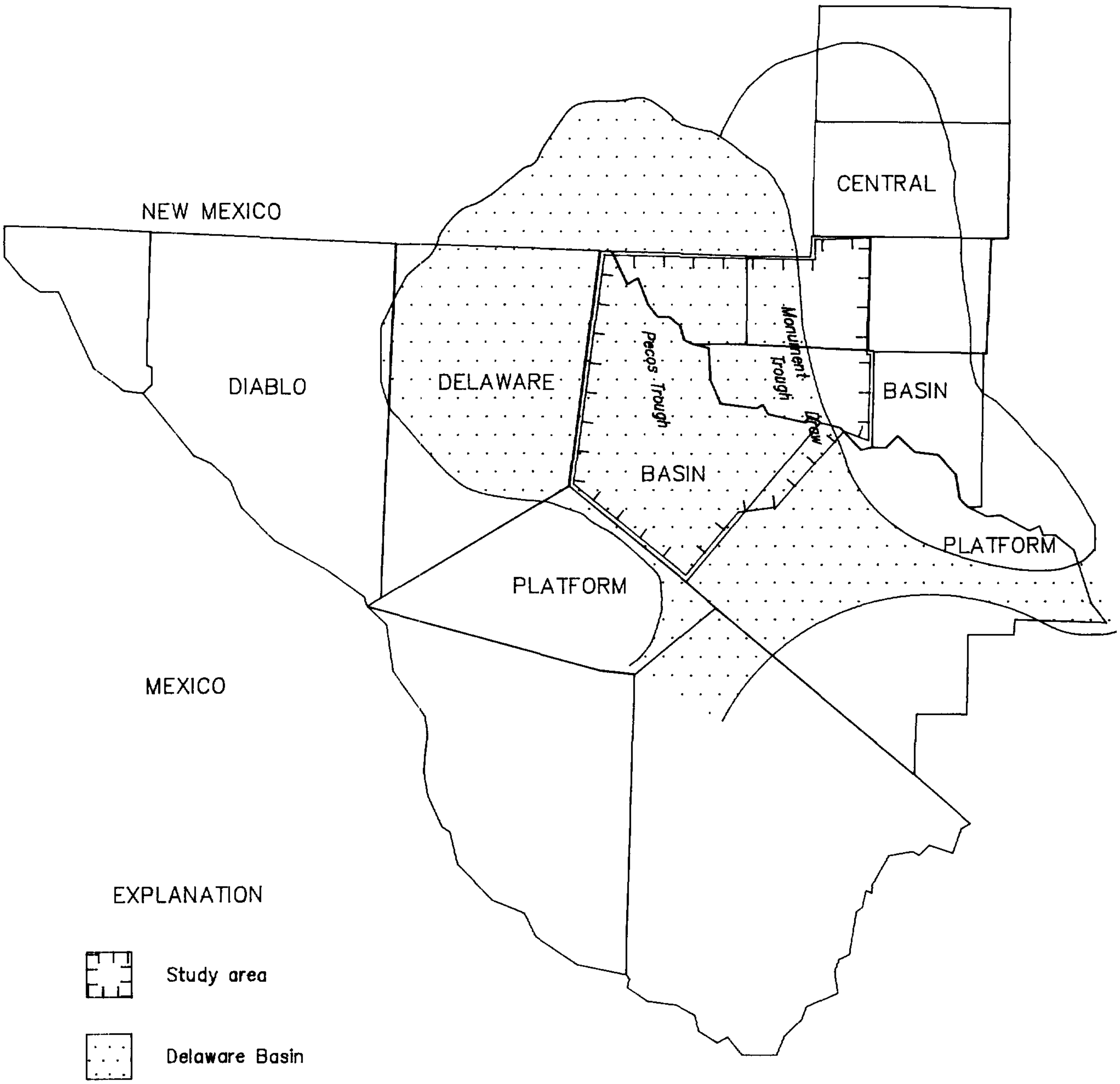


Figure 2

REGIONAL STRUCTURE

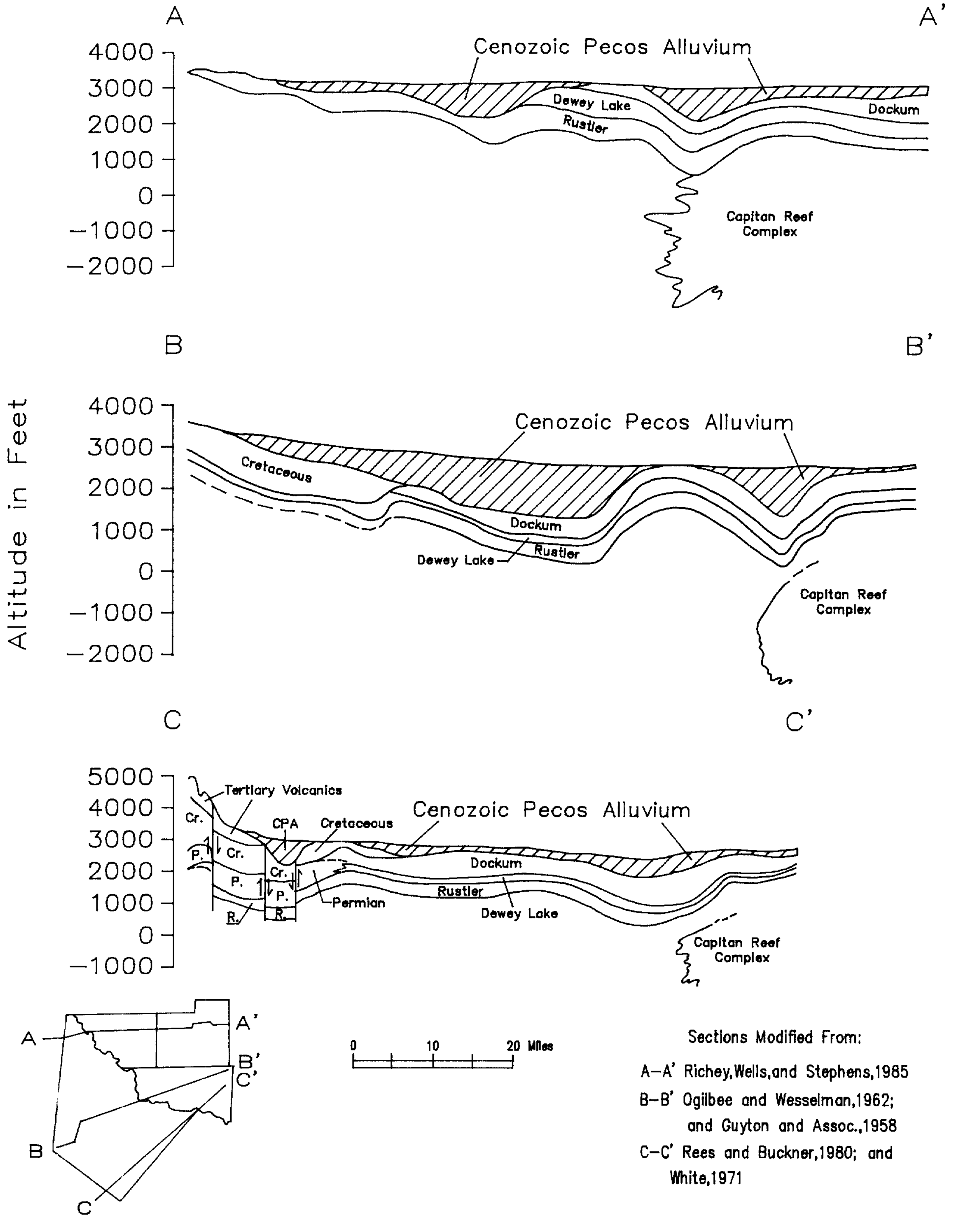


Figure 3
GEOLOGIC SECTIONS

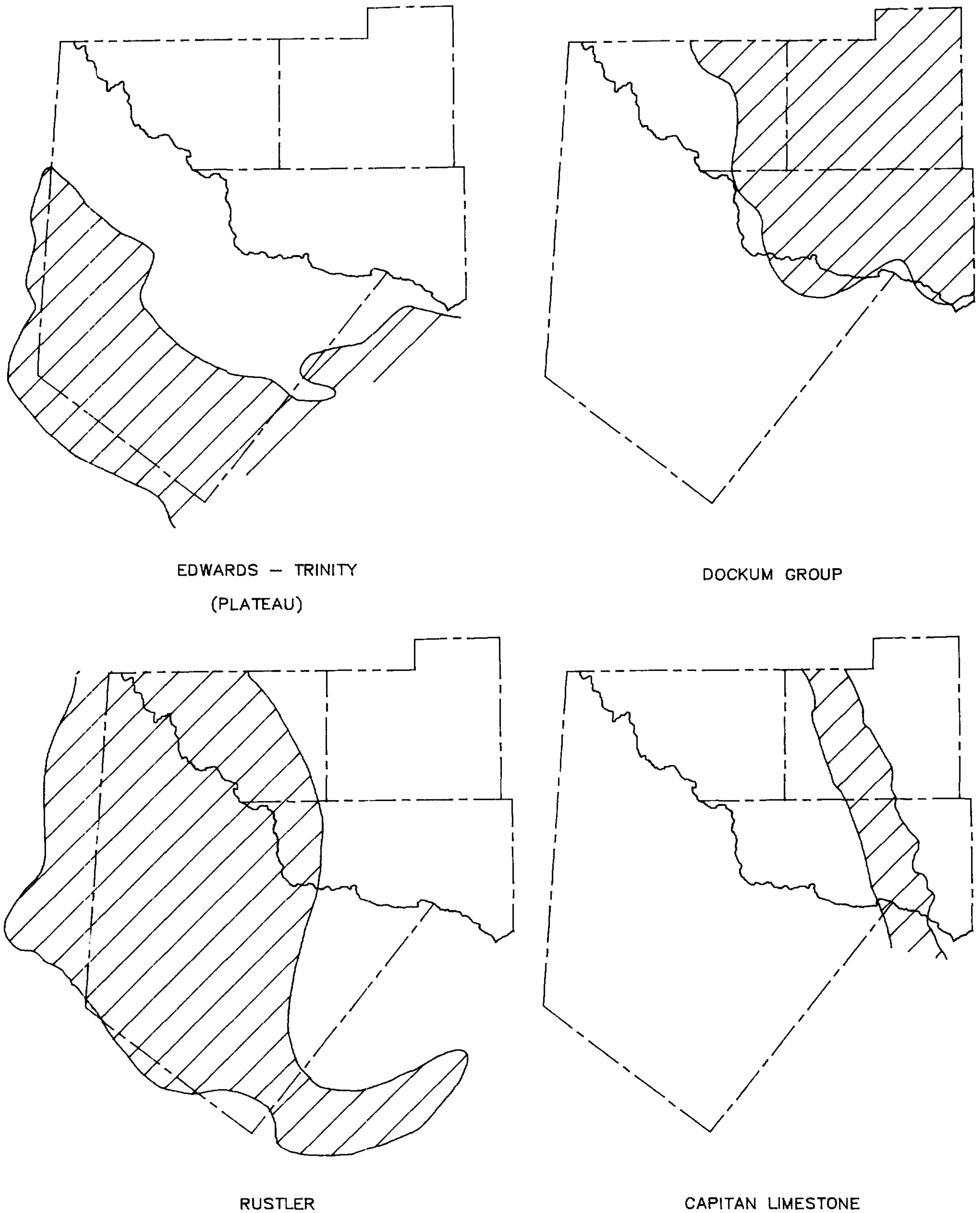


Figure 4

AQUIFERS UNDERLYING THE CENOZOIC PECOS ALLUVIUM

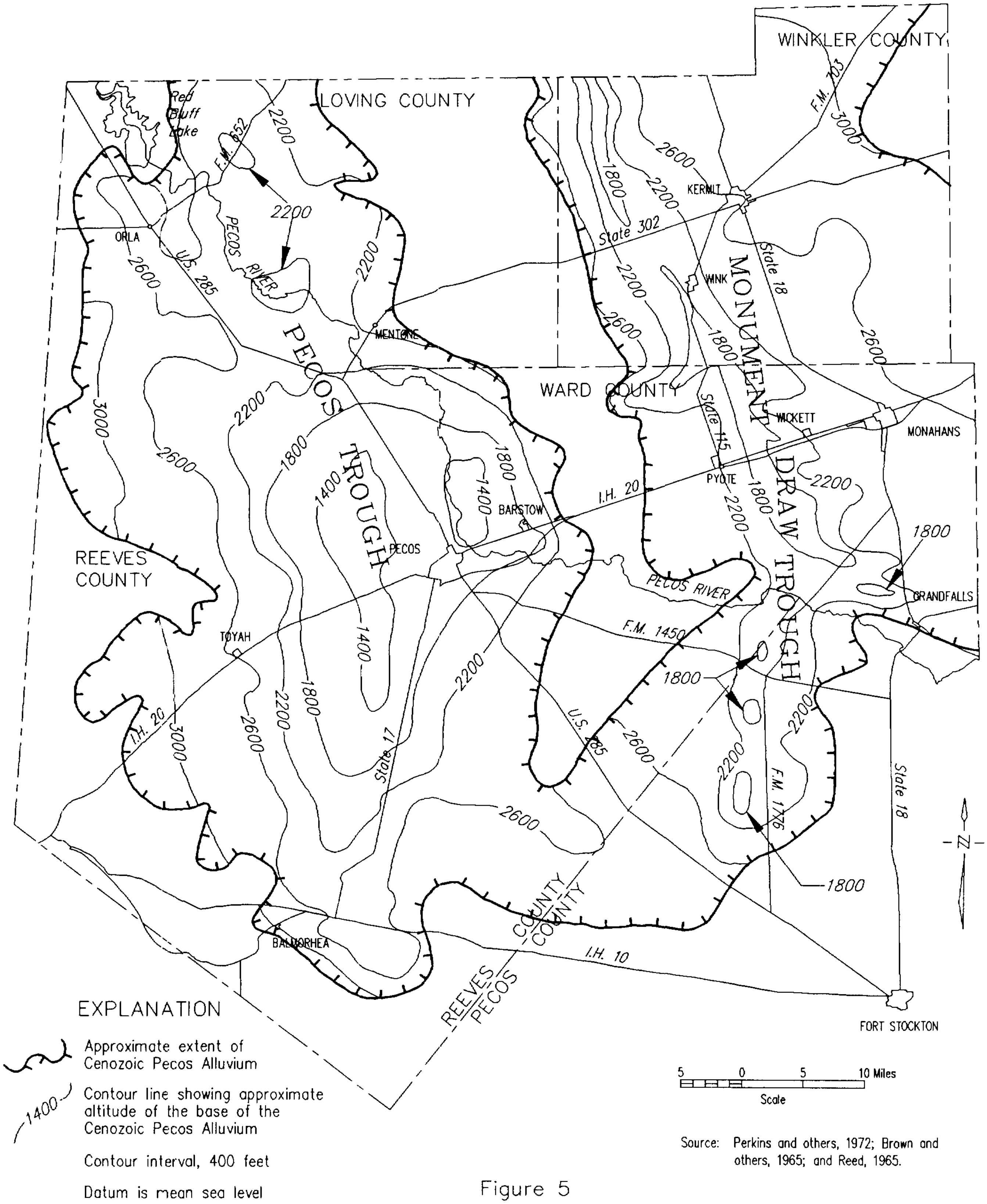


Figure 5

APPROXIMATE ALTITUDE OF THE BASE OF THE CENOZOIC PECOS ALLUVIUM

Cenozoic Pecos Alluvium Aquifer

The Cenozoic Pecos Alluvium is the most important aquifer in the study area and is the principal source of water for irrigation in Reeves and northwest Pecos Counties, and for industrial and public supply use elsewhere. Up to 1,500 feet of alluvial material fills the western Pecos Trough and eastern Monument Draw Trough and consists of unconsolidated to partially consolidated sand, silt, gravel, clay, and caliche (Figure 5).

Recharge

Natural recharge to the Cenozoic Pecos Alluvium aquifer occurs by infiltration of precipitation, seepage from ephemeral stream channels, and lateral subsurface flow from adjacent formations. Artificial recharge results from seepage from irrigation canals and infiltration of irrigation water on fields (Figure 6).

"Recharge from precipitation and streamflow is intermittent and largely contingent on heavy rainfall. The aquifer is substantially recharged only when storms of long duration or of frequent occurrence saturate the soil so that deep percolation takes place" (White, 1971). Lateral underflow from adjacent aquifers occurs primarily from Permian formations to the west and Cretaceous formations and Tertiary volcanics to the south.

In addition to natural recharge, water returns to the aquifer via seepage from irrigation canals and irrigation return flow. Hydrologic studies conducted by the Pecos River Joint Investigation indicate that canal losses ranged from 30 to 72 percent, and that approximately 20 percent of the irrigation water applied to cropland in the area percolated to the water table (U.S. National Resources Planning Board, 1942).

The methodology used to determine the annual effective recharge for the Cenozoic Pecos Alluvium aquifer (Muller and Price, 1979) was based on a seepage study along the Pecos River conducted by the U.S. Geological Survey in 1918 (Grover and others, 1922) prior to extensive ground-water development. The method assumes that under natural conditions (pre development) the aquifer is full and thus the amount of water entering the aquifer as recharge is equal to the amount naturally discharging. The study determined that there was an increase in base flow of approximately 34,000 acre-feet along a segment of the river between the Texas-New Mexico state line and Gervin in Pecos County. After eliminating approximately 3,000 acre-feet, which was determined to be coming from Crane County, there remains 31,000 acre-feet assigned to the counties in the study area.

Additional effective recharge of 36,800 acre-feet per year resulting from irrigation-water seepage into the aquifer was estimated using 60 percent of the Pecos River average annual diversions for irrigation (White, 1971; and Muller and Price, 1979). Hence, the total annual effective recharge for the Cenozoic Pecos Alluvium aquifer in the study area is estimated to be 67,800 acre-feet.

Water Level

Ground water in the Cenozoic Pecos Alluvium aquifer generally occurs under semiconfined or unconfined conditions although confining clay beds may create localized artesian conditions. Prior to extensive irrigation development, deep wells near the City of Pecos had flowed for several years. Water levels measured in a few wells in the irrigated area south of the City of Pecos confirm that some ground water occurs in perched zones above the normal water table (Ogilbee and Wesselman, 1962).

Depth to the water table ranges from less than 50 feet around the periphery of the aquifer to approximately 300 feet in parts of the irrigation areas of Reeves and Pecos Counties. The approximate altitude of the water table, based on measurements made by the staff of the Texas Water Development Board in February 1989, is shown on Figure 7. Saturated thickness of the aquifer, based on these measurements, is illustrated on Figure 8.

Water levels in the irrigation area of Reeves County generally exhibit a seasonal fluctuation. Measurements made in 31 wells in early fall of 1988 during the pumping season and again in the winter showed an average water-level change of approximately six feet. This seasonal fluctuation can be seen on the hydrograph in Figure 9.

Water-level declines in excess of 200 feet have historically occurred in south-central Reeves and northwest Pecos Counties, but have moderated since the mid 1970's due to a decrease in irrigation pumpage. Likewise, north-central Ward and south-central Winkler Counties have experienced water-level declines of less magnitude. Elsewhere in the study area, there have been no significant changes in the water levels. Water-level fluctuations in the aquifer are discussed in detail in the report section titled "Ground-Water Problems/Water-Level Decline".

Movement

Figure 7 indicates that ground water in the Monument Draw Trough in Ward and Winkler Counties moves generally toward the southwest and to a lesser extent toward the more heavily pumped area of north-central Ward County. In the Coyanosa area of Pecos and Reeves Counties, movement is normally northward toward the Pecos River, and is partially diverted toward the area of heaviest pumpage. Ground-water movement in the Pecos Trough is toward the Pecos River in northern Reeves and western Loving and Ward Counties, and toward the irrigation pumpage center in central Reeves County. There is virtually no ground-water movement in the Cenozoic Pecos Alluvium aquifer from one trough to the other, therefore, each trough should be recognized as a separate ground-water system.

Water Quality

The chemical quality of water in the Cenozoic Pecos Alluvium is highly variable, differing naturally with location and depth. Major factors influencing the quality include:

1. Presence of adjacent evaporite beds in the northern and western part of the Pecos Trough which increases the concentration of sulfate in the water.

2. Recharge of highly mineralized water by irrigation return flow in south- central Reeves County and the Coyanosa area.

3. Concentration by evapotranspiration of shallow mineralized water in the alluvium of the Pecos River Valley.

4. Saline-water encroachment in areas of heavy pumpage.

5. Local contamination by oil field brine, primarily in Winkler and Loving Counties.

Water from the aquifer is generally hard to very hard (more than 120 mg/l carbonate hardness) and contains dissolved-solids concentrations ranging from less than 300 milligrams per liter (mg/l) to more than 5,000 mg/l (Figure 10). The quality of water stored in the alluvial deposits in both troughs normally deteriorates with depth. Sulfate and chloride are the two most prominent constituents (Figures 11 and 12). The degree of change in quality and its effect on water use is further discussed in the report section titled "Ground-Water Problems/Water-Quality Deterioration".

Figure 10 shows that most of the Monument Draw Trough contains fresh water (less than 1,000 mg/l), with higher concentrations of dissolved solids occurring in the following areas:

1. Winkler County: area west of Kermit and north of Wink.

2. Ward County: area from northwest to southeast of Pyote; an area south of Monahans; and, an area north and east of Grandfalls.

3. Pecos County: area consisting of the Coyanosa farming region and extending to the Pecos River.

Ground water in the Pecos Trough is generally poorer, ranging from slightly to moderately saline over almost the entire region (Figure 10). Areas in which the ground water contains dissolved solids in excess of 5,000 mg/l occur in extreme western Ward County and the central part of Reeves County south and west of the City of Pecos.

Two distinct water types in the Cenozoic Pecos Alluvium aquifer can be delineated in Reeves County based on the relative concentration of sulfate to chloride (Perkins and others, 1972; and La Fave, 1987). Water with a sulfate concentration in excess of 1,000 mg/l and a ratio to chloride of greater than, or equal to, two occurs predominantly in the west and northern part of the county. Water with a sulfate to chloride ratio of less than two occurs mostly in the southern part of the county. The two water types are a result of different recharge origins. The sulfate-rich water has moved through evaporite beds in the Rustler Hills to the west, while the chloride-dominant water originated from other sources primarily to the south and southwest (La Fave, 1987).

Forty three wells within the study area were sampled for the following metals: arsenic, barium, iron, manganese, and selenium. Of these, iron in seven samples, manganese in six samples, and selenium in three samples were found to be above the Federal Safe Drinking Water Act limits of 0.3, 0.05, and 0.01 mg/l respectively.

Water samples from five wells in Reeves County and one in Pecos County were analyzed for naturally occurring radioactive substances known as radionuclides. Two of the samples, one each in Reeves and Pecos Counties, showed measured gross alpha activities of 25 ± 4 and 18 ± 5 picocuries per liter (pCi/l) which exceed maximum levels considered safe (15 pCi/l) by the Texas Department of Health for drinking purposes. Also, one additional well sample in Reeves County contained 1.9 ± 0.1 pCi/l of radium-226 and 4.9 ± 0.9 pCi/l of radium-228, slightly exceeding the recommended combined upper limit of 5 pCi/l.

Radionuclides are found as trace elements in most rocks and soils and are formed principally by the radioactive decay of uranium-238 and thorium-232 (Zapecza and Szabo, 1986). The original source of much of the radioactive elements in the Cenozoic Pecos Alluvium is probably the Tertiary volcanic rocks south of the study area.

The quality of ground water for human consumption is always of primary concern. In 1974 the Safe Drinking Water Act was adopted and on December 10, 1975 the U.S. Environmental Protection Agency established national standards for drinking water quality. These standards apply, selectively, to all types of public water systems of Texas, and enforcement of these standards was assumed by the Texas Department of Health on July 1, 1977 (revised April, 1988). Ground water in most of the area in Figure 10 shown as slightly saline or worse (more than 1,000 mg/l dissolved solids) is undesirable or unusable as drinking water.

Most of the public supply systems within the study area depend solely on ground water. Table 2 lists the average concentration of selected constituents in water samples taken from several public supply wells in 1985 and 1987. The table indicates that, based on the wells sampled, ground water pumped from City of Pecos and City of Grandfalls well fields contain concentration levels of sulfate, chloride, and dissolved solids that are near or exceed recommended upper limits for drinking water. Fluoride content in the aquifer throughout the study area is generally below the recommended upper limit, averaging less than 2.0 mg/l.

The suitability of ground water for irrigation purposes is largely dependent on the chemical composition of the water. The extent to which the chemical quality will affect the growth of crops is in part determined by the climate, soil, management practices, crops grown, drainage, and quantity of water applied. Primary characteristics that determine the suitability of ground water for irrigation are total concentration of soluble salts, relative proportion of sodium to other cations (magnesium, calcium, and potassium), and concentration of boron or other toxic elements. These have been termed, respectively, the salinity hazard (specific conductivity), the sodium hazard (SAR), and the boron hazard.

A comparison of SAR and specific conductivity values of water samples from 21 wells in the Toyah basin irrigation area of Reeves County indicates that the sodium hazard (SAR) increases directly with the increase in salinity hazard (specific conductivity). Ground water with

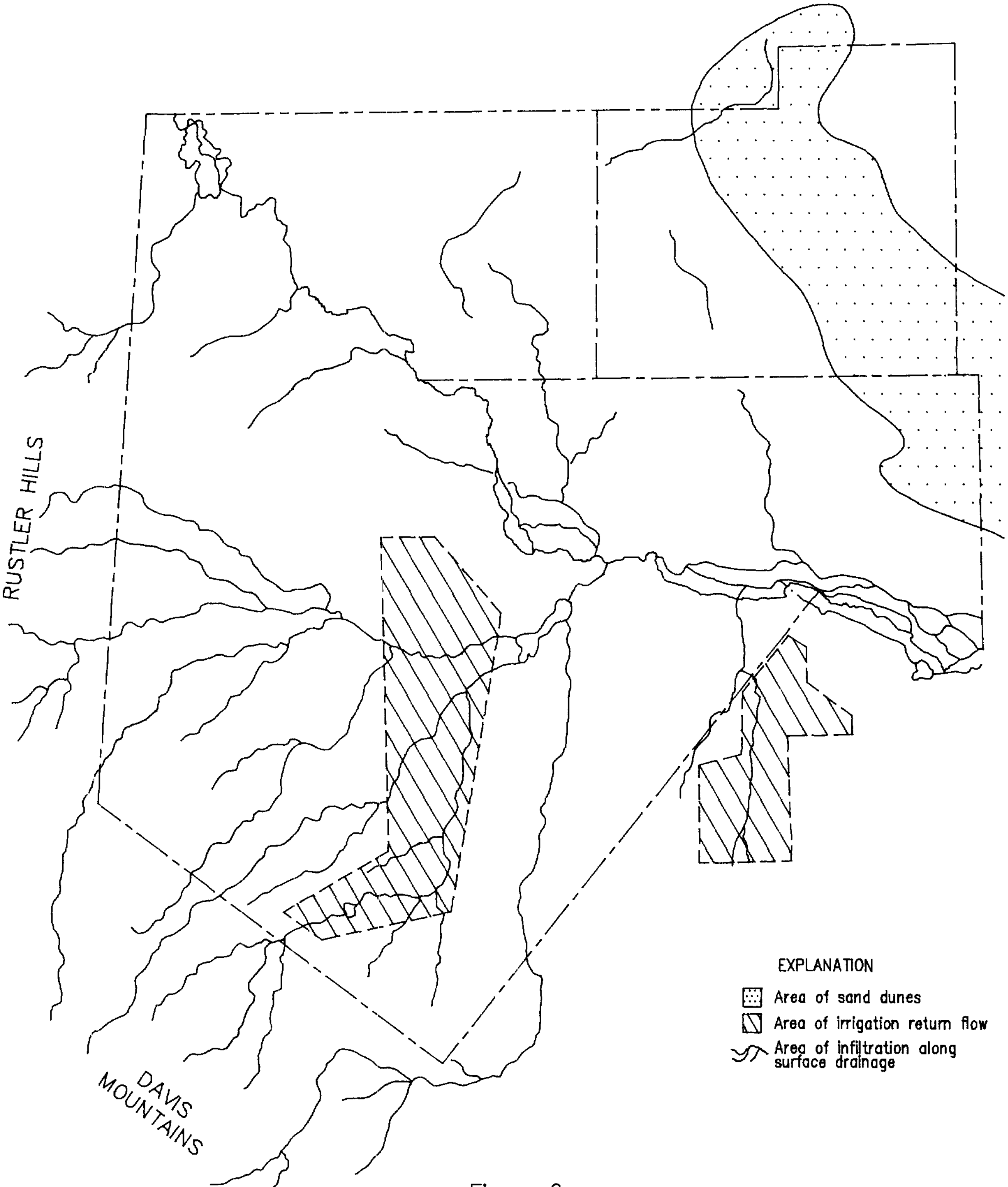


Figure 6

PRIMARY RECHARGE AREAS

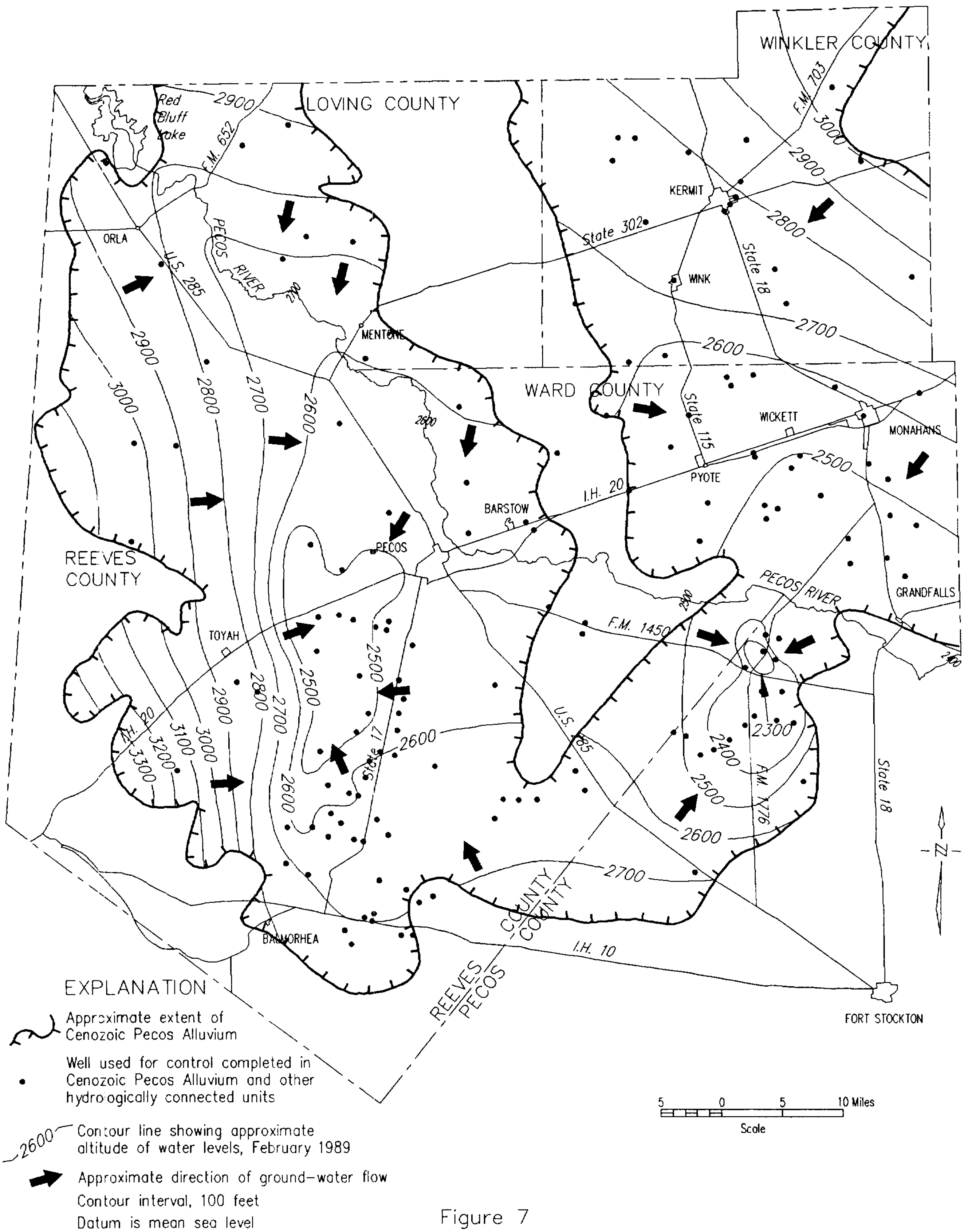
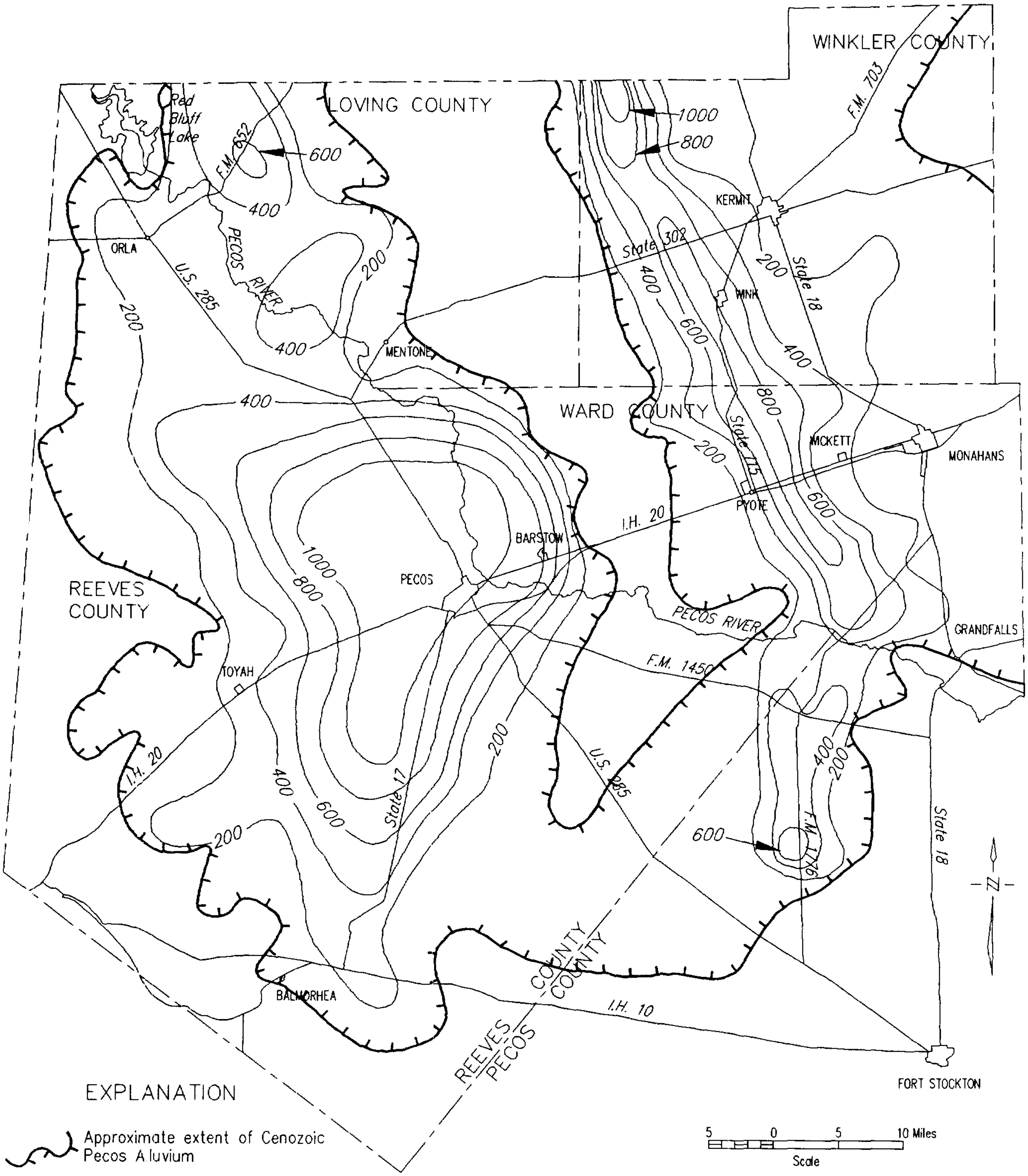


Figure 7

APPROXIMATE ALTITUDE OF WATER LEVELS, 1989



EXPLANATION

Approximate extent of Cenozoic Pecos Alluvium

Contour line showing approximate total saturated thickness of the Cenozoic Pecos Alluvium

400

Contour interval, 200 feet

Figure 8

APPROXIMATE SATURATED THICKNESS OF THE CENOZOIC PECOS ALLUVIUM, 1989

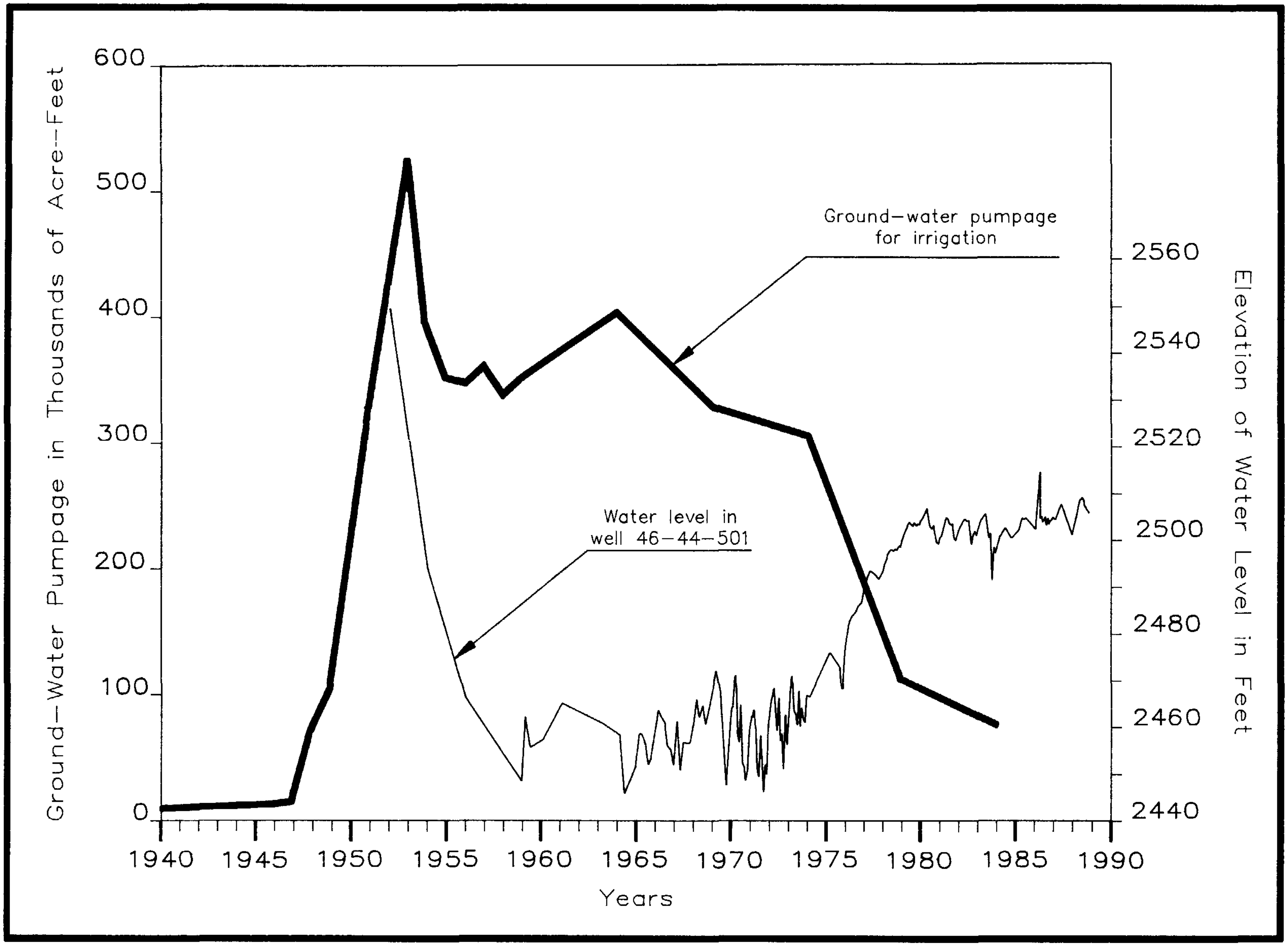


Figure 9

IRRIGATION PUMPAGE IN REEVES COUNTY
VERSUS WATER-LEVEL CHANGE OVER TIME

Table 2
Average Concentration of Selected Constituents in Water Samples Taken From Public Supply Systems in 1985 and 1987

Water Supply Entity	Number of Wells Averaged	Sulfate (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Nitrate (mg/l)	Dissolved Solids (mg/l)
City of Pecos (Ward Co. Field)	4	323	420	3.2	3.0	1,366
City of Pecos (Reeves Co. Field)	9	258	315	1.4	6.8	1,036
City of Kermit	9	75	66	1.0	8.1	357
City of Wink	7	74	117	1.6	1.5	434
City of Grandfalls	3	276	553	1.8	1.7	1,523
City of Wickett	1	152	68	1.7	4.6	514
City of Monahans	6	78	78	2.1	6.9	431
Colorado River MWD (Pyote Field)	1	140	124	2.6	9.1	639
Colorado River MWD (Wickett Field)	16	159	171	1.8	4.1	707
TDH recommended upper limits		300	300	4.0*	44.3	1,000

Samples collected by staff of the Texas Water Development Board and analyzed by the Texas Department of Health Laboratory.

*2.0 under secondary standards

a specific conductance of up to 7,000 micromhos (very high salinity hazard), and SAR values within the low to medium sodium hazard range, is successfully being used to water crops. Specific conductance in excess of 7,000 micromhos correlates to a high to very high sodium hazard range. Special management practices are needed to grow salt tolerant crops, such as cotton, under these conditions (U.S. Salinity Laboratory Staff, 1954).

The effect caused by irrigating with ground water containing a high salinity hazard in Reeves County is minimized by a leaching process that requires the application of water beyond what the crops require. The annual rainfall, by itself, is not sufficient to leach the salts out of the root zone (U.S. Soil Conservation Service, 1980). Additional information on soil and water salinity management can be obtained from the local office of the Soil Conservation Service and The Texas A&M Agricultural Extension Service.

Boron is necessary for good plant growth, but rapidly becomes highly toxic at concentrations above acceptable levels. Maximum tolerable levels for various crops range from 1.0 to 3.09 mg/l (Scofield, 1936). The concentration of boron was determined in 40 samples in Reeves County and ranged from 0.10 to 1.49 mg/l and averaged 0.50 mg/l. Only three out of the 40 samples contained a concentration of boron above 1.0 mg/l. Boron, therefore, does not generally appear to be a prominent hazard to agriculture in the Reeves County irrigation area. Water samples from wells in the remainder of the study area, likewise, do not contain detrimental levels of boron.

Pecos River

The Pecos River enters Texas from New Mexico and traverses the study area from northwest to southeast. Prior to the development of large-scale irrigation, base flow gain studies indicated that ground-water inflow to the river between Red Bluff Reservoir near the New Mexico-Texas state line and Gervin, Texas, averaged 30,000 acre-feet or more per year (Grover and others, 1922; and U.S. National Resources Planning Board, 1942). Increased irrigation pumpage in the 1950's and 1960's resulted in declining water levels, which caused the ground water to reverse direction and flow away from the river. In 1965, Grozier and others (1966), measured a streamflow loss of approximately 2,480 acre-feet of water in the Red Bluff to Gervin segment.

Low flow into Red Bluff Reservoir typically contains a high concentration of dissolved solids, mostly sodium and chloride. However, flood water inflow tends to dilute this concentration, resulting in a calcium-sulfate type water suitable for irrigation of free-draining soils (Grozier and others, 1968). The chemical quality generally deteriorates in a downstream direction, with chloride concentrations often doubling or tripling between Red Bluff Reservoir and Gervin. In recent times, fish kills in the river have been attributed to high concentrations of algae. Also, elevated dissolved oxygen and fecal coliform levels periodically occur (Texas Water Commission, 1988). The following table presents water-quality data for a segment of the Pecos River from the Red Bluff Dam to Val Verde County, Texas from October 1, 1983 through September 30, 1987:

Parameter	Number of Samples	Minimum	Maximum	Mean
Dissolved Oxygen (mg/l)	59	4.2	14.7	9.4
pH	49	6.0	9.2	8.0
Chloride (mg/l)	43	845	6,005	3,296
Sulfate (mg/l)	43	530	3,856	1,977
Total Dissolved Solids (mg/l)	59	1,415	11,000	6,160

Source of data: Texas Water Commission, 1988

GROUND-WATER PROBLEMS

Water-Level Decline

Prior to extensive ground-water withdrawals, the water level fluctuated only slightly with changes in recharge and was generally less than 50 feet below the land surface. After 1940, large withdrawals, mostly for irrigation, resulted in rapid water-level declines, primarily in Reeves and Pecos Counties. Figure 9 shows a comparison of annual ground-water pumpage in Reeves County with a hydrograph of the water level in well 46-44-501.

Major water-level declines in the Pecos Trough area have historically occurred in south-central Reeves County as a result of irrigation pumpage overdrafts in which withdrawals have exceeded recharge (Figure 13). Texas Water Development Board water-level monitoring records show that declines of up to 200 feet have occurred since the development of large-scale irrigation began in the late 1940's. Irrigation pumpage began to decrease in the mid 1970's and the water level has since risen over much of the area. In the last 10 years only a narrow strip along State Highway 17 between the Cities of Pecos and Balmorhea (Figures 13, 14, and 15) continues to experience a continuous water-level decline. The economic effect of a declining water level in an irrigation well in the study area can be estimated by approximating a cost of \$.01 per foot of additional lift to produce one acre-inch of water based on the current energy cost of about \$.07 per KWH (J. Henggeler-Texas Agricultural Extension Service, 1989, personal communication).

Pumpage has been less intense in the Monument Draw Trough area and, therefore, no serious water-level declines have occurred. However, the level has declined at a rate of one to two feet per year over the past ten years in an area in central Ward County oriented generally northwest to southeast of the City of Wickett and in a small part of the Coyanosa area (Figures 13, 14, and 15). Ground water in these areas is being withdrawn for municipal, industrial, and irrigation use.

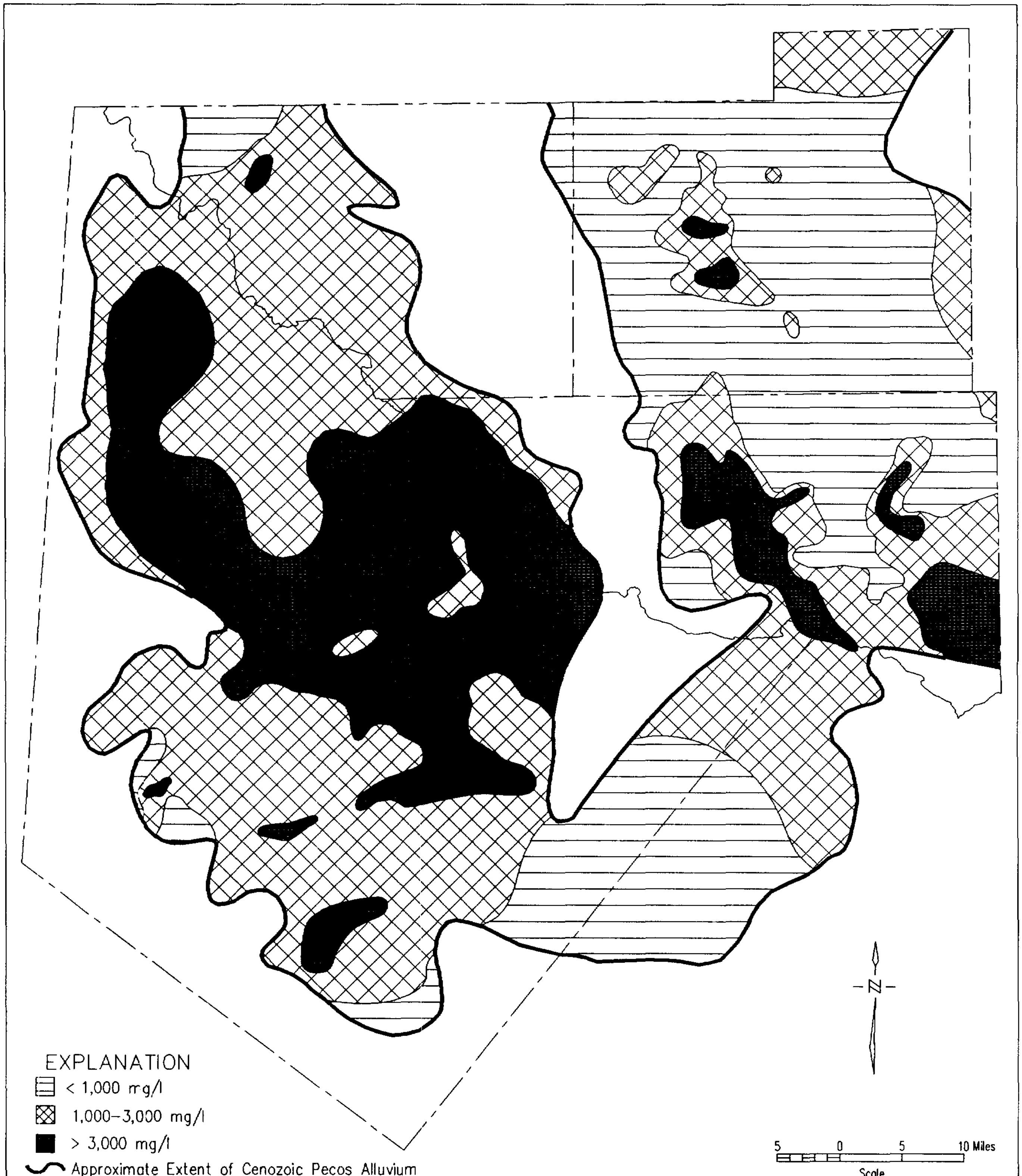


Figure 10

DISSOLVED–SOLIDS CONTENT OF WATER IN THE CENOZOIC PECOS ALLUVIUM AND ADJACENT AQUIFERS

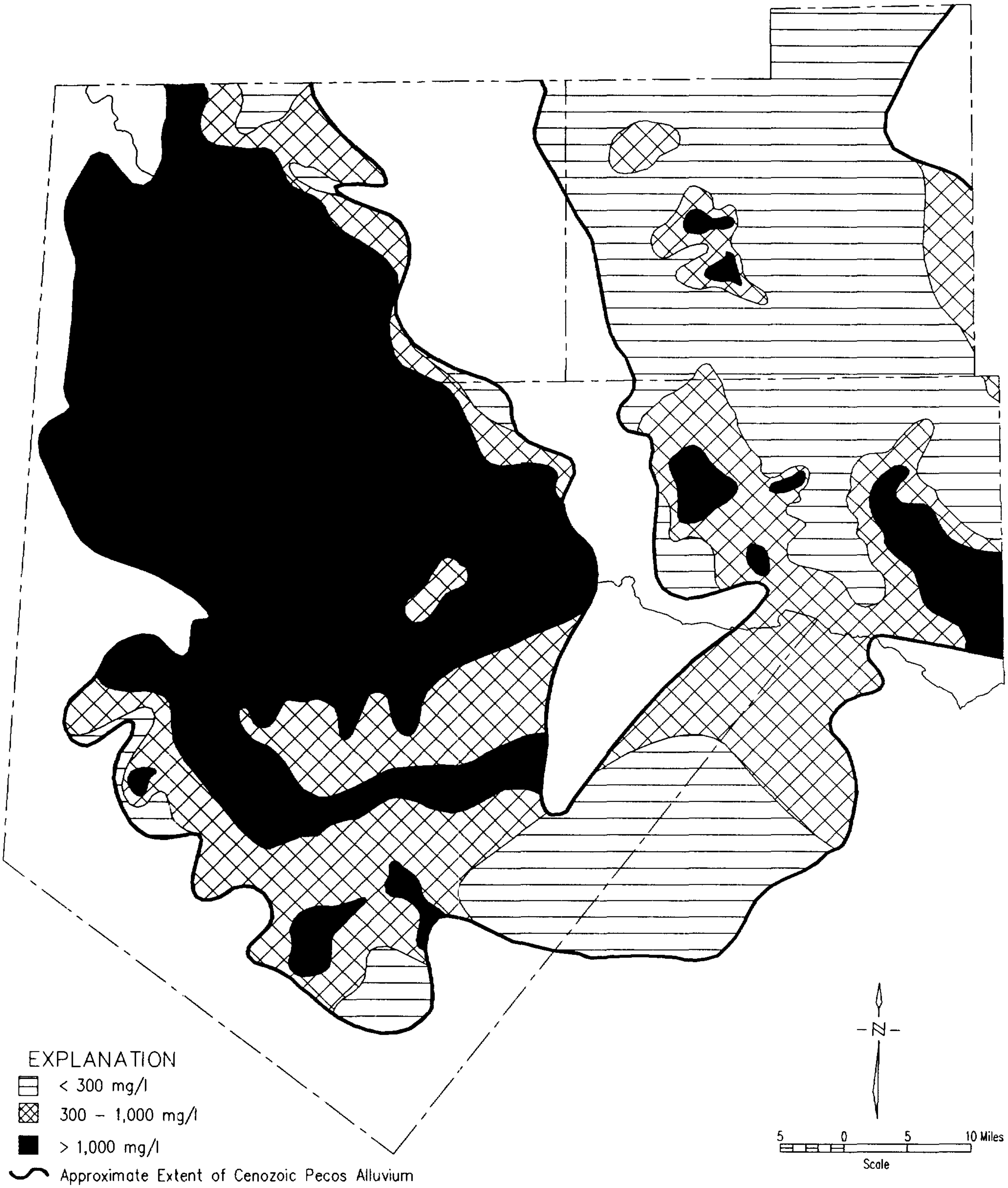


Figure 11

SULFATE CONTENT OF WATER IN THE CENOZOIC PECOS ALLUVIUM AND ADJACENT AQUIFERS

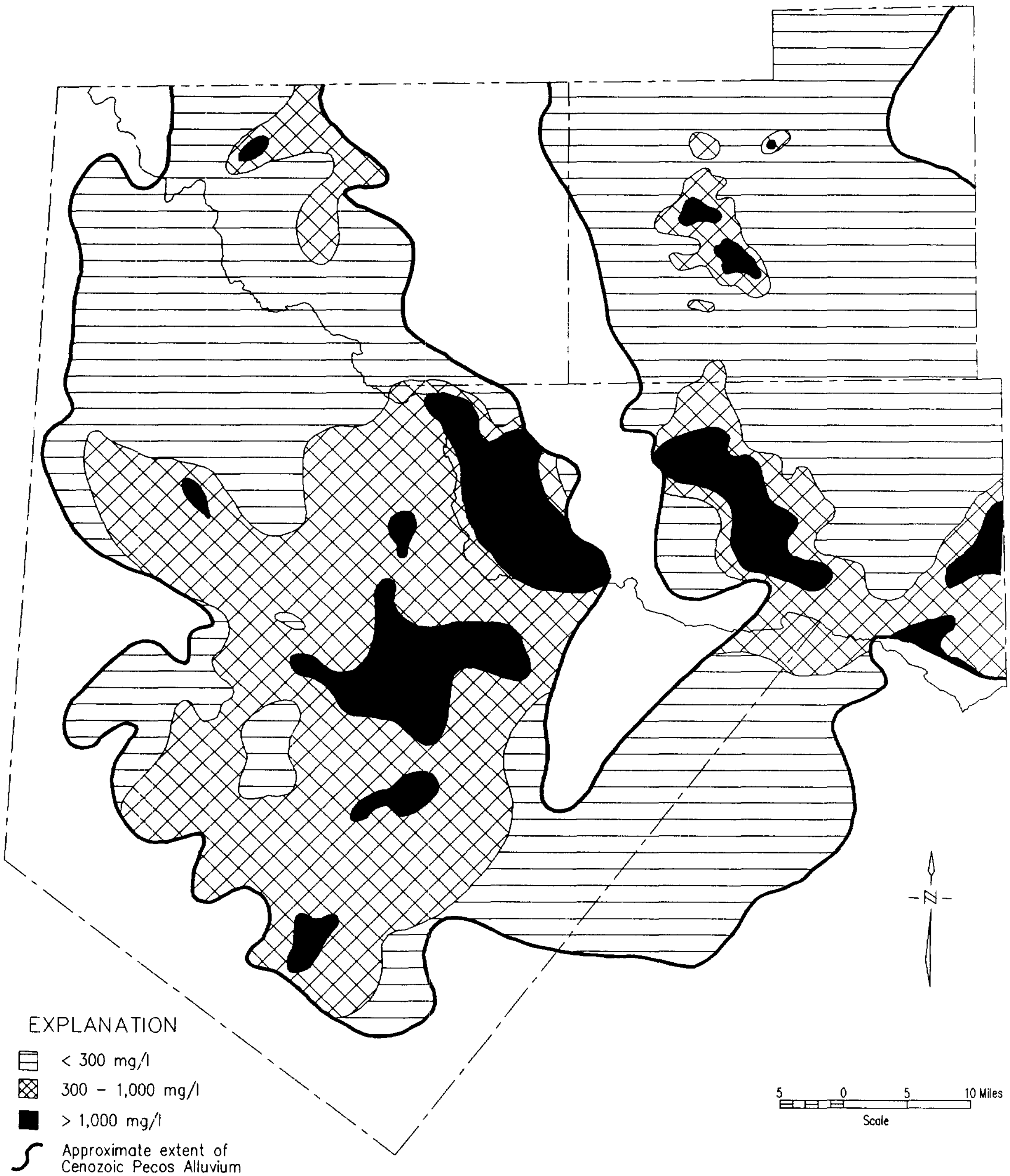


Figure 12

CHLORIDE CONTENT OF WATER IN THE CENOZOIC PECOS ALLUVIUM AND ADJACENT AQUIFERS

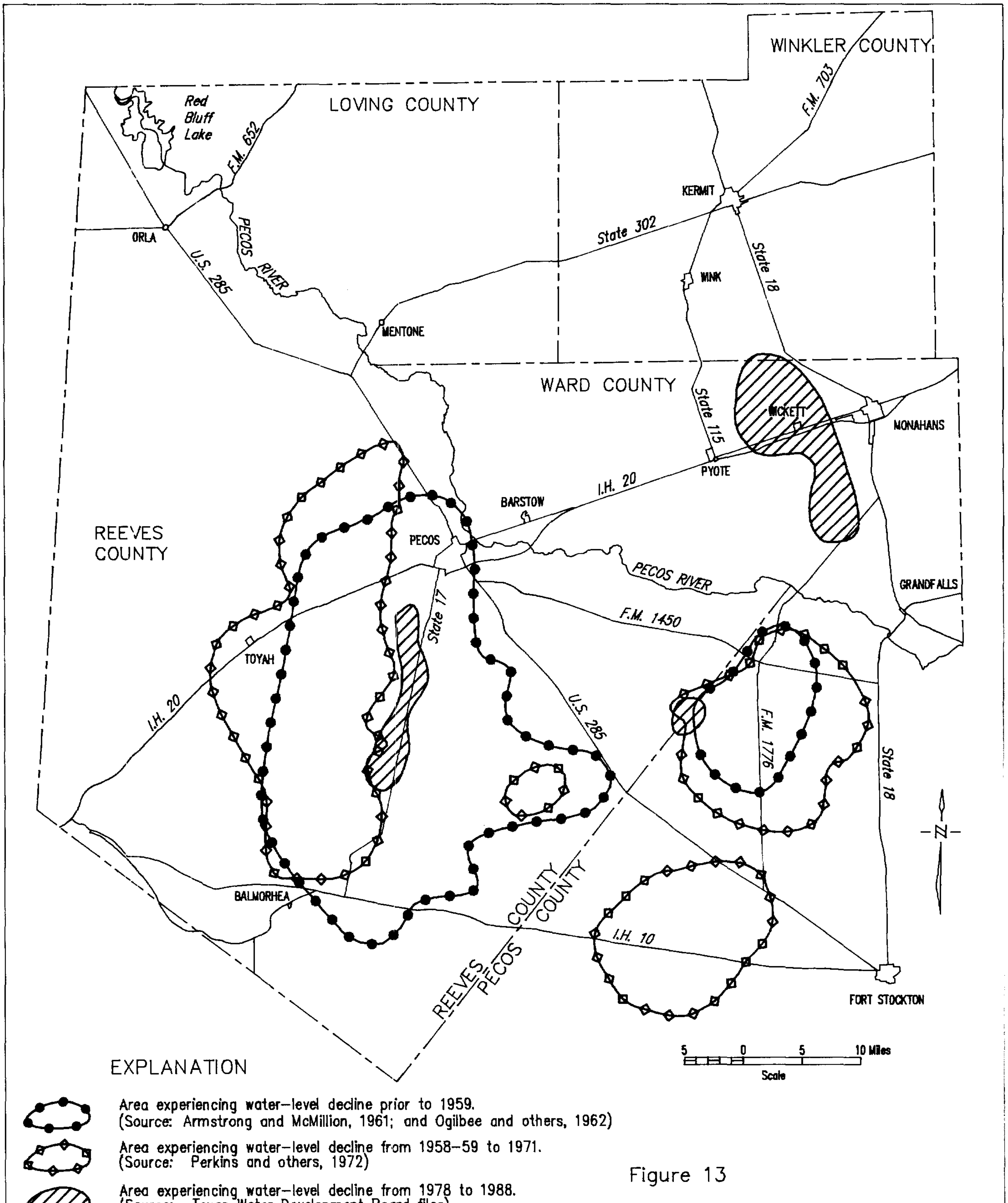


Figure 13

AREAS OF WATER-LEVEL DECLINE DURING THREE TIME PERIODS

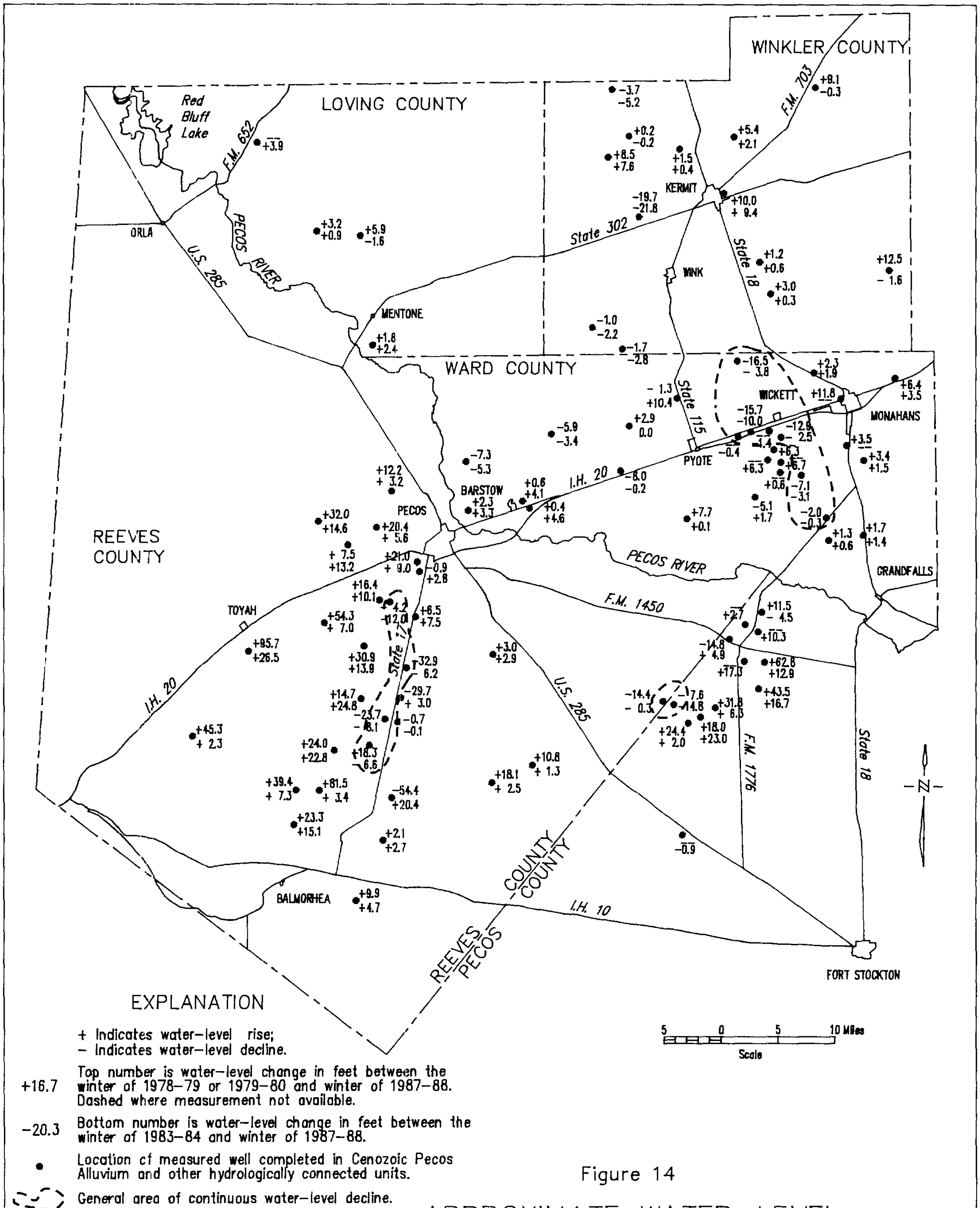


Figure 14

APPROXIMATE WATER-LEVEL CHANGE SINCE 1979 AND 1984 TO 1988

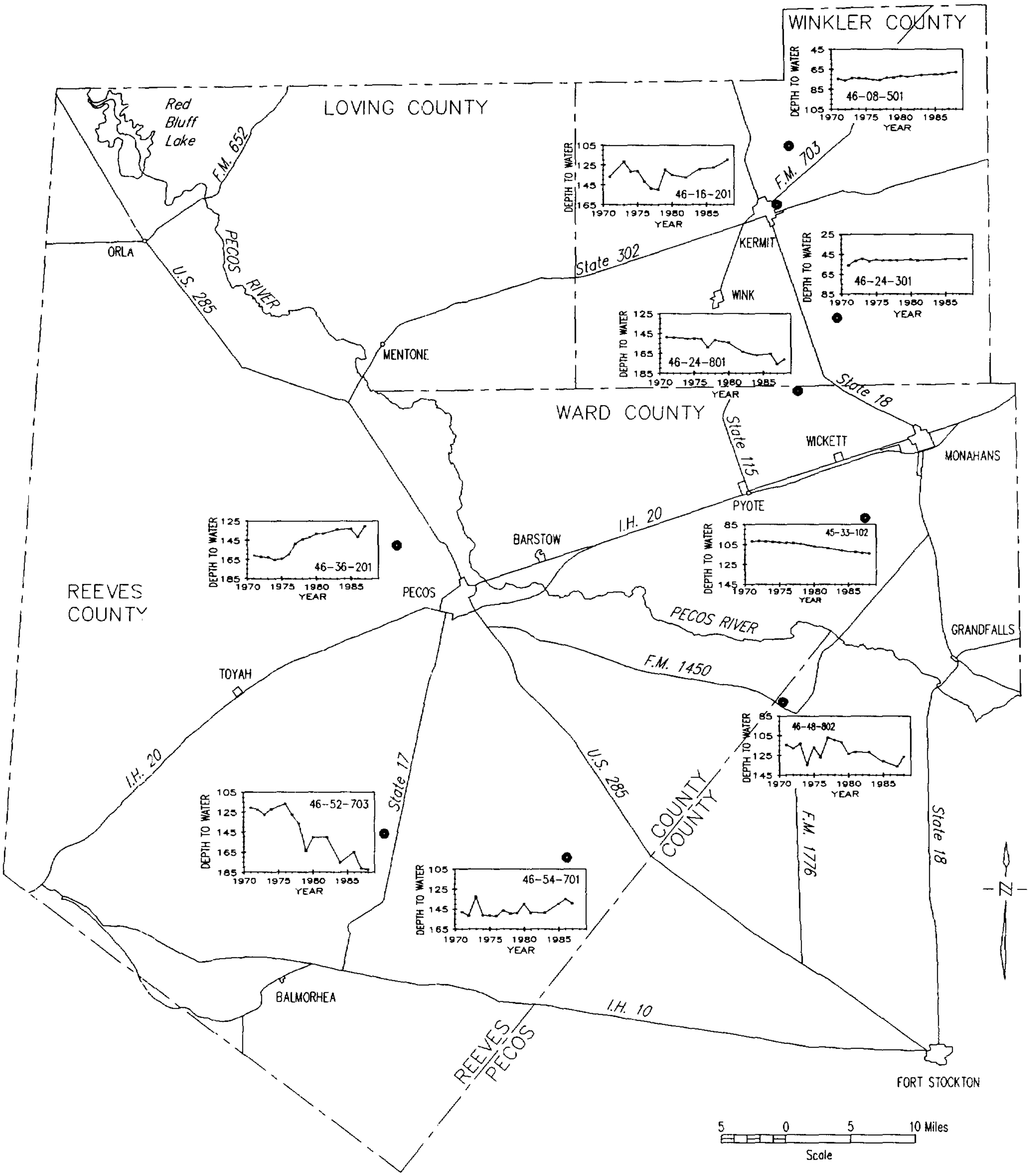


Figure 15

HYDROGRAPHS OF SELECTED WELLS

Water-Quality Deterioration

Even though the natural chemical quality of the ground water in parts of the study area has been relatively poor since before its early development by man, certain areas have experienced a definite deterioration in quality as a result of human activities. This quality deterioration is primarily the result of petroleum industry activities in Loving, Ward, and Winkler Counties and irrigation practices in Pecos, Reeves, and Ward Counties. There is also generally a natural deterioration of quality with increasing depth of the water-bearing strata.

Petroleum Industry Activities

Probably the greatest cause of ground-water contamination has been the disposal of oil-field brines (water containing greater than 35,000 mg/l dissolved solids) into unlined surface pits prior to the statewide "no pit" order of the Railroad Commission of Texas, which became effective on January 1, 1969. Much of the water discharged into these pits probably seeped into the ground and eventually into the ground-water system.

White (1971) and Garza and Wesselman (1959) site several occurrences of the practice of disposing of thousands of acre-feet of oil-field brine in unlined surface pits in Ward and Winkler Counties and the subsequent deterioration of ground-water quality in the vicinity of the pits. For example, between the years of 1937 and 1957 about 800,000 acre-feet of water was produced from production wells in the Hendricks oil field in Winkler County. A great majority of this water was disposed of in unlined pits or directed to a communal disposal lake north of Wink (Garza and Wesselman, 1959, p. 47). The resulting effect of this disposal practice can be seen on Figures 10, 11, and 12 where a large area, north of Wink and west of Kermit, contains substantially poorer quality ground water.

Disposal of salt water in open pits, abandoned oil and gas wells, and unsatisfactory cementation of surface casing are probably the cause of reported contamination of shallow stock water in Loving County (M. Lindley and E. R. Jones, 1989, personal communication). The Railroad Commission of Texas is currently in the process of making rule changes in Loving County which are intended to eliminate these practices.

Improperly or inadequately cased oil and gas wells are a potential hazard to ground-water supplies in the region. The Oil and Gas Division of the Railroad Commission of Texas is responsible for seeing that oil and gas wells are properly constructed and maintained in order to protect all fresh water. The Texas Water Commission provides recommendations concerning the depth to which usable-quality water should be protected. Usable-quality water in the area includes water that is presently used or potentially will be used for domestic, livestock, irrigation, public supply, or for some restricted industrial purposes. In the study area, this protection is given to all water contained in the Cenozoic Pecos Alluvium, Dockum Group, Capitan Limestone (Reef), and the Rustler Formation where it occurs in most of Loving, all of Reeves, western Ward, and northwestern Pecos Counties. Some older oil fields, such as the South Ward Field in Ward County (White, 1971, p. 60), had old field rules pertaining to surface-casing requirements that did not adequately protect to the base of usable quality water.

Since 1963 the City of Monahans has assured proper well construction of all wells drilled within their well field by a city ordinance that requires observation during drilling by a registered professional engineer.

Underground injection wells are used in the petroleum industry for disposal of salt water that accompanies production and in secondary recovery operations. The Underground Injection Control Section in the Oil and Gas Division of the Railroad Commission has permitting and enforcement authority over these operations. Injection of oil-field brines into wells for purposes of either brine disposal or secondary recovery is a potential source of contamination of the fresh-water aquifer, especially in older well fields in which some of the accompanying wells may be inadequately cased.

Abandoned oil and gas wells are particularly hazardous to the area. Abandoned and unplugged or improperly plugged oil and gas wells provide a conduit for salt water to rise in the wells and leak into fresh-water zones. These wells are particularly hazardous when located near underground injection wells which induce pressures that may push salt water much higher than normal in the abandoned wells. Due to the corrosive nature of salt water, metal casings in old oil and gas wells cannot be expected to remain intact forever. In 1983, the Legislature enacted a drilling permit fee in the petroleum industry. Revenues from this fee are to be used by the Railroad Commission to plug abandoned oil and gas wells when ownership cannot be determined and to enforce pollution preventative rules. The Railroad Commission is actively pursuing this plugging procedure, but some abandoned wells no longer visible at the surface may go undetected.

Collapse features, formed by the dissolution of subsurface salt beds, have been a common occurrence historically, especially along the axis of the two troughs. Similar collapse features, such as the Wink Sink that formed in June 1980, "exist where underground salt beds have been intentionally dissolved during solution mining or accidentally dissolved as a result of petroleum production activities" (Johnson, 1986).

Another potential source of contamination exists with the numerous buried pipelines that transport both gas and fluid petroleum products across the region. A major spill could seep downward into the aquifer, especially in areas where the pipeline is underlain by highly permeable material. Even small, undetected leaks can have a detrimental effect in time.

Irrigation Practices

Water quality appears to have changed in some parts of the principal irrigated area (Toyah basin) south and west of Pecos in Reeves County. A review of 598 analyses of water samples from 341 wells throughout the county collected over the past 48 years reveals that a significant increase in dissolved solids has occurred in some wells in this area. LaFave (1987) suggests that the quality degradation may be caused by irrigation return flow which becomes concentrated by evapotranspiration and the leaching of natural salts from the unsaturated zone. Such a process results in an increase in dissolved constituents without much change in their relative proportions.

Ground-water quality deterioration is recognized in only a few wells and thus has not generally affected the entire irrigation area. Quality deterioration due to irrigation return flow can be expected to have a more pronounced effect on the upper part of the aquifer and in perched zones, and may not immediately be detected in wells in which the pump intake level is significantly below the top of the water table. However, it has been reported that falling water due to casing failure can be heard in an increasing number of abandoned wells (Alan Zeman, 1989, personal communication). Therefore, lower zones may be contaminated in increasing amounts as deterioration of casings continue.

In the Barstow area of Ward County, a considerable amount of water-quality deterioration has occurred as a result of irrigation return flow. But, in contrast to the Toyah basin area in Reeves County, the Barstow area has historically used large quantities of water diverted from the Pecos River which often contains significantly high levels of sodium chloride. Well samples analyzed in 1967 show an average increase of over 2,000 mg/l dissolved solids when compared to quality analyses made prior to 1950. In almost every case the increase in dissolved solids can be attributed almost entirely to the increase in sodium chloride. Most ground water in this area now contains between 7,000 and 10,000 mg/l dissolved solids and is classified as having very high salinity and sodium hazards for irrigated crops.

Ground water in the Coyanosa irrigation area of northwest Pecos County has increased in dissolved solids by an average of about 200 mg/l which appears to be the result of both irrigation return flow and lateral underflow. Water in the area is generally undesirable for human drinking needs because of its high sulfate content but remains acceptable for irrigation use.

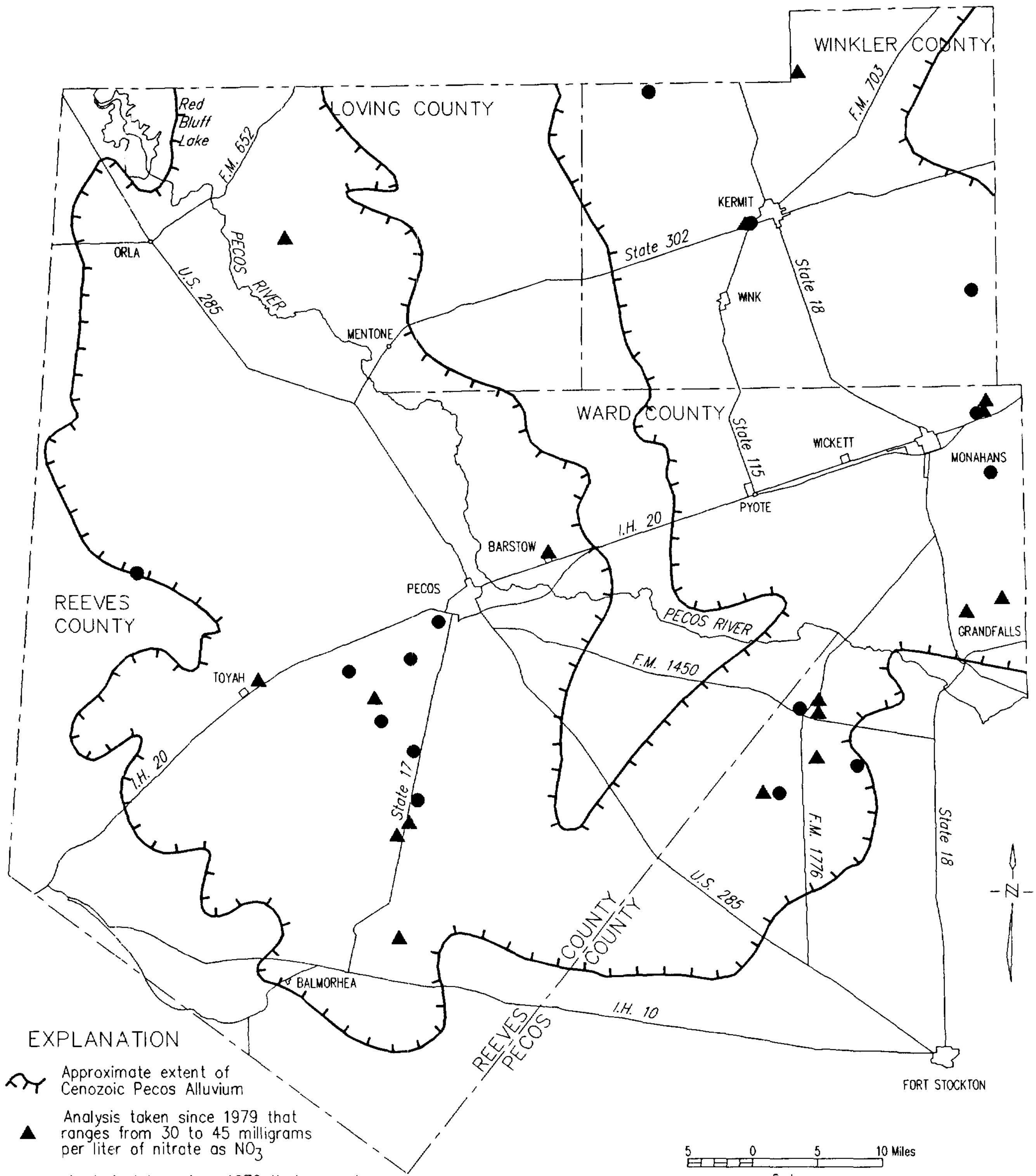
A 1967 Pecos River delivery study documented a general water discharge loss along the segment of the river nearest the Coyanosa area (Grozier and others, 1968). Excessive water-level declines could cause the river discharge loss, with its high chloride content, to flow in the subsurface toward the Coyanosa area.

A high level of nitrate appears to be common to the Toyah basin of Reeves County and the Coyanosa area of Pecos County (Figure 16). Use of water in these two areas is almost exclusively for irrigation which suggests that the source of the nitrates is from the application of fertilizers containing ammonia. Water containing nitrate as NO3 in concentrations in excess of 44.3 mg/l (Texas Department of Health, Safe Drinking Water standard) can lead to serious health problems, especially in infants up to six months of age. Elsewhere in the study area, the number of well samples that tested high in nitrate were few suggesting that the hazard is restricted to each local well site.

Numerous unused wells, mostly irrigation and industrial, occur in the study area. Abandoned or improperly completed water wells are potential passageways for contaminates to reach the aquifer. Contaminates, such as septic tank effluent and agricultural fertilizers and pesticides from fields, can reach the aquifer when runoff is allowed to flow down the outside of inadequately cemented casing in wells. Besides being a potential contamination problem, open wells are also a physical hazard to both humans and animals. The Texas Water Commission is presently engaged in a program of locating abandoned water wells and having them plugged or capped.

Leaking Underground Storage Tanks

Underground storage tanks, especially those that are constructed of unlined metal material, tend to deteriorate rapidly in the study area due to the highly alkaline nature of the shallow subsurface. The Texas Water Commission is actively seeking out these defective storage tanks and mitigating the problem. Thus far, contamination due to leaking underground storage tanks has been detected within the city limits of Monahans and Pecos.



EXPLANATION

Approximate extent of Cenozoic Pecos Alluvium

▲ Analysis taken since 1979 that ranges from 30 to 45 milligrams per liter of nitrate as NO_3

● Analysis taken since 1979 that exceeds Texas Department of Health Safe Drinking Water standard of 44.3 milligrams per liter of nitrate as NO_3

Figure 16

SITES OF ELEVATED NITRATE CONCENTRATION IN THE CENOZOIC PECOS ALLUVIVM AQUIFER

PROJECTED WATER DEMAND

Population

The regional population is generally sparse and depends heavily on the economic conditions in both agriculture and petroleum related industries. In 1985, the total population of the study area was 42,254, of which 76 percent resided in the Cities of Pecos, Monahans, Kermit, and Wink. Much of the remaining 24 percent resided in several smaller communities.

The City of Odessa, with a 1985 population of 101,165, is outside of the study area but obtains part of its water supply from a well field in Ward County. Odessa's population is more than double the entire population of the study area.

The total population of the study area is expected to increase by about 8.5 percent through the year 2010. The 1980 and 1985 population for cities and rural areas, along with projected estimates for the years 1990, 2000, and 2010, are shown in Table 3. Population projections for the study area were estimated by extending Bureau of Census statistics according to growth rates used in the 1988 Texas Water Development Board Revised Data Series population projection methodology.

Water Use

The total amount of water used in 1985 within the study area was about 131,000 acre-feet. This amount is a 45 percent reduction from the 1980 use and is a result of a substantial decrease in irrigation and mining operations. The following table lists the quantity of water by type of use for the year 1985, and Figure 17 shows the areas of greatest ground-water pumpage.

Use	1985 Ground Water (acre-feet)	1985 Surface Water (acre-feet)
Public Supply	15,616	0
Rural	1,928	332
Manufacturing	227	0
Power	6,520	0
Irrigation	85,374	12,909
Mining	5,123	0
Livestock	2,642	143
Total	117,430	13,384

Source: Texas Water Development Board 1988 Revised Data Series

Table 3
Current and Projected Population*

	1980	1985	1990	2000	2010
Loving County					
City of Mentone	25	26	30	34	37
Rural	66	35	67	79	90
Total	91	61	97	113	127
Pecos County					
Rural	216	227	237	246	274
Reeves County					
City of Pecos	12,855	13,220	13,373	14,753	16,609
Rural	3,615	3,445	3,279	3,382	3,409
Total	16,470	16,665	16,652	18,135	20,018
Ward County					
City of Monahans	8,397	9,219	9,610	10,108	10,425
Rural	4,914	5,282	5,867	6,630	6,830
Total	13,311	14,501	15,477	16,738	17,255
Winkler County					
City of Kermit	8,015	8,289	8,300	8,564	9,354
City of Wink	1,182	1,553	1,588	1,616	1,753
Rural	743	958	738	740	740
Total	9,940	10,800	10,626	10,920	11,847
County Total					
Cities	30,474	32,307	32,901	35,075	38,178
Rural	9,554	9,947	10,188	11,077	11,343
Total	40,028	42,254	43,089	46,152	49,521
City of Odessa	90,027	101,165	111,198	120,259	131,486

* 1980 and 1985 population is based on Bureau of Census statistics. 1990, 2000, and 2010 population is based on 1988 Texas Water Development Board Revised High Series population projection. Population estimates are for the entire counties of Loving, Reeves, Ward, and Winkler, and only the part of Pecos County that contains the Cenozoic Pecos Alluvium. The term "Rural" includes unincorporated areas and all rural population.

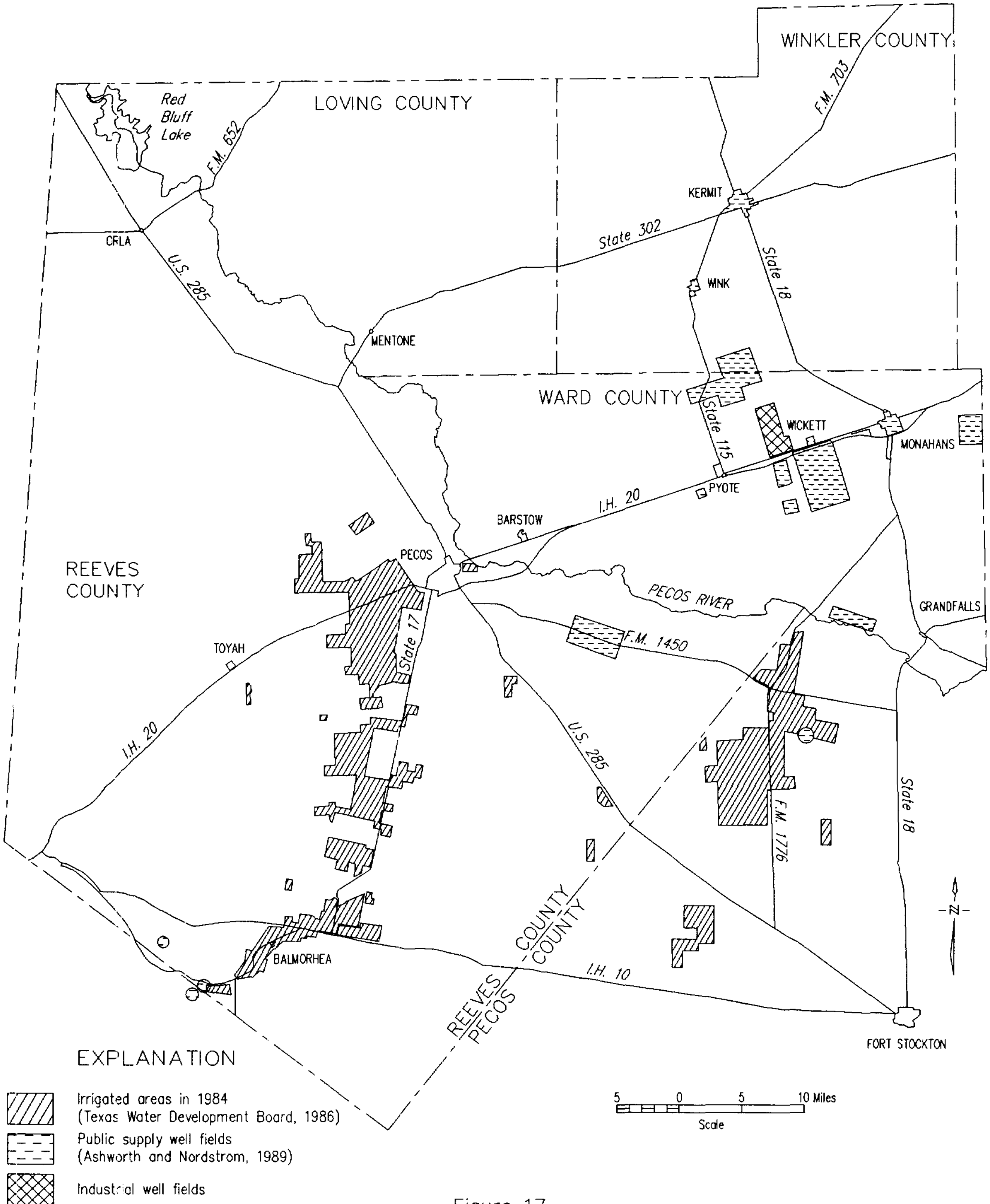


Figure 17

AREAS OF GREATEST GROUND-WATER PUMPAGE

1985 water use, as reported in this section, was compiled by the Texas Water Development Board and is documented in their 1988 Revised Data Series preliminary draft. Public supply and rural use is based on amounts reported by cities or other suppliers and apportioned by population where appropriate. Livestock use is based on the study area's rural geographical share apportioned to county total livestock use. All other use is based on site-specific computed use.

Public Supply

The municipal water needs of the various cities and smaller communities are exclusively supplied from ground-water sources except for the Communities of Balmorhea and Toyah in Reeves County which receive a portion of their water supply from surface lakes that are primarily spring fed. In 1985 8,775 acre-feet of ground water was supplied to communities within the study area and an additional 6,841 acre-feet was supplied to the City of Odessa outside the area by the Colorado River Municipal Water District (Texas Water Development Board, 1988). Public supply use represents approximately 14 percent of the total ground-water pumpage. The following table lists the major municipalities and the quantity of ground water pumped from the study area for each in 1985.

City	1985 Ground-Water Pumpage (acre-feet)
Kermit	2,816
Monahans	2,767
Odessa (C.R.M.W.D.)	6,841
Pecos	2,924

Source: Texas Water Development Board 1988 Revised Data Series

Rural

The rural population is quite sparse, mostly concentrated around small unincorporated communities, and in 1985 used 1,928 acre-feet of ground water and 332 acre-feet of surface water. Ground water for rural domestic use is pumped from private wells, or provided through small community systems such as at Wickett, or bought from a larger entity such as occurs at Barstow and Pyote. Surface water for rural domestic use occurs in the Balmorhea area of southern Reeves County. The Madera Valley Water Supply Corporation supplies both ground and surface water in Reeves County.

Manufacturing, Mining, and Power

Manufacturing, mining, and power represent the industrial use of water in the study area. In 1985 manufacturing use amounted to only 227 acre-feet of ground-water pumpage. Mining operations, which include sulfur mining in Reeves County, water-flooding in Ward and Winkler Counties, and sand and gravel washing in Ward County, used a total of 5,123 acre-feet of ground water in 1985, down from approximately 30,000 acre-feet in 1980. A substantial part of the ground water used in both the sulfur mining and water-flooding operations is derived from aquifers other than the Cenozoic Pecos Alluvium. The generation of electrical power by the Texas Utilities

Electric Company used 6,520 acre-feet of ground water pumped from their well field in Ward County in 1985.

Livestock

Water used for livestock in the study area in 1985 amounted to 2,785 acre-feet, 95 percent of which was ground water. Ninety percent of the total amount of water used for livestock was in Reeves County.

Irrigation

More water is used for irrigation, primarily in Pecos and Reeves Counties, than for any other purpose in the study area. Rapid development of irrigation farming in Reeves County began in the late 1940's, peaked in 1953 with 525,000 acre-feet of pumpage, and remained at a rate above 300,000 acre-feet of pumpage annually until the mid 1970's (Figure 9) (Ogilbee and others, 1962; and Texas Water Development Board, 1986). Since that time irrigation pumpage has decreased substantially due to agricultural economic downtrends and escalating energy cost. Approximately 11,000 acres in Reeves County are currently placed in the federally sponsored "Conservation Reserve Program", which provides a subsidy to land owners who take their land out of cultivation for at least 10 years.

In 1985 almost 100,000 acre-feet of water was used for irrigation which is 75 percent of all the water used in the study area. 87 percent of this amount was pumped from underground aquifers while the remaining 13 percent was surface water in the Balmorhea area and to a lessor extent, water released from Red Bluff Reservoir and taken out of the Pecos River downstream. The following table lists the 1985 irrigation water use by county.

County	Ground Water (acre-feet)	Surface Water (acre-feet)
Pecos (Coyanosa area only)	24,803	0
Reeves	58,521	12,909
Ward	1,250	0
Winkler	800	0

Source: Texas Water Development Board, 1988

Figure 18 shows the reported diversions from the Pecos River for irrigation use as supported by Red Bluff Reservoir releases from 1950 to 1987. The amounts include water required to fill deficits in river and canal flow plus amounts actually applied to fields.

Projected Water Demand, 1990-2010

The total annual water requirement for the study area, excluding the amount exported to the City of Odessa, is expected to increase by approximately 45 percent from 1985 to the year 2010 but should be less than the 1980 amount. Irrigation, the primary use of both ground and surface water, is expected to revive substantially from the 1985 use but probably will not exceed pre-1980 rates. Water used in mining operations, primarily in Reeves and Ward Counties, is also expected to increase through the year 2010. All other use of water, including public supply, is expected to remain about equal to the current rate or increase only slightly. Projected water demand by use category is listed in Table 4.

Officials with Texas Utilities Electric report that in the future an additional 11,800 acre-feet of water may be needed annually for the generation of power (R. L. Johnson and J. Cash, 1989, personal communication). Ground water supplied to the City of Odessa from the study area is expected to decrease after the completion of Stacy Reservoir (J.R. Lewis-CRMWD, 1989, personal communication).

Projections of future public supply and rural requirements are based upon 1988 Texas Water Development Board population projections and projected high per capita water use with conservation. All other water use projections are based upon Texas Water Development Board High Series (preliminary draft) projected demands and the apportioned share of total county demands. High series projections take into account the demands that are likely to occur during drought conditions.

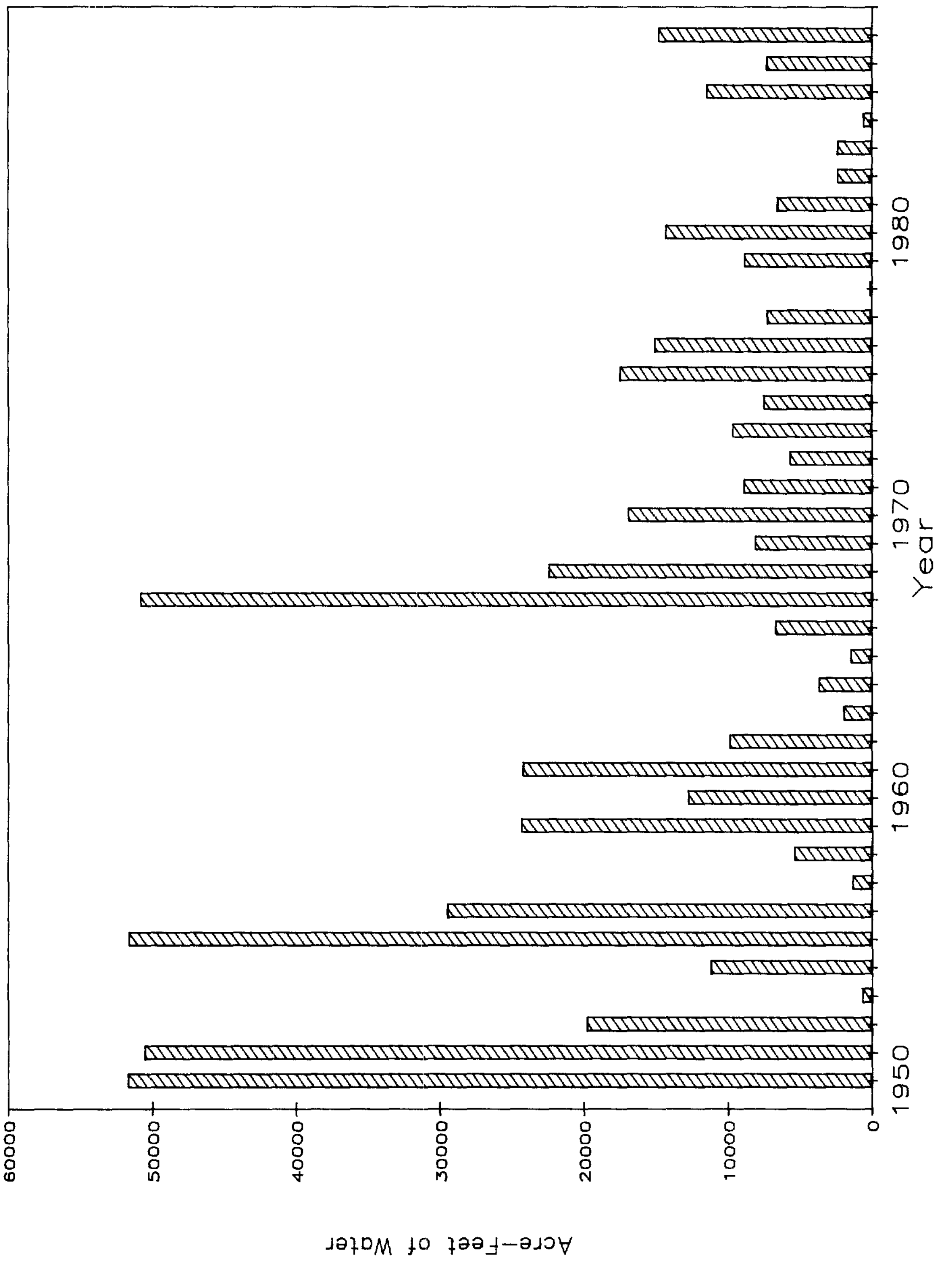


Figure 18

REPORTED DIVERSIONS FROM RED BLUFF RESERVOIR FOR IRRIGATION USE

Source: Texas Water Commission surface water diversion report

Table 4. Projected Total Water Demand by Use in the Study Area [1]
(Units in Acre-Feet)

County [2]	Year	Public Supply [3]	Rural [4]	Manufacturing	Power	Irrigation [5]	Mining	Livestock	Total
Loving	1990	5	11	0	0	0	0	81	97
	2000	5	12	0	0	0	0	94	111
	2010	6	13	0	0	0	0	94	113
Pecos	1990	0	33	0	0	40,036	21	113	40,203
	2000	0	32	0	0	40,036	21	130	40,219
	2010	0	34	0	0	40,036	25	130	40,225
Reeves	1990	3,885	787	112	0	81,828	8,023	2,324	96,959
	2000	4,066	766	143	0	81,828	8,340	2,694	97,837
	2010	4,330	728	175	0	81,340	9,722	2,694	98,989
Ward	1990	3,737	1,179	101	6,500	1,515	14,093	121	27,246
	2000	3,728	1,264	137	7,000	1,515	17,376	141	31,161
	2010	3,637	1,232	179	7,000	1,506	19,500	141	33,195
Winkler	1990	3,076	174	56	0	1,000	2,309	159	6,774
	2000	3,007	165	80	0	1,000	3,620	185	8,057
	2010	3,104	157	107	0	1,000	2,509	185	7,062
Total by use	1990	10,703	2,184	269	6,500	124,379	24,446	2,798	171,279
	2000	10,806	2,239	360	7,000	124,379	29,357	3,244	177,385
	2010	11,077	2,164	461	7,000	123,882	31,756	3,244	179,584

1 Projected water demand is based on Texas Water Development Board High Series (Preliminary Draft) projected demands, dated September 1988.

2 Water demand estimates are for the entire area of each county except Pecos which includes only the northwestern part shown in Figure 1.

3 Public Supply includes projected demands for the Cities of Kermit, Mentone, Monahans, Pecos and Wink and does not include the City of Odessa. Projected demands for the City of Odessa which include sources from outside of the study area are 25,989; 26,725; and 27,579 acre-feet for the three projection periods.

4 Rural includes smaller towns and all rural population use. Domestic surface water use in the Balmorhea area is also included.

5 Irrigation includes a substantial amount of surface-water use derived primarily from Balmorhea Springs Pool and release from Red Bluff Reservoir on the Pecos River.

AVAILABILITY OF WATER

Current Availability of Ground Water

The amount of fresh to moderately saline ground water available on a perennial basis from the Cenozoic Pecos Alluvium aquifer within the study area is approximately 67,800 acre-feet, which is the approximate average annual effective recharge to the aquifer. The method used to compute this quantity was discussed previously. Theoretically, this quantity can be developed without reducing the quantity of ground water in storage, although it should be recognized that a single well, or well field, cannot recover the total sustainable annual yield of the aquifer. Annual withdrawal by pumpage (117,430 acre-feet in 1985) exceeds this available quantity, thus resulting in areas of water-level decline as shown in Figure 14.

Ground water in transient storage in the Cenozoic Pecos Alluvium aquifer within the study area is approximately 98 million acre-feet, 60 percent of which is in the Pecos Trough. This estimate is based on an average specific yield of 0.25 of the permeable material which occupies 55 percent of the Monument Draw Trough and 40 percent of the Pecos Trough as determined by Guyton and Associates (1958) and applied to the saturated thickness map shown in Figure 8. Muller and Price (1979) used a specific yield factor of 0.15 for the total saturated thickness in their evaluation of the ground-water availability.

The amount of "usable-quality" ground water in storage is considerably less than the 98 million acre-feet in total storage due to the variance in chemical quality both laterally and vertically throughout the aquifer. Usable quality water is defined differently within the study area and is based on its most extensive use. Water in Ward and Winkler Counties is used primarily for public supply and industrial purposes which generally require fresh quality (less than 1,000 mg/l dissolved solids). In Reeves and northwest Pecos Counties irrigation is of primary concern and water containing dissolved solids from 3,000 to 5,000 mg/l is considered usable depending on the condition of the soil.

Based on the above criteria, Muller and Price (1979) state that in the areas that are suitable for ground-water withdrawal, more than 30 million acre-feet of fresh to slightly saline ground water is estimated to be in storage in the Cenozoic Pecos Alluvium aquifer. Of this amount, they suggest that only 9.48 million acre-feet (3.68 million in Pecos and Reeves Counties and 5.80 million in Ward and Winkler Counties) can be withdrawn by wells if significant ground-water quality degradation is to be avoided.

Potential for Conjunctive Use of Ground and Surface Water

Two sources of surface water occur in the study area, the Pecos River which traverses from northwest to southeast through the center of the region, and substantial spring flow in the Balmorhea area of southern Reeves County. Both sources are presently being used to near their full capacity for irrigation and recreation, and, in addition, the springs are also used for public supply. The completion of Stacy Reservoir will provide an additional water supply for the cities of Midland and Odessa, thus relieving some future reliance on ground water derived from the study area.

Four irrigation projects were organized between 1888 and 1906 (U.S. Natural Resources Planning Board, 1942) to divert water from the Pecos River for irrigation of lowlands bordering the river. Some 28,000 acres of land can be irrigated from the river (Ogilbee and others, 1961); however, the number of acres irrigated varies from year to year, depending on the quantity and quality of water in Red Bluff Reservoir. In 1984, no water was reported diverted for irrigation use. A United States Supreme Court mandated increase of river flow out of New Mexico has once again revitalized interest in diverting river water for irrigation. Over 10,000 acres in Pecos, Reeves, and Ward Counties are expected to be irrigated in 1989 by water diverted from the Pecos River. Water from the river is generally not of acceptable quality for purposes other than irrigation, livestock, and recreation.

Springs in southern Reeves and northwestern Jeff Davis Counties have provided a source of water for irrigation dating back to the time of Indian occupation and, later (mid 1880's), settlement by white men (Brune, 1975). Major springs, including Phantom Lake, Saragosa, Sandia, Giffen, and San Solomon, are still used for irrigation, recreation (Balmorhea State Park), and public supply (Cities of Balmorhea and Toyah).

Potential for Additional Ground-Water Development

Additional ground-water development from the Cenozoic Pecos Alluvium in the study area is limited by quality and economic restrictions. Because effective recharge is minimal, additional fresh water (less than 1,000 mg/l) development should be located in areas with significant saturated thickness that are not presently under full development. Such areas primarily occur in the central part of Winkler County, limited areas in the northeast part of Ward County, and, to a lesser extent, in the eastern part of Reeves and the northwestern part of Pecos Counties.

Slightly saline ground water (1,000 to 3,000 mg/l) is available for additional development in much larger quantities. Water of this quality is being used extensively for irrigation and livestock, and some could be used, with proper conditioning or mixing, for additional public supply use. Slightly saline ground water in the Cenozoic Pecos Alluvium occurs adjacent to and, in most cases, underlying fresh ground water throughout the study area (Figure 10). The high cost of energy to raise this water to the surface presently restricts the unlimited use of all water in this category.

Full development of ground water in the underlying aquifers (Figure 4) has only occurred in localized areas. Significant quantities of slightly to very saline ground water are elsewhere available from these aquifers for appropriate uses. Extensive development of the aquifers in some areas is not anticipated because of the great depth required to be drilled to complete wells in these formations.

Potential Methods of Increasing Aquifer Recharge

Recharge is the process by which water is absorbed and added to the zone of saturation and can occur both naturally and artificially. As described earlier, natural recharge to the aquifer primarily occurs as water, derived from precipitation, percolates downward from the surface. Any activity by man, either intentional or unintentional, that increases or supplements the rate of replenishment to the aquifer, is called artificial recharge.

Precipitation falling in the study area and stormwater runoff from mountains to the west and south generally penetrate into the ground rapidly due to the relatively flat surface and highly permeable soils. Even high intensity storms rarely produce enough flood drainage to reach the Pecos River. Much of this potential recharge water, however, is lost due to evapotranspiration.

The high ratio of evaporation to precipitation generally results in the loss of water that is retained in the upper few inches of soil. In addition, much water in the upper few feet of the surface is transpired to the atmosphere through the emission of water vapor by plants. Little can be done about the loss due to evaporation but, by controlling woody plants (mostly mesquite and saltcedar) on both rangeland and drainageways, a significant amount of water can remain available to percolate on down to the water table.

Another method of producing additional recharge to the aquifer involves recycling water in the form of treated sewage effluent from the various municipal water systems. Treated effluent can be returned to the aquifer by way of spreading basins or recharge wells. Both procedures should be successful due to the permeable nature of the formation in the study area. The City of Monahans presently irrigates City parks, a golf course, and some pasture land with an average of 750 thousand gallons of treated wastewater daily. This task not only may result in recharge but also serves as a conservation measure of their fresh water (Wesley Barnes, 1989, personal communication).

Projected Availability Through the Year 2010

The amount of ground water needed to supply projected demands through the year 2010 is in excess of the estimated annual effective recharge to the aquifer. Therefore, although much of the water pumped in the study area will be replaced by recharge, a portion will continue to be drawn from storage within the aquifer. Based on the storage depletion rate shown in the following table, by the year 2010 approximately 13 percent of the usable-quality ground water held in storage in the aquifer will have been used with approximately 7.3 million acre-feet remaining.

Year	Ground -Water Demand [1]	Average Annual Effective Recharge	Storage [2] Depletion	Water Remaining in the Aquifer
1985	117,400	67,800	49,600	9,480,000
1990	154,200	67,800	86,400	9,140,000
2000	159,600	67,800	91,800	8,249,000
2010	161,600	67,800	93,800	7,321,000

Water quantity in acre-feet.

1/ 1990 through 2010 amounts reflect approximately 90 percent of total water demand shown on Table 4.

2/ Pumpage minus recharge.

According to the above projections, there should be an adequate supply of ground water from the Cenozoic Pecos Alluvium aquifer for both public supply and industrial use through the year 2010. An adequate quantity of ground water for irrigation use should also be available through the year 2010 although heavy pumpage in a concentrated area, especially during drought periods, will probably result in significant water-level declines. Although there appears to be a reasonable quantity of ground water available for the area through the year 2010, the continued deterioration of the chemical quality could limit the usefulness of some of this water.

SUMMARY

The Cenozoic Pecos Alluvium aquifer is geographically divisible both hydrologically and by economic use. The Pecos and Monument Draw Troughs form two recognizably separate ground-water systems in which recharge, discharge, and chemical quality conditions in each have little if any effect on the other. Ground water in Loving and Reeves Counties of the Pecos Trough is primarily used for irrigation and livestock, while the Monument Draw Trough ground-water use in Ward and Winkler Counties is mostly for public supply and industrial purposes and for irrigation in the Coyanosa area of northwest Pecos County.

Current and projected water demands are in excess of the estimated annual recharge rate of 67,800 acre-feet. By the year 2010, approximately 13 percent of the usable-quality water currently held in storage in the aquifer is projected to have been withdrawn, with approximately 7.3 million acre-feet remaining. This quantity should be adequate to meet projected needs through the year 2010, although continued deterioration of the chemical quality could limit the use of some of this water.

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