Evaluation of Ground-Water Resources In Parts of Midland, Reagan, and Upton Counties, Texas

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ABSTRACT

The evaluation of ground-water conditions in parts of Midland, Reagan, and Upton Counties 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 theState that are experiencing, or expected to experience within the next 20 years, critical underground water problems. The study area is located on the northern edge of the Edwards Plateau in west-central Texas and 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 Edwards-Trinity (Plateau) aquifer which occurs in the Edwards Limestone and Antlers Sand formations of Lower Cretaceous age and, where hydrologically connected, in sandy units of the Dockum Group of Triassic age. Average recharge to the Edwards-Trinity (Plateau) aquifer is calculated to be 30,000 acre-feet per year and is derived principally from precipitation that falls within the study area. Water-level declines of over 100 feet have occurred in southern Glasscock and northern Reagan Counties since irrigation development was initiated in the late 1940's; however, water levels have changed very little over the past five years.

The chemical quality of the ground water over most of the study area does not meet Federal drinking water standards, although the water supplied to the cities of Big Lake and Rankin is acceptable. The quality of water is generally acceptable for irrigation use, but special management practices are needed to grow salt-tolerant crops in some areas. Dissolved solids generally range between 1,000 and 10,000 milligrams per liter, and calcium- and sodium-sulfate are the predominate hydrochemical facies, although, high concentrations of chloride also occur locally.

In 1985, the total pumpage of ground water within the study area was about 43,628 acre-feet, of which 96 percent was used for agriculture irrigation. This amount is projected to increase slightly by the year 2010. The average annual effective recharge to the aquifer is less than the present and projected water demand; therefore, with the projected level of pumpage, water in the aquifer will be drawn from storage. By the year 2010, approximately seven percent of the water held in storage in the aquifer will have been used, with approximately 7,004,000 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 Midland, Reagan, and Upton Counties was conducted to address the problems of overdraft and contamination with respect to the Edwards-Trinity (Plateau) aquifer, which is the primary aquifer in the area.

Location and Extent

The study area is located in parts of Midland, Reagan, and Upton Counties on the northern part of the Edwards Plateau in west-central Texas (Figure 1). Midland, most of Reagan, and the northeast half of Upton County lie within the Colorado River basin, while southwestern Upton County and extreme southwestern Reagan County are in the Rio Grande basin. Cities in the area include Big Lake in Reagan County and Rankin in Upton County. The study area generally falls within the boundary of an "underground water reservoir" delineated by the Texas Water Rights Commission in 1969. Major emphasis in the report is placed on southeast Midland County, northwest Reagan County, and northeast Upton County, a rural agricultural area. In order to more completely describe the aquifer, several of the maps in the report extend into Glasscock County; however, current and projected water use is reported only for the area of primary concern designated in Figure 1. Glasscock County is included in an underground water conservation district.

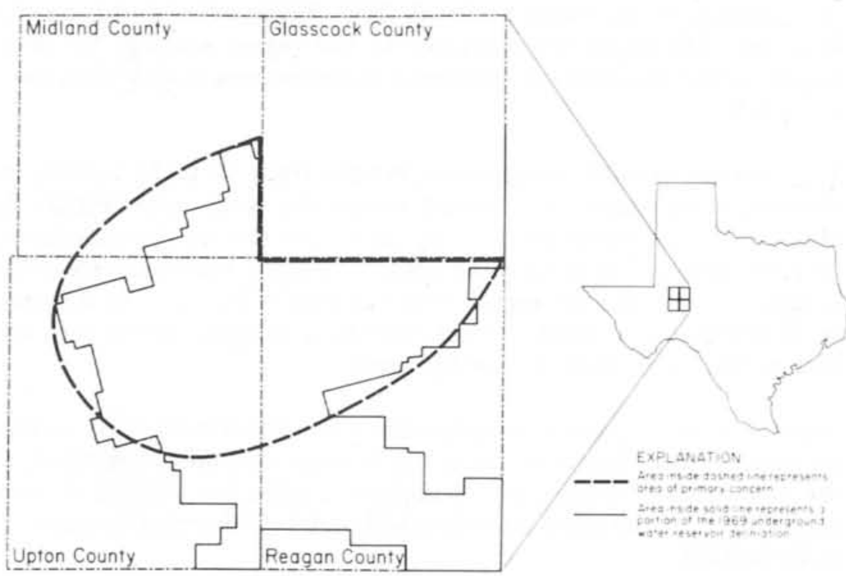


Figure 1
Location of Study Area

Geographic Setting

Topography and Drainage

The northern part of the study area is characterized topographically by a relatively broad, flat plateau. Further south, the plateau becomes more dissected, with wide valleys separating flat-topped ridges and mesas in many places.

The northern plateau area is underlain by limestone strata and covered by a veneer of caliche and silty clay loam. Numerous small depressions and isolated ephemeral streams occur on the surface. Southern uplands in the study area are underlain by resistive limestone beds that are capped by calichefied soils ,while the valleys between the ridges contain clayey alkaline soil.

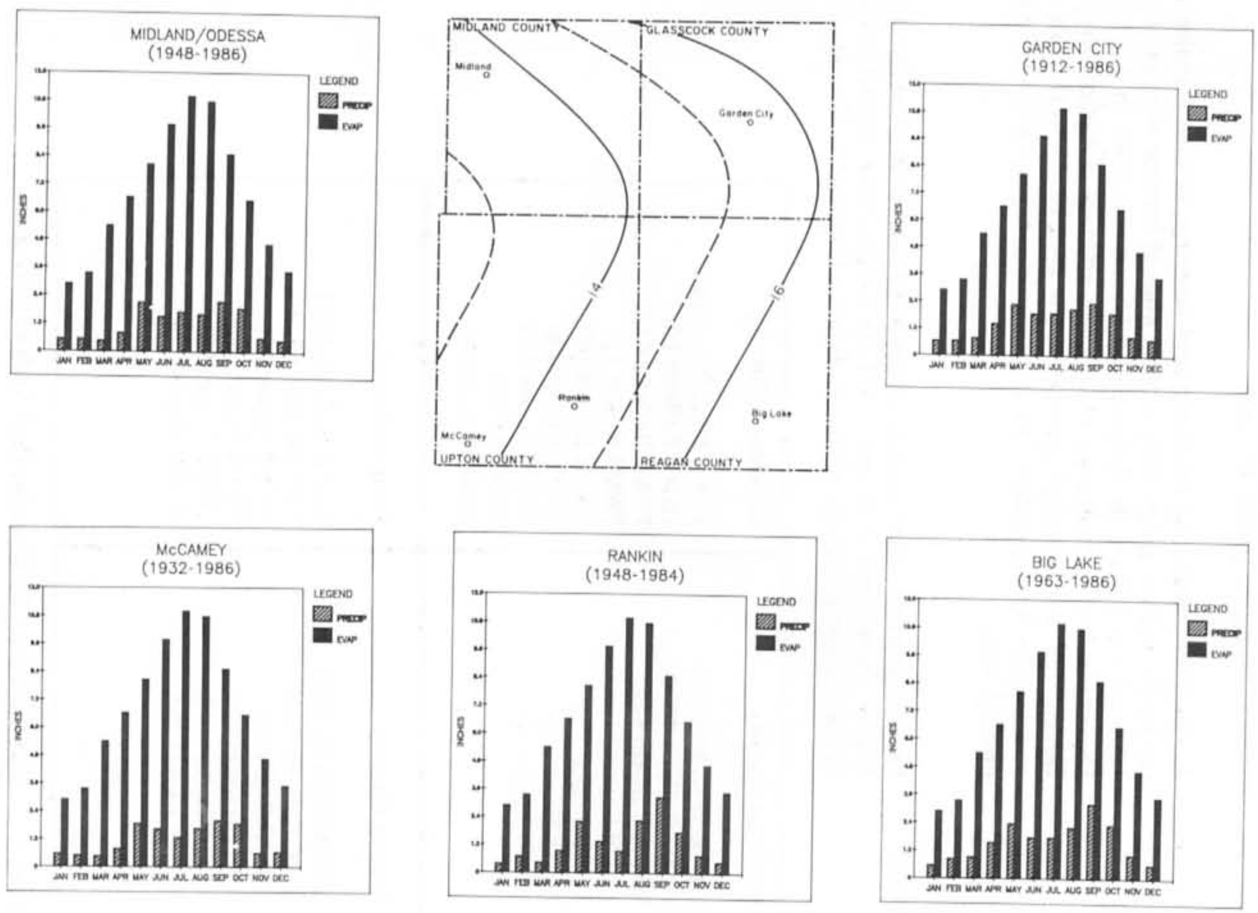
Interior drainage patterns are common in many parts of the study area. Precipitation that does not sink immediately into the ground or evaporate back into the atmosphere collects mostly in the numerous surface depressions, or playas, that are common to the plateau area. During heavy rainfall, runoff drains mostly northeastward through Johnson Draw and eastward through Lacy Creek in the northern part, and eastward through Centralia Draw in the central to southern area. Lacy Creek and Centralia Draw are tributaries to the North and Middle Concho Rivers, respectively. Drainage from the uplands in the southern extremity of the study area is to the south and southwest along Five Mile Creek and other tributaries of the Pecos River.

Climate

The semi-arid climate in the region, as recorded by the National Weather Service, is characterized by low rainfall, high rate of evaporation, and wide temperature ranges. Temperatures sometimes drop below freezing when cold fronts pass through the region during winter months, while rising to break 100° F periodically during the summer. Minimum temperatures in the region average 28° F in January, in comparison to maximum temperatures in July that average 95° F.

The average annual precipitation ranges from 13 to 16 inches, increasing in an eastward direction across the study area (Figure 2). Most of the precipitation in this area falls during thunderstorms between May and October when prevailing south-southeasterly winds bring moist air into the region from the Gulf of Mexico. As a result, large differences in rainfall occur over the area from year to year and within relatively small geographic areas.

Average annual gross lake evaporation is approximately 81 inches, an amount more than five times the average annual precipitation in the same region (Figure 2). Evaporation rates are highest in summer months at the same time that soil moisture demand by plants is at its highest.



EXPLANATION

—14—

Average Annual Precipitation (1951-1980) in inches

Isohyets adapted from Larkin and Bomar, 1983

Precipitation Graphs from National Weather Service Data

Figure 2
Average Annual Precipitation, and Average Monthly Precipitation vs. Gross Lake Evaporation for Period of Record at Selected Stations

Economy

The economy of the region is based primarily on the production of oil and gas, raising of cattle and sheep, and irrigated farm production, all of which are heavily dependent on ground water.

Oil was discovered in the Santa Rita Well No. 1 on University Land in Reagan County in 1923. Additional discoveries were made in Reagan and Upton Counties in 1925 which brought about a sharp increase in population. A second oil boom that began in the late 1940's and included development of the Spraberry Trend in Glasscock and Reagan Counties substantially revitalized the economy of the area. Total crude production as of January 1, 1987 for Glasscock, Reagan, and Upton Counties was 1.2 billion barrels (Railroad Commission of Texas, 1986). The industry suffered a major depression in 1982 as world oil prices dropped.

Agriculture, including ranching and farming, is also a major industry in the region, generating a total annual income of approximately 12.8 million dollars in Reagan and Upton Counties in 1985 (Texas Department of Agriculture and U.S. Department of Agriculture, 1985). Development of irrigated farming in the area began in the late 1940's and is heavily dependent on the quantity and quality of available ground water.

Previous and Current 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 (Figure 3). The most exten-

Midland County	**Glasscock County**
TBWE Misc. Pub. 187 TBWE Bulletin 5906 TBWE Bulletin 6107 TWDB Report 51 TDWR Report 235 TDWR Report 288 TDWR Report 294	TBWE Misc. Pub. 094 TBWE Bulletin 5903 TBWE Bulletin 6107 TWDB Report 51 TWDB Report 143 TDWR Report 235 TDWR Report 288 TDWR LP 203 TDWR Report 294
Upton County	**Reagan County**
TBWE Bulletin 5903 TWC Bulletin 6502 TWDB Report 51 TWDB Report 078 TDWR Report 235 TDWR Report 294	TBWE Bulletin 5903 TWC Bulletin 6502 TWDB Report 51 TWDB Report 145 TDWR Report 235 TDWR Report 294

Figure 3 **State Reports, by County, that Address Ground - Water Resources.**

TBWE: Texas Board of Water Engineers
TDWR: Texas Department of Water Resouces
TWC: Texas Water Commission
TWDB: Texas Water Development Board

sive investigation (Walker, 1979) made by the state included the four county area in a regional study of the entire Edwards-Trinity (Plateau) aquifer. In addition, a few local water-availability studies have been conducted by private consulting firms at the request of water-supply organizations. Publications containing information relating to the geology and hydrology of the aquifer in the study area are listed in the selected references at the end of this report.

Geologic mapping in the study area is best presented on the Big Spring, Hobbs, Pecos, and San Angelo Geologic Atlas Sheets published by the University of Texas, Bureau of Economic Geology . The base map for this report was adapted from these sheets. A number of publications by the Bureau describe both Cretaceous and Triassic sediments in the area.

The Texas Water Development Board has maintained a water-level and chemical quality monitoring network within the study area since the mid 1960's. The network consists of 102 water-level observation wells measured annually and 1,218 chemical analyses of water samples taken from 931 wells. Monitoring of the aquifer is also being done in nearby Glasscock County by the Glasscock County Underground Water Conservation District.

A regional investigation of the Edwards-Trinity (Plateau) aquifer was initiated by the U.S. Geological Survey in 1985 and is scheduled to be completed in 1991. The Edwards-Trinity "regional aquifer system analysis" (RASA) project is intended to define the hydrogeologic framework and to describe the geochemistry and ground-water flow of the aquifer system in order to provide a better understanding of its long-term water-yielding potential.

Acknowledgements

The authors wish to thank numerous individuals for their cooperation in providing information on the aquifer in their area. More specifically, appreciation is extended to city, county, and water supply district officials who furnished information concerning their municipal water-supply systems, and to the many property owners who allowed access to their wells to measure water levels and sample for chemical quality. Mr. Mark Hoelsher, previous manager of the Glasscock County Underground Water Conservation District, provided vital information pertaining to aquifer conditions within Glasscock County.

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 Edwards-Trinity (Plateau) 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 the ground water in the study area.

GEOHYDROLOGY

Geology as Related to Ground Water

Regional Structure

The most prominent geologic structures under the study area are the Central Basin Platform, a structural high in the southwestern corner of Upton County, and the Midland Basin, a structural depression underlying the rest of the study area. Both features are subdivisions of the more extensive Permian Basin (Figure 4). As shown in section X-X', the Triassic and Permian strata, which underlie Cretaceous strata, are relatively thin and flat-lying on the Central Basin Platform, thicken and dip sharply basinward along the flanks of the platform, and are thickest in the Midland Basin. In contrast, the Cretaceous strata dip gently toward the southeast and do not appreciably reflect the underlying platform-basin structure.

Local structural features include subsurface depressions apparently caused by solution of Permian evaporites and collapse of overlying sediments. These depressions were later filled with collapse debris and subsequent sediments. Similar solution features also occur in the Cretaceous limestone which often produce conduits to the surface through which water or other fluids can rapidly be conveyed into the Edwards-Trinity (Plateau) aquifer.

Stratigraphy

Geologic units in the study area that contain ground water range in age from Early Paleozoic to Quaternary. Permian and older aquifers produce very saline to brine quality water, while Triassic, Cretaceous, and more recent aquifers contain moderately saline to fresh water. Surface exposures of geologic units in the study area are illustrated in Figure 5, and the thickness, lithology, and water-bearing characteristics of these units are summarized in Table 1.

Paleozoic Era

Early and middle Paleozoic age formations in the study area are composed largely of shallow marine shelf carbonates that range from 3,000 to 6,000 feet thick. Late Paleozoic strata include marine carbonate and evaporite sequences of Permian age that measure over 8,000 feet thick in places. These strata accumulated in and around the Permian basin, a shallow structural depression that developed in West Texas during the Permian.

Triassic System

The Dockum Group unconformably overlies strata of Permian age and dips northwestward toward the center of the Midland Basin. Three subdivisions of the Dockum are identified within the study area. The lower unit consists of 100 to 200 feet of red shale and siltstone and is difficult to discern from the underlying Dewey Lake Redbeds.

A middle, sandy unit, commonly referred to as the Santa Rosa Sandstone, consists of brownish red to greenish gray, fine- to coarse-grained, micaceous sandstone interbedded with variegated shale and is the primary water-bearing zone in the Dockum. Downhole geophysical log

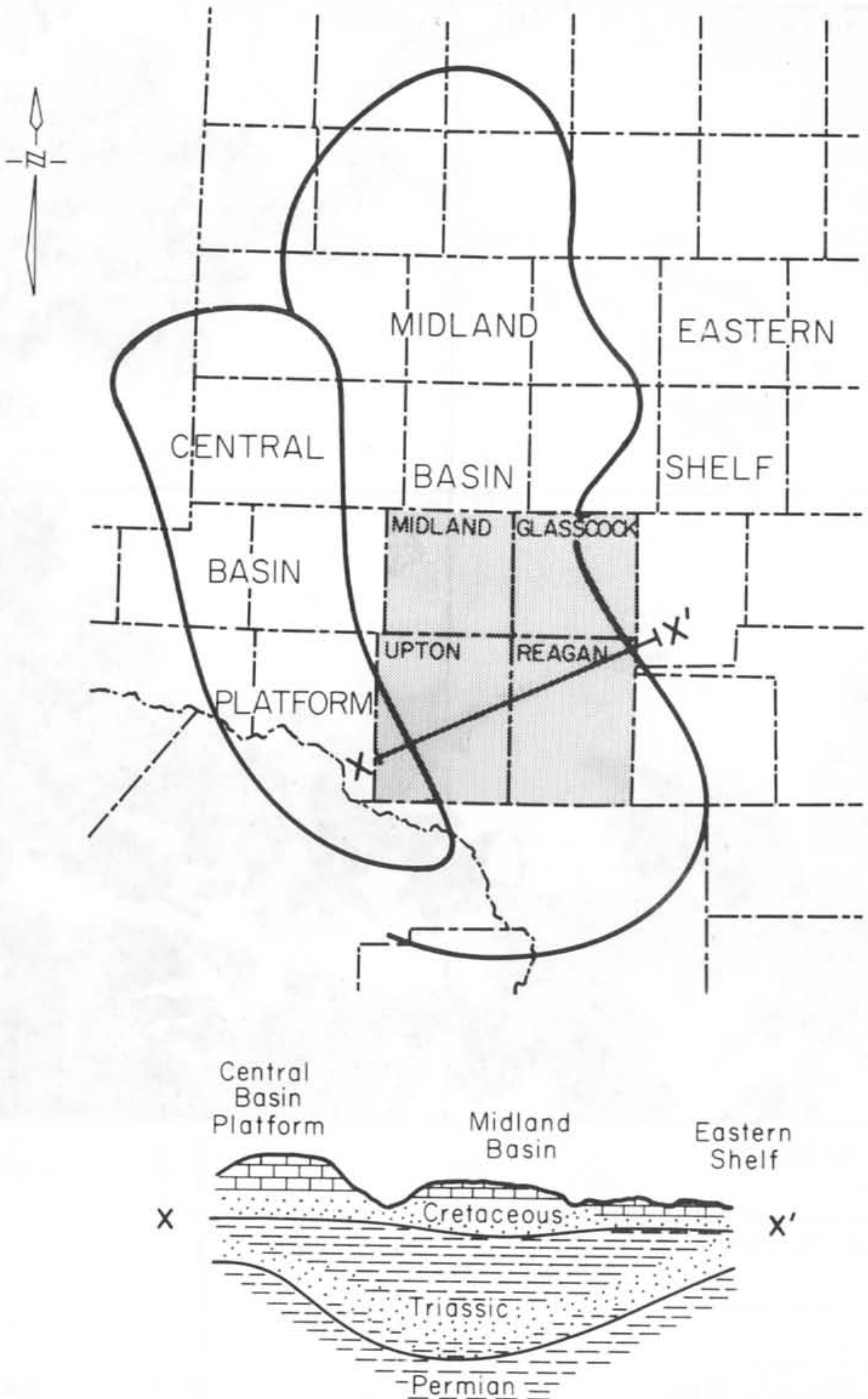


Figure 4
Regional Structure

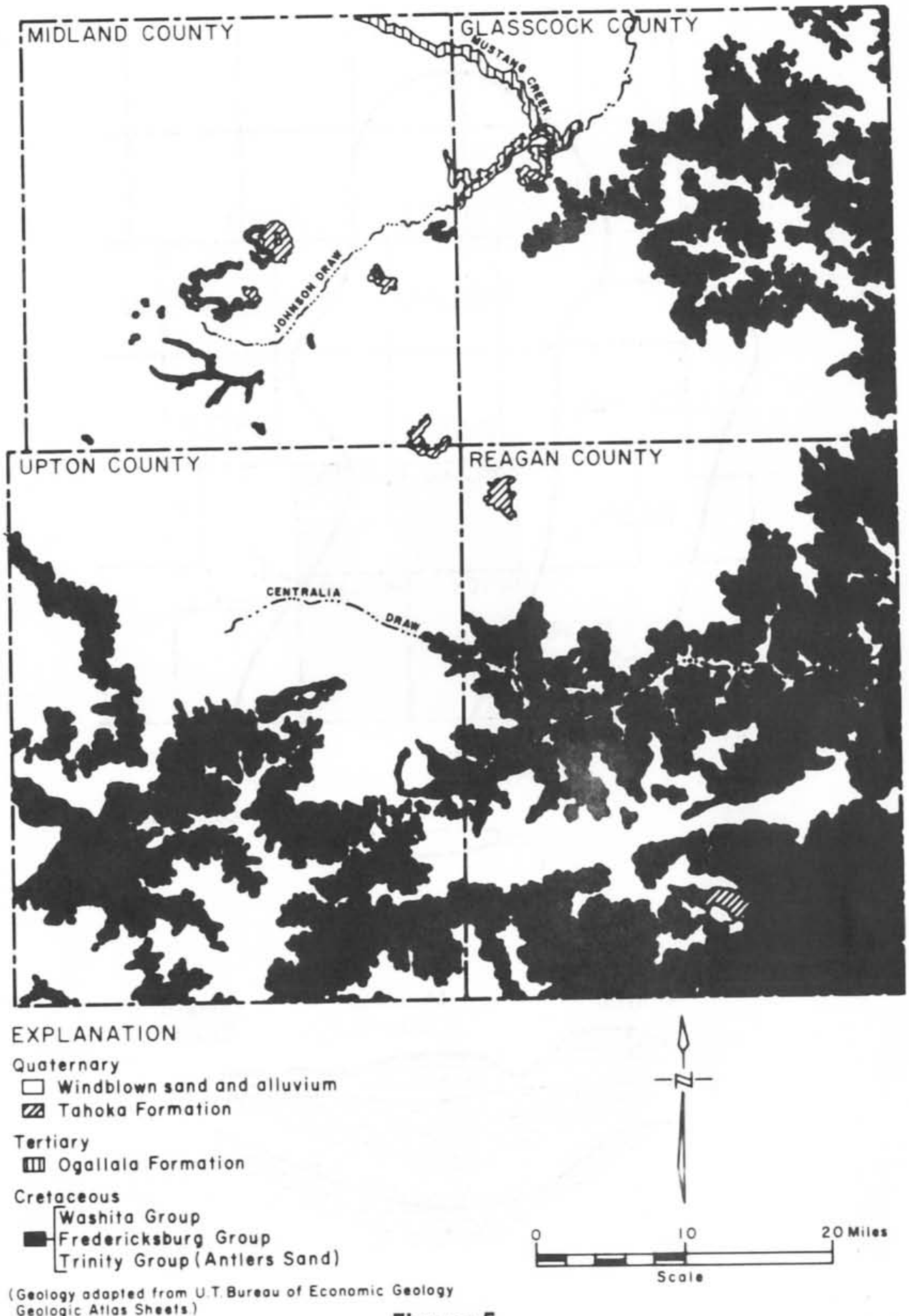


Figure 5
Generalized Geologic Map

Table 1. Geologic Units and Their Water-Bearing Characteristics

Era	System	Group	Stratigraphic Unit	Approximate Maximum Thickness	Character of Rocks	Water-Bearing Characteristics*
Cenozoic	Quaternary		Playa Deposits	--	Clay and silt.	Not known to yield water to wells.
			Windblown Cover Sand	20	Grayish red to brown sand.	
			Alluvium	200	Clay, sand, gravel and caliche in floodplain and terrace deposits.	Yields small amounts of water to domestic and stock wells in stream valleys.
			Tahoka Formation	40	Gray clay, silt and sand in lake deposits.	Contains small amounts of saline water.
	Tertiary		Ogallala	--	Tan, yellow, and reddish brown silty sand mixed with clay, gravel, and caliche layers.	The Ogallala aquifer does not occur in the study area, but fresh water may flow laterally from it into the Trinity Group.
Mesozoic	Cretaceous	Washita	Buda Limestone	80	Clay, marl, and limestone.	Yields small to moderate amounts of water to wells mostly in the southern part of Upton and Reagan Counties.
		Fredericksburg	Edwards Limestone: Segovia Formation Fort Terrett Formation	170	Gray to brown limestone and dolomite.	
		Trinity	Antlers Sand	225	Buff to gray sand and sandstone with red shale layers.	Primary aquifer throughout the area. Yields small to moderate amounts of fresh to moderately saline water to wells.
	Triassic	Dockum		1,200	Upper part: red, maroon and purple shale with red and gray siltsone and sandstone lenses. Middle part: brownish red to greenish gray sandstone and shale. Lower part: red shale and siltstone.	Upper part yields small amounts of slightly to moderately saline water to some wells. Middle part yields small to moderate amounts of fresh to slightly saline water to wells in eastern Reagan and southwestern Upton Counties, and moderate to very saline water to wells in the remainder of the area. Lower part not known to yield water to wells.
Paleozoic	Permian			14,000	Marine carbonates and evaporites.	Yields very saline to brine water as a byproduct from oil wells.

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

characteristics, large sandstone volumes, and high sand/mud ratios indicate that this unit is a prograding fan-delta deposit within the study area (Granata, 1981). The unit is thickest along the eastern flank of the Central Basin Platform in southwestern Upton County (Figure 6, section A-A'). Figure 7 shows the base of the sand unit, which indicates a dip both northeastward away from the Platform and northwestward toward the center of the Midland Basin.

The upper unit of the Dockum consists of red to maroon and purple shale and lenticular beds of fine-grained, red and gray sandstone and siltstone. This unit is often referred to as the "redbed" by water well drillers and is nonwater-bearing, except for thin sandstone lenses. The top of the unit has been subjected to erosion, resulting in an angular unconformity with the overlying strata.

Cretaceous System

Cretaceous sands, shales, and limestones were deposited on an eroded land surface by the last great epicontinental sea advance over the North American mid-continent. The stratigraphy of the Cretaceous in the study area consists only of the Comanche Series, which is divisible into the Trinity, Fredericksburg, and Washita Groups.

A basal sand unit, that unconformably overlies Triassic rocks, is termed the Antlers Sand of the Trinity Group and consists of buff to gray, fine- to medium-grained, cross-bedded, quartz sand and sandstone interbedded with lesser amounts of red, gray, and purple shale (Walker, 1979). In some places, a fine gravel may occur at the base. The base of the formation is often difficult to determine due to the reworking of Triassic and Permian age red shales by the Early Cretaceous seas. Laterally extensive red shale layers occur within the formation over much of the study area and appear to have some confining effect on ground water below the layers. Thickness of the Antlers Sand varies because of the uneven eroded surface on which the sand was deposited and ranges from less than 75 to more than 225 feet (Figure 8). The formation dips southeasterly at an average rate of about ten feet per mile (Figure 9). This unit is the primary water-producing zone in the study area.

The Antlers Sand is overlain by the Fort Terrett and Segovia Formations (Edwards Limestone) of the Fredericksburg Group. The Fort Terrett Formation consists of a light gray to yellowish brown, argillaceous, nodular limestone in the lower part, grading upward into a light to dark gray limestone and brownish gray dolomite. The overlying Segovia Formation consists of light gray, cherty limestone and brownish gray dolomite, the uppermost beds of which include one or more thick limestone units that form the flat resistive layer capping many of the hills. This formation underlies the windblown cover sand that occurs over most of the farming belt on the upland-plateau area.

The Washita Group, represented primarily by the Buda Limestone, occurs in the southern part of Reagan County where it overlies the Segovia Formation. The formation consists of thin-bedded, hard, sparry limestone at the top and microcrystalline limestone at the bottom, separated by yellow, fossiliferous, nodular marl. In the southwestern part of Upton County, the Washita Group has not been differentiated and consists of calcareous clay, marl, and thin- to massive-bedded limestone that caps the highest hills, such as King Mountain.

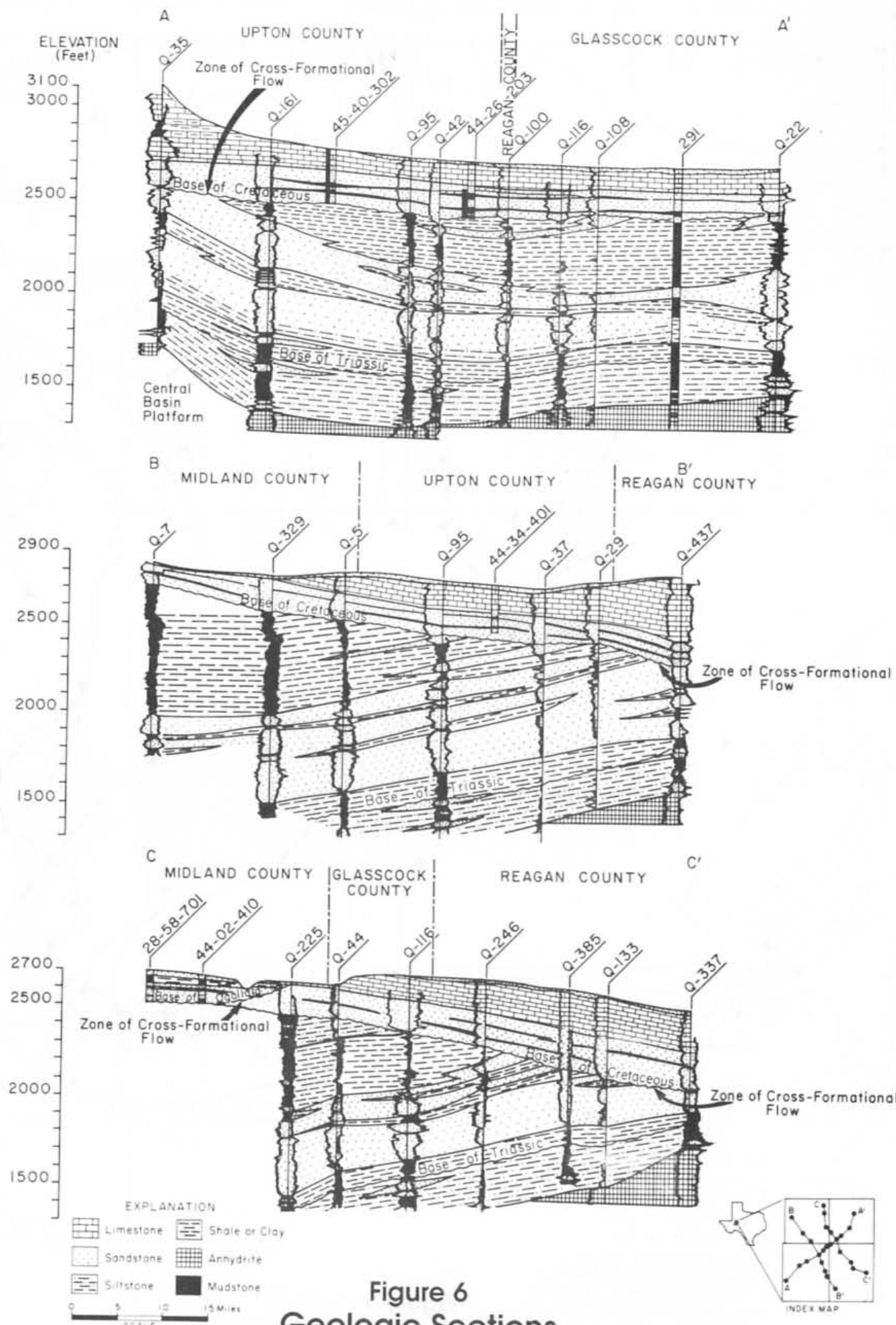


Figure 6
Geologic Sections

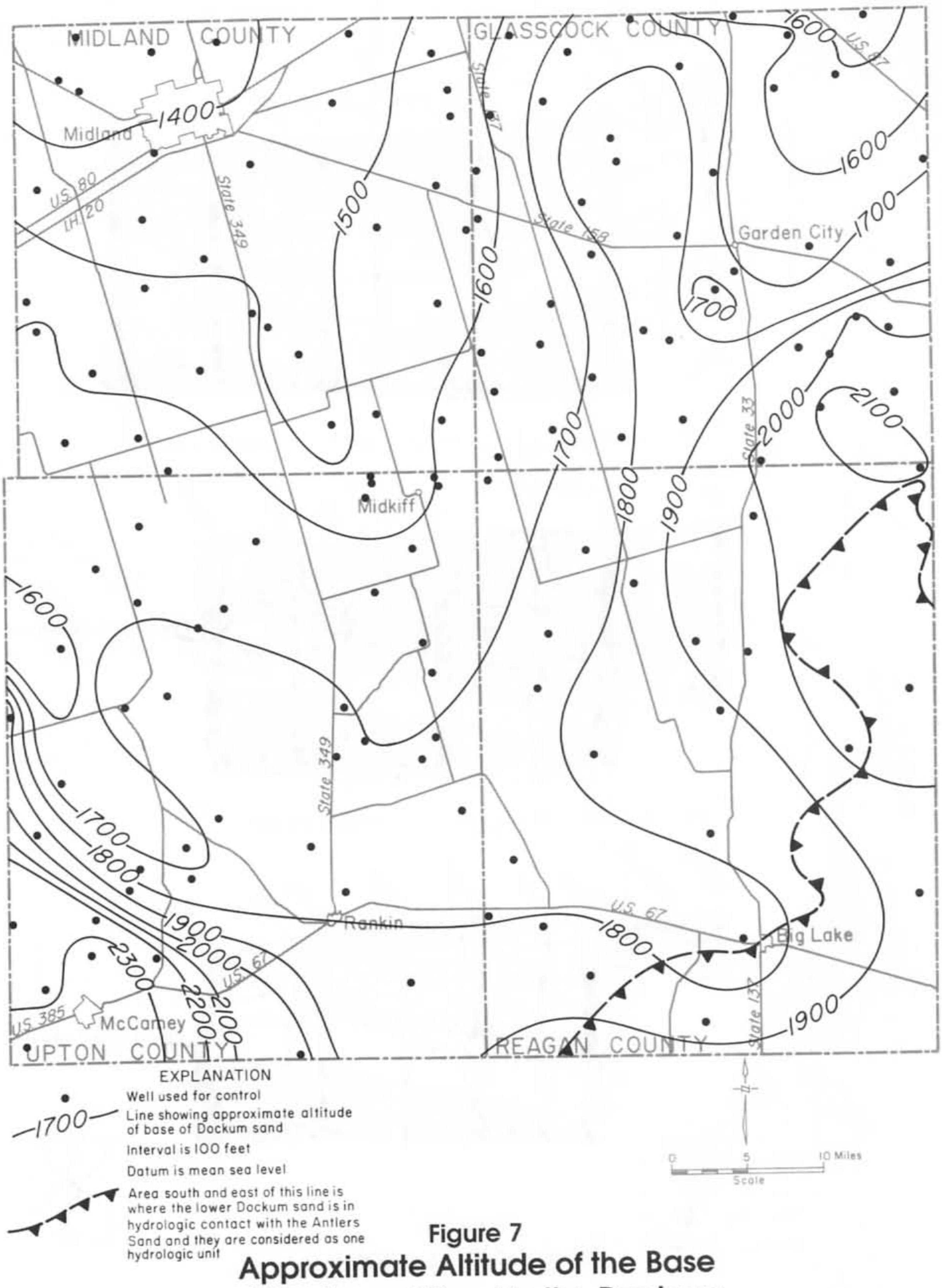


Figure 7

Approximate Altitude of the Base of the Lowest Sand in the Dockum

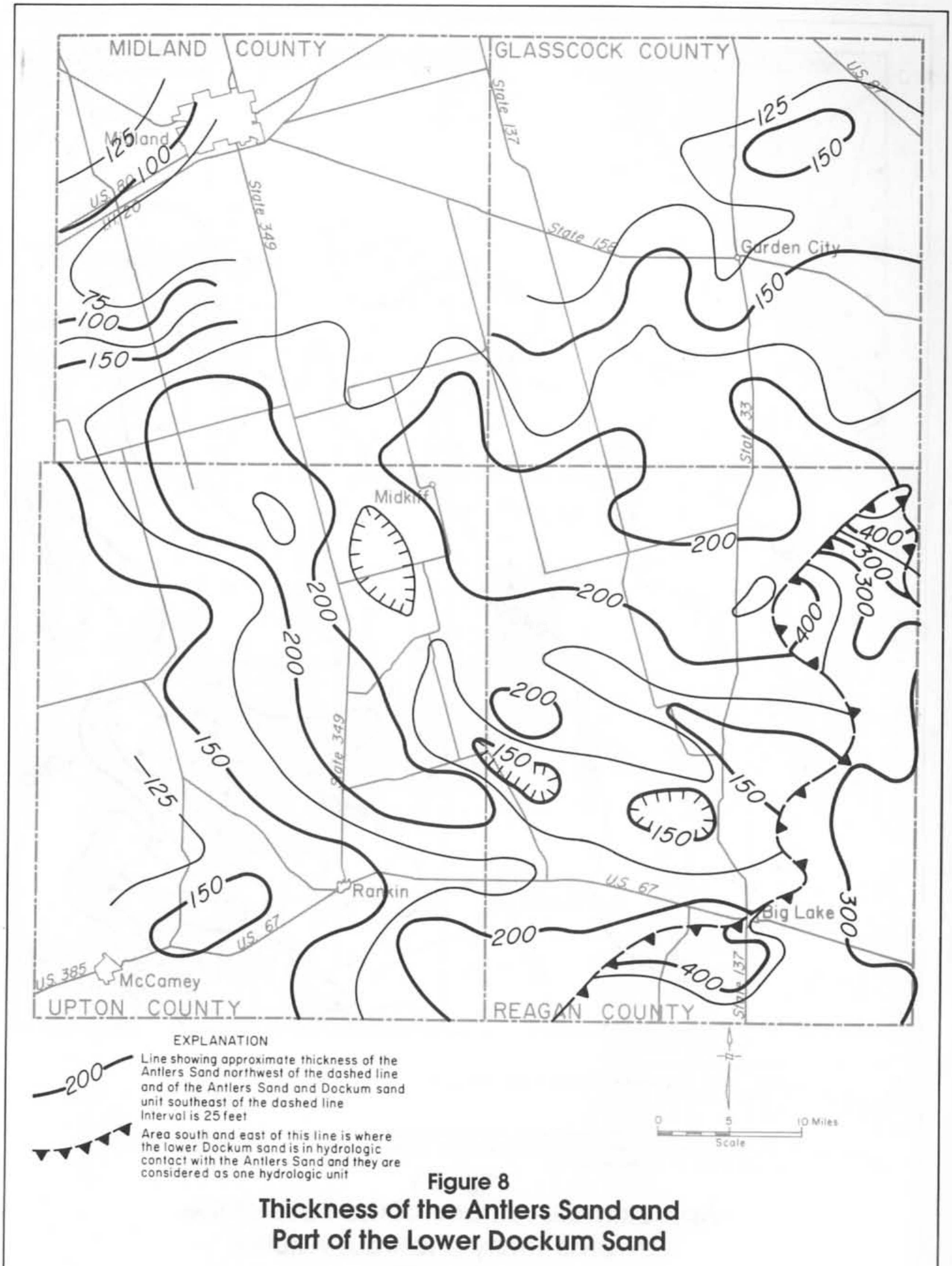


Figure 8
Thickness of the Antlers Sand and Part of the Lower Dockum Sand

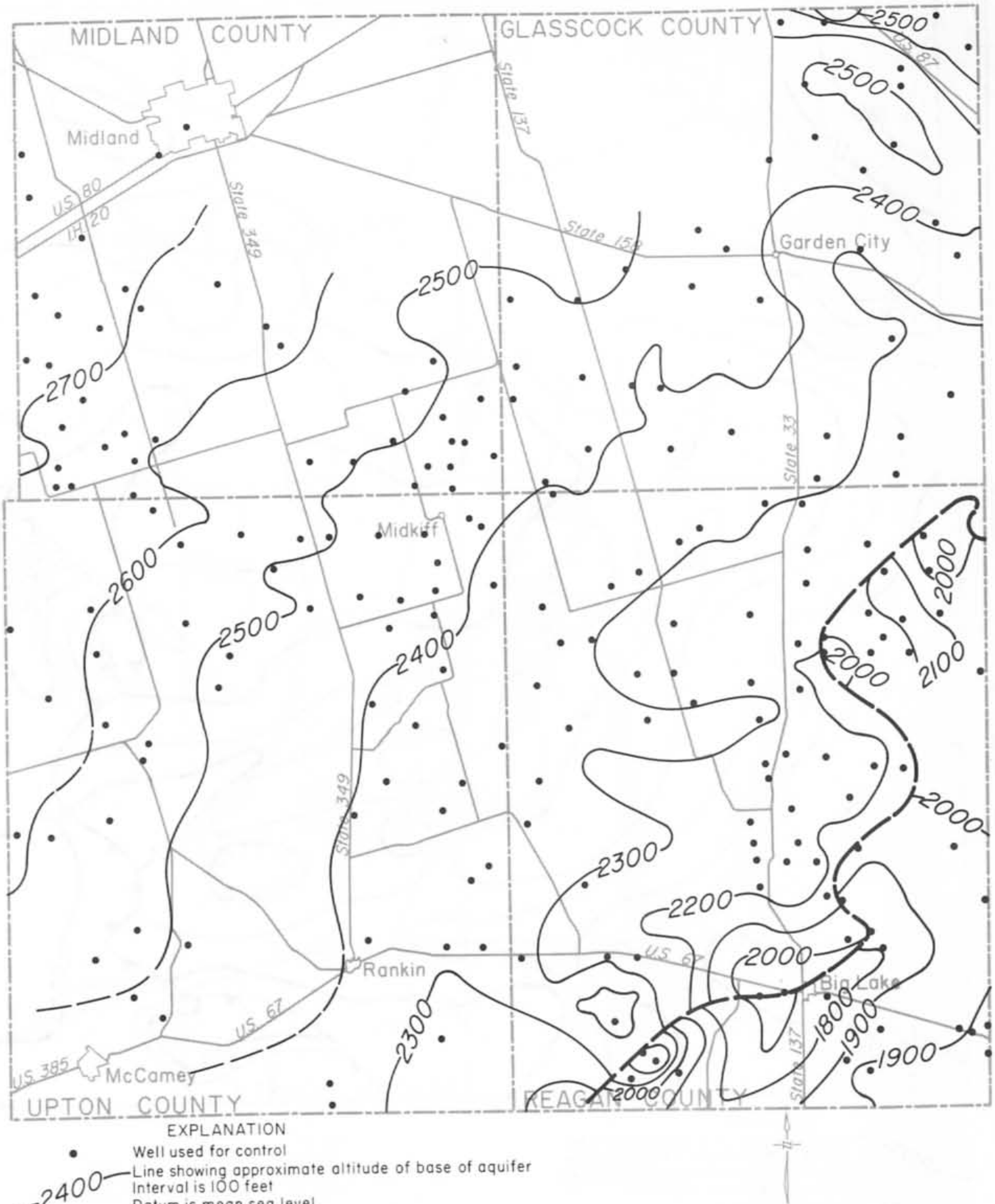


Figure 9

Approximate Altitude of the Base of the Edwards-Trinity (Plateau) Aquifer

(After Walker, 1979)

Tertiary System

The Ogallala Formation does not occur in the study area but is important in that it abuts Cretaceous sediments along the northern edge of the region, thus providing access for lateral flow between formations (Figure 6, section C-C'). Ogallala sediments crop out along Johnson and Mustang Draws in northern Glasscock and Midland Counties and elsewhere are overlain by windblown cover sand. The formation consists of fine- to medium-grained sand, silt, clay, and in places, gravel and caliche.

Quaternary System

The Tahoka Formation is a lacustrine, or lake, deposit consisting of light gray to bluish gray clay, silt, sand, and occasionally gravel that accumulated in shallow closed topographic depressions and ranges in thickness up to 40 feet. The formation is limited in extent, occurring primarily in the vicinity of Johnson Draw in Midland and Glasscock Counties, north and west of the town of Midkiff, and south of the city of Big Lake (Figure 5). Shallow ground water occurring in this formation is saline due to the highly evaporative nature of the closed basins.

Alluvium occurs as floodplain and low terrace deposits in stream valleys and consists of clay, sand, gravel, and caliche derived largely from eroded Cretaceous rocks. These deposits range in thickness from a few feet to about 200 feet and are in hydraulic contact with the underlying Cretaceous strata. Alluvial deposits yield small quantities of fresh to slightly saline water for livestock and rural domestic wells along stream courses, which occur primarily around the periphery of the study area.

Windblown cover sand up to 20 feet thick mantles the flat upland area and forms the soil in the farming district. These eolian deposits consist of grayish red to brown, fine- to medium-grained, calcareous quartz sand.

Playa deposits fill the numerous shallow depressions that exist throughout the four county region, but occur in greater density on the flat upland area. The deposits consist of clay and silt and create an almost impermeable layer below ponded water.

Source and Occurrence

The source of fresh ground water in the region is precipitation in the immediate area and in the areas mainly to the north and west. The direct infiltration of rainfall is minimal because most of the water is evaporated or transpired by plants. Water that escapes runoff, evaporation, and transpiration migrates downward by gravity until it reaches the zone of saturation or water table.

Ground water in the study area may occur at several different horizons or zones (Figure 10). Shallow water may accumulate in thicker sections of alluvium, primarily along stream channels and valleys. Developed mostly for stock wells, shallow ground-water zones are typically low yielding and susceptible to depletion during dry periods.

Sandy lenses, joints, fractures, and crevices in the Edwards Limestone also contain minor amounts of fresh ground water perched above the main water table in some places. Generally, the perched-water zones are relatively small and have very limited yields.

The primary zone from which water is pumped in the study area is the Trinity (Antlers Sand) which produces small to moderate quantities of fresh to moderately saline water for all purposes, mainly municipal supply and irrigation. That part of the Trinity, the overlying Edwards, and the underlying Dockum sand beds, where fresh water occurs as one hydrologically connected unit is referred to as the Edwards-Trinity (Plateau) aquifer.

The lower sand unit of the Dockum Group, often referred to as the Santa Rosa Sandstone, is an artesian aquifer in which the water is confined by overlying shale. Wells completed in this zone produce fresh to very saline water which has been used mostly for secondary recovery purposes by the petroleum industry. The best quality water in the unit occurs where the Dockum sand bed is in hydrologic contact with the Antlers Sand in the eastern part of Reagan County, and in the south-western corner of Upton County where the unit occurs at shallower depths (Figure 6). Thin sandstone and siltstone lenses higher in the Dockum may also contain a minor amount of water of variable quality.

Deeper Paleozoic formations below the Dockum produce very saline to brine quality water as a biproduct of oil production. These aquifers are probably under sufficient artesian pressure to cause the water to rise in a well to a height significantly close to the fresh-water zone.

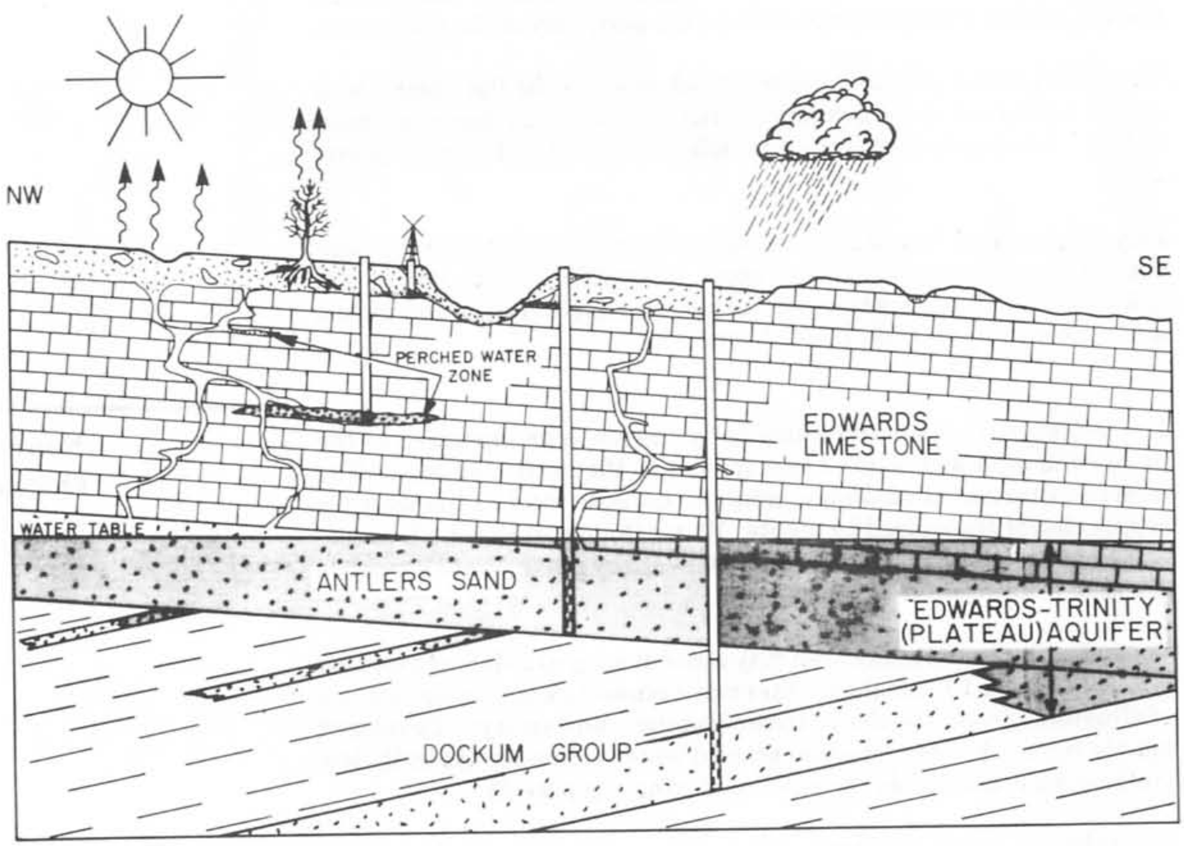


Figure 10
Occurrence of Ground Water

Recharge, Movement, and Discharge

The annual effective recharge to the Edward-Trinity (Plateau) aquifer in the study area is approximately 30,000 acre-feet. Total effective recharge for the Edwards-Trinity (Plateau) aquifer in the Colorado River basin was determined using historical springflow discharge into tributaries of the Colorado River and historical pumpage (Muller and Price, 1979). The amount of effective recharge for this study area equals that total multiplied by the percentage of the total basin that is in this study area. Practically all of the study area falls within the Colorado basin.

Regional recharge to the Edwards-Trinity (Plateau) aquifer is by the downward percolation of water occurring on the surface and, to a lesser extent, by local cross-formational flow. Water occurring on the surface is principally derived from precipitation, although some recharge may also result from irrigation return flow. Many irrigators in the area avoid over watering by using soil moisture blocks, a procedure where soil is wetted down only to the base of the root zone, leaving no excess water to percolate further downward to an underlying aquifer. Most of the water at the surface is lost to evapotranspiration. This procedure thus far has not resulted in excessive salt buildup in the soil.

The type of soil and its physical characteristics primarily determine the rate at which water initially percolates downward from the surface. Five of the predominant soil types within the study area, along with their ability to transmit water, are listed below (U.S. Soil Conservation Service, 1977):

Soil Series	Description and Occurrence	Permeability inches/hour
Angelo	Deep, loamy soils on uplands	0.60 - 2.00
Conger	Shallow, loamy soils on uplands	0.60 - 2.00
Lipan	Deep, clayey soils filling depressions	0.00< 0.06
Reagan	Deep, loamy soils on uplands	0.60 - 2.00
Rioconcho	Deep, clayey soils on bottomland	0.06 - 0.20

Lowest soil permeabilities occur in the Lipan and Rioconcho soils on which surface drainage is most likely to concentrate. Local farmers often cultivate these soils to enhance their permeability. This practice usually increases the recharge rate for relatively short periods after rainfall, but as the clay in the soil becomes wet, it swells and seals off downward percolation. Recharge is more likely to occur in the more permeable Angelo, Conger, and Reagan upland soils.

The greatest amount of recharge from precipitation probably occurs where the limestone bedrock is exposed, allowing water to percolate unhindered through highly permeable joints, crevices, and solution openings. An unknown amount of recharge also occurs when surface water, derived from either precipitation or irrigation, flows down man-made openings in the land surface such as abandoned wells and shot holes.

The hydrograph of well 44-19-505 (Figure 11) shows that the aquifer does undergo recharge, at least in the area of the well. During 1986 and 1987, the area received well above average rainfall and experienced minimal pumpage. The water level rose in the well during this period to a 15 -year high, well above the level expected during the non-pumping season.

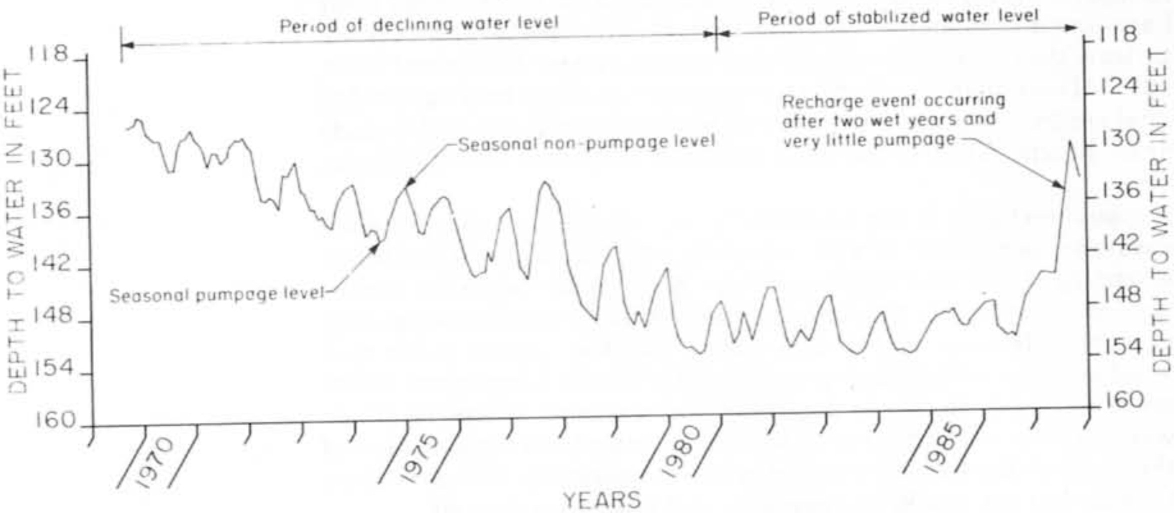


Figure 11
Hydrograph of Well 44-19-505 in Glasscock County

Cross-formational recharge occurs where reservoirs in the Ogallala Formation abut the northern part of the aquifer in Glasscock and Midland Counties (Figure 6, section C-C'). Direction of ground-water flow in the Ogallala Formation is toward the east and southeast.

Recharge to the Dockum Group occurs primarily in counties to the northeast where the sand units crop out at the surface, and to the west where it is in hydrologic contact with overlying alluvial formations.

Ground water moves in the direction of the hydraulic gradient from areas of recharge to areas of discharge. The movement is perpendicular to lines of equal elevation on the water-table, or piezometric, surface (Figure 12) and in the direction of decreasing elevation. The regional direction of the ground-water flow in the Edwards-Trinity (Plateau) aquifer is toward the southeast; however, heavy pumpage, resulting in extensive cones of depression, has partially altered the direction of movement toward these pumpage centers. The rate of movement of ground water is slow, only a few feet per year, depending upon the hydraulic gradient and permeability of the strata at any given location.

Regional studies of the Dockum aquifer in the southern High Plains (Dutton and Simpkins, 1986) indicate a general drainage toward the southeast. It is probable, however, that in much of Upton County the direction of movement may be easterly, away from the Central Basin Platform. Ground-water movement in the Dockum is slow, a few feet per year, due to low permeability.

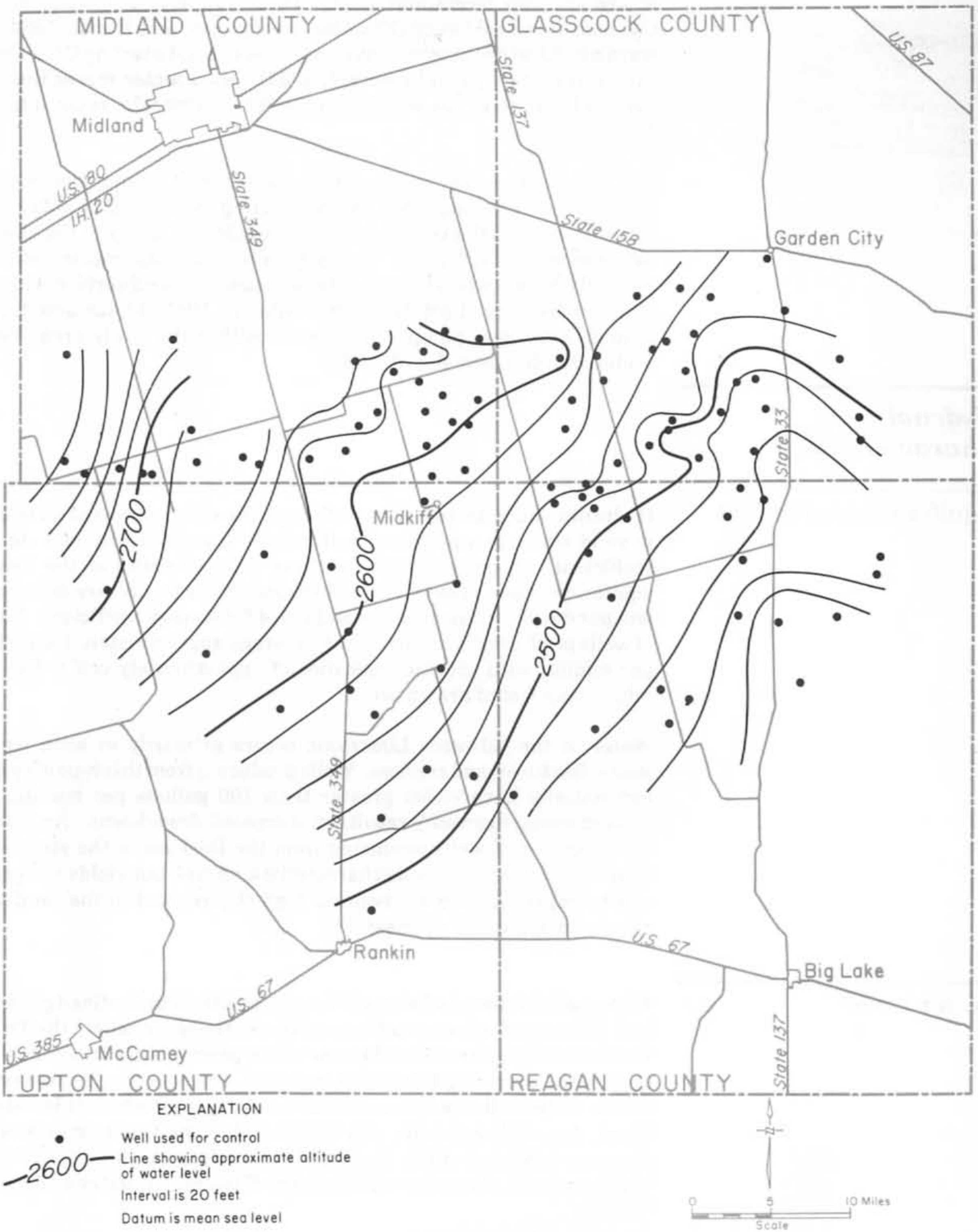


Figure 12
Approximate Altitude of Water Levels in the Edwards-Trinity (Plateau) Aquifer, 1987

Lateral movement of ground water from the Ogallala Formation to the Trinity Antlers Sand likely occurs along the northern edge of the region where the two formations abut. However, flow directions in the Ogallala trend eastward (Knowles, Nordstrom, and Klemt, 1984) toward a natural drainageway through Howard and Sterling Counties to the northeast (Frye and Leonard, 1964). More water moves through this pathway than the southeasterly, less permeable, route into the Trinity.

Natural discharge of ground water in the form of spring flow does not occur in the study area, but springs issuing from the Edwards Limestone do occur in the vicinity of Mertzon in Irion County to the east. A minor amount of natural discharge results from evapotranspiration in alluvial deposits when the water table is near the land surface. Ground water is discharged artificially by wells. In 1985, 43,628 acre-feet of ground water was pumped from wells within the study area (Texas Water Development Board, 1988).

Hydraulic Characteristics

Aquifer Characteristics

Hydraulic characteristics that influence the effectiveness of an aquifer to yield water to a pumping well include transmissivity and storage coefficient. Average values for these characteristics of the Trinity aquifer, as reported by Walker (1979) and White (1968), are 365 square feet per day for transmissivity and 0.074 for storage coefficient. Yields of wells producing from the Trinity average approximately 100 gallons per minute with specific capacities of approximately one gallon per minute per foot of drawdown.

Water in the Edwards Limestone occurs primarily in sand lenses, joints, fractures, and crevices. Wells producing from this type of system can initially have yields greater than 100 gallons per minute, but limited storage capacity results in increased drawdowns. An insufficient number of wells producing from the Dockum in the study area have been tested to provide characteristic values, but yields can generally be expected to be low because high clay content in the sandstone results in decreased permeability.

Water Level

Water in the Edwards-Trinity (Plateau) aquifer is unconfined generally and is thus under water- table conditions. However, where the Trinity Group is fully saturated and a zone of low permeability occurs near the base of the overlying Edwards Limestone, artesian conditions exist in which water will rise in a well above the depth at which it is encountered. Laterally extensive clay lenses within the Trinity may produce the same confining effect. In part of the study area, particularly to the south and east, the water table is in the Edwards Limestone, above the Trinity.

Figure 12 is a map showing the 1987 static water level in wells completed in the Edwards-Trinity (Plateau) aquifer. The water table dips regionally toward the southeast at approximately eight feet per mile. Local areas deviating from this pattern are the result of heavy pumpage, which has lowered the water table in relation to the surrounding area. The water table has dropped since the 1940's when irrigation development started and is discussed in more detail later in the report.

Water levels in the study area generally exhibit a seasonal fluctuation. Figure 11 shows that the water table drops several feet during that portion of the year when irrigation pumpage is at its maximum. Later in the year, when pumpage has ceased, the water table rebounds. Prior to 1980, this rebound level was generally lower than the corresponding level of the previous year. After 1980, the levels do not show this year-to-year decline. The hydrograph also shows a dramatic recharge event in 1987 following two years of above- average precipitation, along with very little pumpage in the vicinity of the well.

Water Quality

The natural quality of ground water in the Edwards-Trinity (Plateau) aquifer throughout the study area prior to industrial and agricultural development has not been well documented, but was probably similar to the quality of water that occurs presently in undeveloped parts of the same aquifer. Chemical analyses of water samples collected by Texas Water Development Board staff indicate that unaffected natural ground water in areas adjacent to the study area is typically hard to very hard (more than 120 milligrams per liter [mg/l] carbonate hardness) and has less than 1,000 mg/l dissolved solids. Ground water of this quality occurs in the northeastern part of Reagan County, in parts of western Upton County, and in much of Glasscock and Midland Counties (Figure 13).

Ground water throughout the central portion of the study area generally contains from 1,000 to over 10,000 mg/l dissolved solids (Figure 13) and probably has been altered to various degrees by human activity. Calcium-sulfate hydrochemical facies predominate in the aquifer in north-central parts of Upton County while calcium- and sodium-sulfate facies dominate in northwestern to central Reagan County and southern Upton County. Several parts of the aquifer have elevated concentrations of dissolved solids as shown in Figure 13.

The fluoride content of Edwards-Trinity water in the study area is commonly high. A majority of samples collected from wells in the area contained fluoride in concentrations between two and four mg/l, which may cause mottling of teeth. Nitrate levels in the same samples were generally well below the Federal Safe Drinking Water standard recommended limit of 44.3 mg/l. A few higher levels have been reported, but were due to temporary pollution problems. Hardness, expressed as calcium carbonate, exceeds 180 mg/l, which is the lower limit of water classified as very hard. Twelve wells within the irrigation area were sampled for the following metals: arsenic, barium, iron, manganese, and strontium. Of these, only iron in half of the samples was found to be above Federal Safe Drinking Water Act recommended limits, which is 0.3 mg/l for iron.

The quality of ground water for human consumption is always of primary concern. Ground water in most of the area in Figure 13 shown as slightly saline or worse (more than 1,000 mg/l dissolved solids) is undesirable or unusable as drinking water. Persons within this area should consider having their water tested periodically, especially if it is to be used as a drinking supply. High sodium -chloride and sulfate levels are easily detected by their salty taste and "rotten egg" odor, respectively.

In 1974 the Federal Safe Drinking Water Act was adopted and on December 10, 1975 the U. S. Environmental Protection Agency estab-

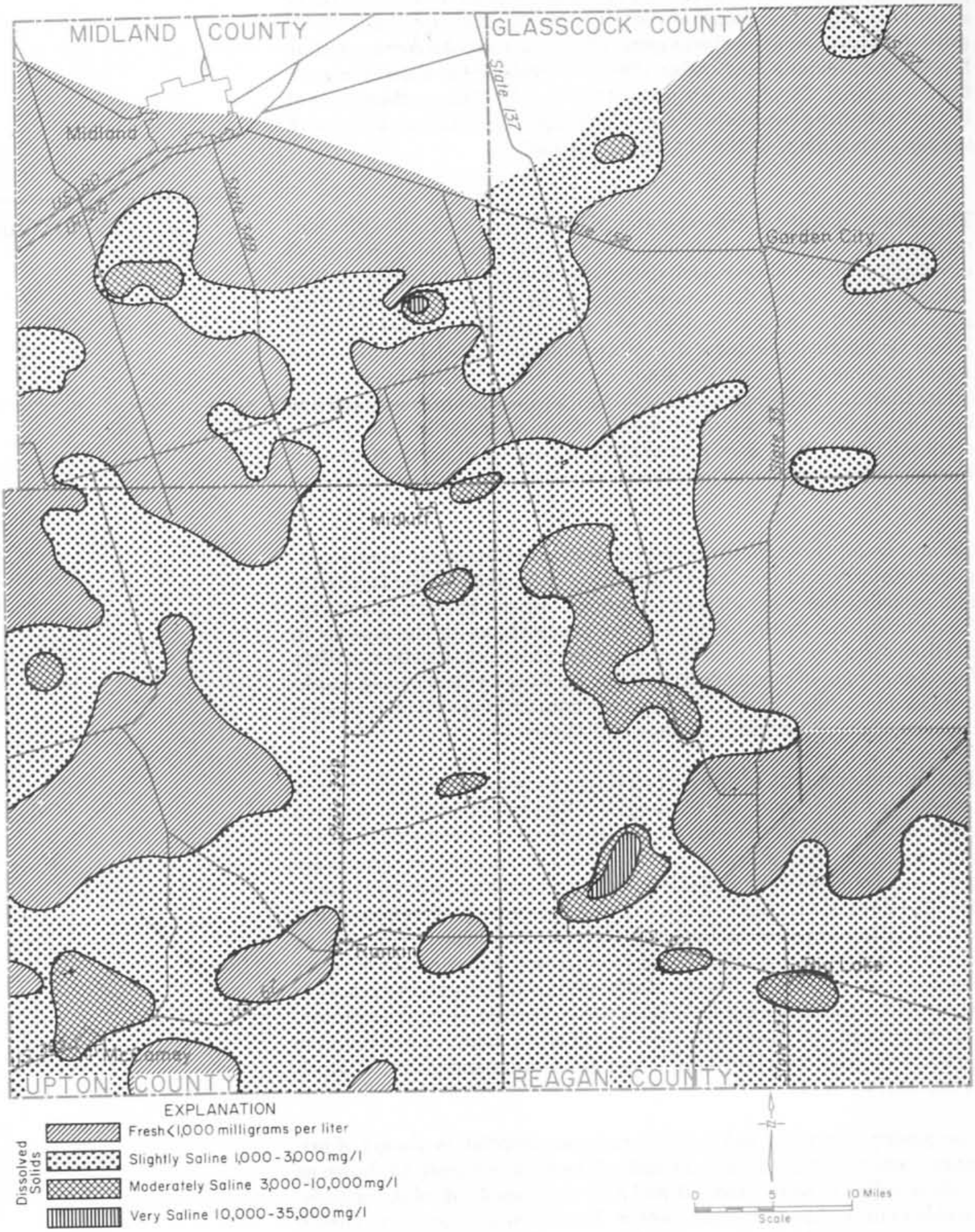


Figure 13
Chemical Quality of Water in the Edwards-Trinity (Plateau) Aquifer

lished 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 March, 1986). Standards which relate to public supplies are of two types: (1) primary and (2) secondary. Primary standards are devoted to constituents and regulations affecting the health of consumers. Secondary standards are those which deal with the aesthetic qualities of drinking water. Contaminants for which secondary maximum contaminant levels are set in these standards do not have a direct impact on the health of the consumers, but their presence in excessive quantities may discourage the use of the water.

Public supply systems within the study area depend solely on ground water and include the Reagan County Water Supply District, which supplies the city of Big Lake and the Upton County system, which supplies the city of Rankin. Well fields for both systems produce from the Edwards-Trinity (Plateau) aquifer but differ somewhat in chemical quality, with city of Big Lake water being good quality, although hard, and city of Rankin water partially exceeding recommended safe drinking water limits. The following table lists the average concentration of some of the more prominent constituents in water samples taken from both systems in 1987.

Constituent	Texas Dept. of Health Safe Drinking Water Standards (mg/l)	Reagan Co. W.S.D.[4] (City of Big Lake) (mg/l)	Upton Co.[5] (City of Rankin) mg/l)
Calcium	—	62.0	166.00
Sodium	—	58.0	138.00
Bicarbonate	—	239.0	323.00
Sulfate	300.0[2]	147.0	571.00
Chloride	300.0[2]	43.0	104.00
Fluoride	4.0[1,3]	1.6	2.06
Nitrate(NO3)	44.3[1]	14.0	31.00
Dissolved Solids	1,000.0[2]	495.0	1,269.00

[1] Regulated under primary standards.
[2] Regulated under secondary standards.
[3] When fluoride ranges between 2.1 and 4.0, it is regulated under secondary standards.
[4] Based on the average from 7 samples taken 5-26-87.
[5] Based on the average from 8 samples taken 4-30-87.

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, the sodium (alkali) hazard, and the boron hazard.

A high concentration of soluble salts in irrigation water may cause a buildup of salts in the soil. Saline soils decrease the ability of plants to take up moisture and nutrients from the soil, resulting in decreased yields. This salinity hazard is expressed in terms of specific conductance, measured in micromhos at 25° C. Irrigation wells sampled in the study area had a specific conductance range from approximately 500 to more than 10,000 micromhos (medium to very high salinity hazard).

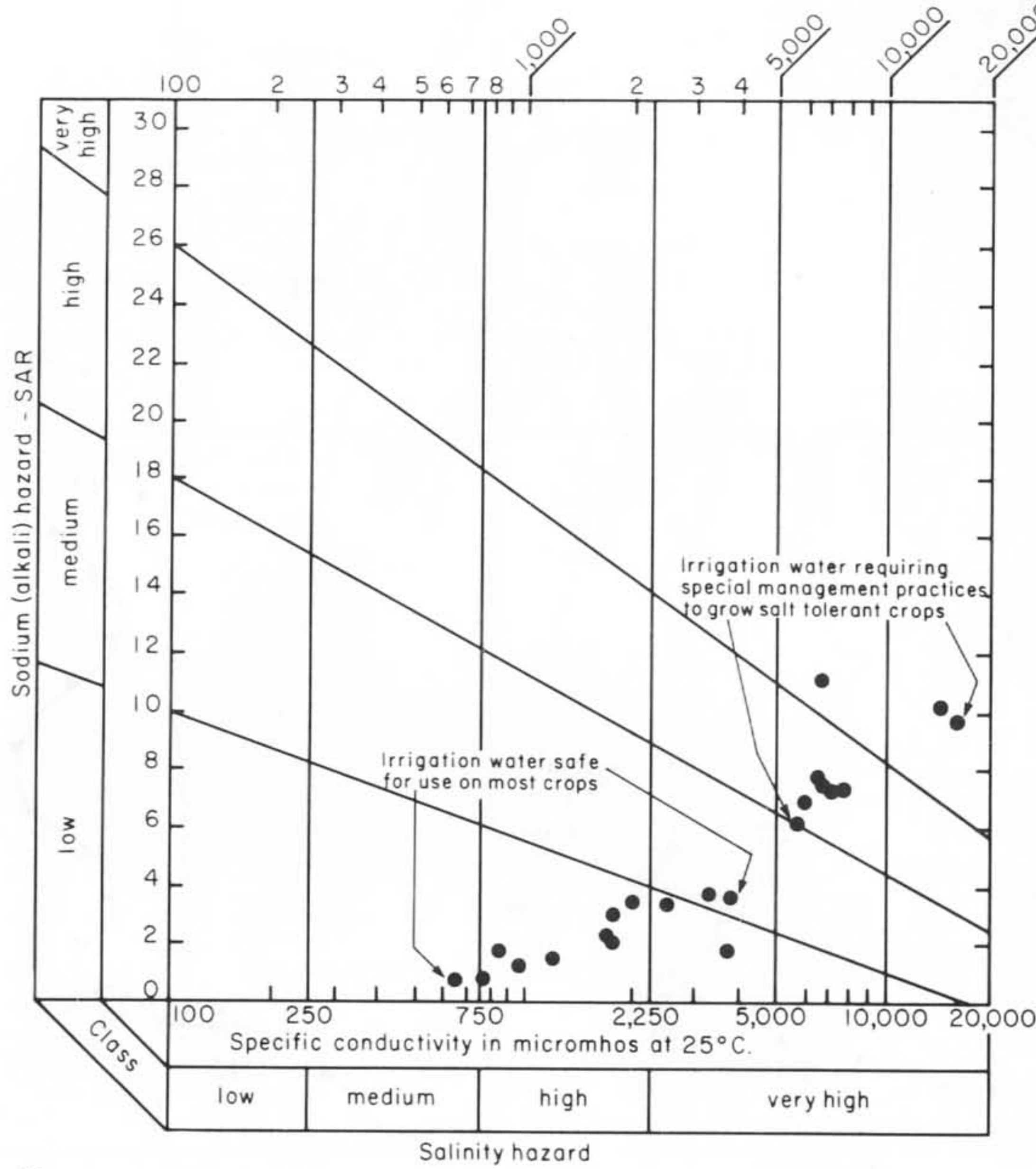
The physical condition of soil can be adversely affected by a high concentration of sodium relative to the concentration of calcium and magnesium in irrigation water. The sodium hazard is expressed as the sodium-adsorption ratio (SAR) which is the measure of the relative activity of sodium ions in exchange reactions with soil. A high SAR in irrigation water affects the soil by forming a hard impermeable crust that results in cultivation and drainage problems.

SAR and specific conductivity values of water samples from 22 wells purposefully selected to illustrate the full range in chemical quality in the area are plotted on a diagram for the classification of irrigation waters (Figure 14). The plotted data indicate that the sodium hazard (SAR) increases directly with the increase in salinity hazard (specific conductivity). Ground water with a specific conductance of up to 5,000 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 5,000 micromhos relates 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).

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 3.0 mg/l (Scofield, 1936). The concentration of boron was determined in 38 samples, and ranged from 0.36 to 4.99 mg/l. Twenty-six percent of the samples had a level of less than 1.0 mg/l, 43percent had a level of between 1.0 and 2.0 mg/l, 18 percent had a level of between 2.0 and 3.0 mg/l, and 13 percent had a level in excess of 3.0 mg/l. Irrigation water in the area containing more than 2,000 mg/l dissolved solids generally contains excessive boron and should be used cautiously.

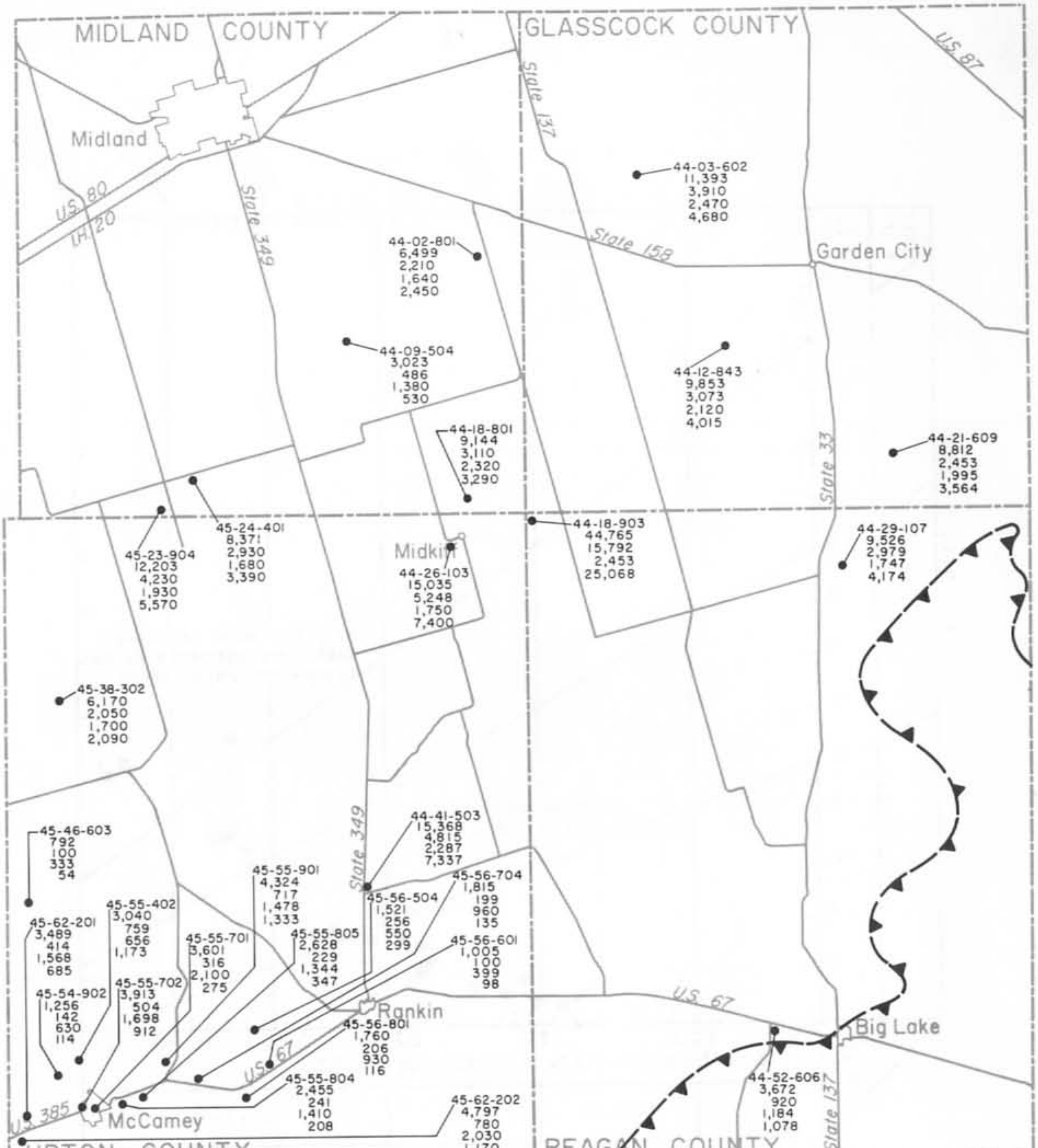
Water in the lower sand unit of the Dockum is moderately to very saline, 3,000 to 35,000 mg/l dissolved solids, over most of the study area, with sodium and chloride being the major ionic constituents (Figure 15). A water sample from well 44-18-903 located in the extreme northwest corner of Reagan County has a dissolved solids content of 44,765 mg/l suggesting contamination. In the southwest corner of Upton County, around the McCamey area, the Dockum occurs at a shallower depth and thus contains better quality water in the slightly to moderately saline range, 1,000 to 10,000 mg/l dissolved solids. Sulfate greatly exceeds the chloride content in this area.

Interformational mixing of water occurs in the eastern part of Reagan County where the lower sand unit of the Dockum abuts the Trinity. Mixing of water with the overlying Trinity aquifer appears to occur primarily near the contact between the two units and probably does not extend on down to the base. For this reason, wells drilled for the new Reagan County Water Supply District well field were completed at depths of at least ten feet above the base of the Trinity in order to avoid upward migration of poorer quality water in the Dockum (Reed and Associates, 1986).



(Diagram after U.S. Salinity Laboratory Staff, 1954)

Figure 14
Classification of Irrigation Waters



EXPLANATION

- • 44-52-606 State well number
- 3,672 Dissolved-solids concentration
- 920 Sodium concentration
- 1,180 Sulfate concentration
- 1,078 Chloride concentration

Chemical concentrations are in milligrams per liter

Area south and east of this line is where the lower Dockum sand is in hydrologic contact with the Antlers Sand and they are considered as one hydrologic unit

Figure 15
Chemical Quality of Water in the Dockum Aquifer

Ground-Water Problems

Water-Level Decline

Declining water levels have been of concern for many years in the region. The water level in an aquifer is primarily influenced by the rate of recharge to and discharge from the aquifer. Low rainfall and high evaporation rates in the area generally result in less water entering the aquifer than is being pumped out. Lower water levels result in decreasing well yield, higher pumping cost, and may contribute to deteriorating water quality.

Texas Water Development Board water-level monitoring records show that declines of over 100 feet have occurred in southern Glasscock and northern Reagan Counties since the late 1940's when irrigation development started. Well 44-20-911, in Reagan County, has had a 118 foot water-level drop since 1949 (Figure 16a). Since 1970 much of this same area has experienced over 30 feet, and in some areas as much as 50 feet, of decline (Figure 17). Up to 30 feet of decline since 1970 has also occurred in an area south of Midkiff in Upton County and in an area in southern Midland County.. In areas of heavy pumpage, approximately two feet per year of water-level decline appear to have been common.

Water levels measured by Board staff between 1980 and 1987 indicate that the rate of decline has moderated. Over half of 17 water-level observation wells monitored within the area have shown a rise since the early 1980's while the remaining wells experienced a very slight decline (Figure 18). The hydrographs on Figure 16 illustrate how the water level in these wells has remained relatively constant since 1980. There are two factors that probably have influenced this trend. Irrigation pumpage has not increased substantially during this period, due primarily to poor agricultural economic conditions, including high energy cost; and, rainfall has been above average the past few years, which has not only helped reduce the need for irrigation, but also has increased the amount of water available for recharging the aquifer.

Not all areas of heavy pumpage experience continuous water-level decline conditions. Annual water-level measurements made by staff of the Texas Water Development Board and by the Upton County Water Department indicate that the Upton County well field, east of Rankin, is less subject to long term water-level decline, apparently because the aquifer in the area recharges rapidly. Wells in the Reagan County Water Supply District well field have only recently been installed and therefore, a long term water-level trend is not available. Also, there is not a sufficient quantity of data available to determine water-level trends in the Dockum aquifer, although poor hydraulic conditions and limited recharge probably will result in declines if the aquifer is heavily pumped.

Water-Quality Deterioration

Water-quality deterioration is a problem in the region. Deterioration of the water quality appears to be partially the result of early oil field development practices in which little regard for the protection of the fresh water in the region was shown (White, 1968; and Walker, 1979). Areas containing the poorest quality water are located over major oil field reservoirs (Figure 19).

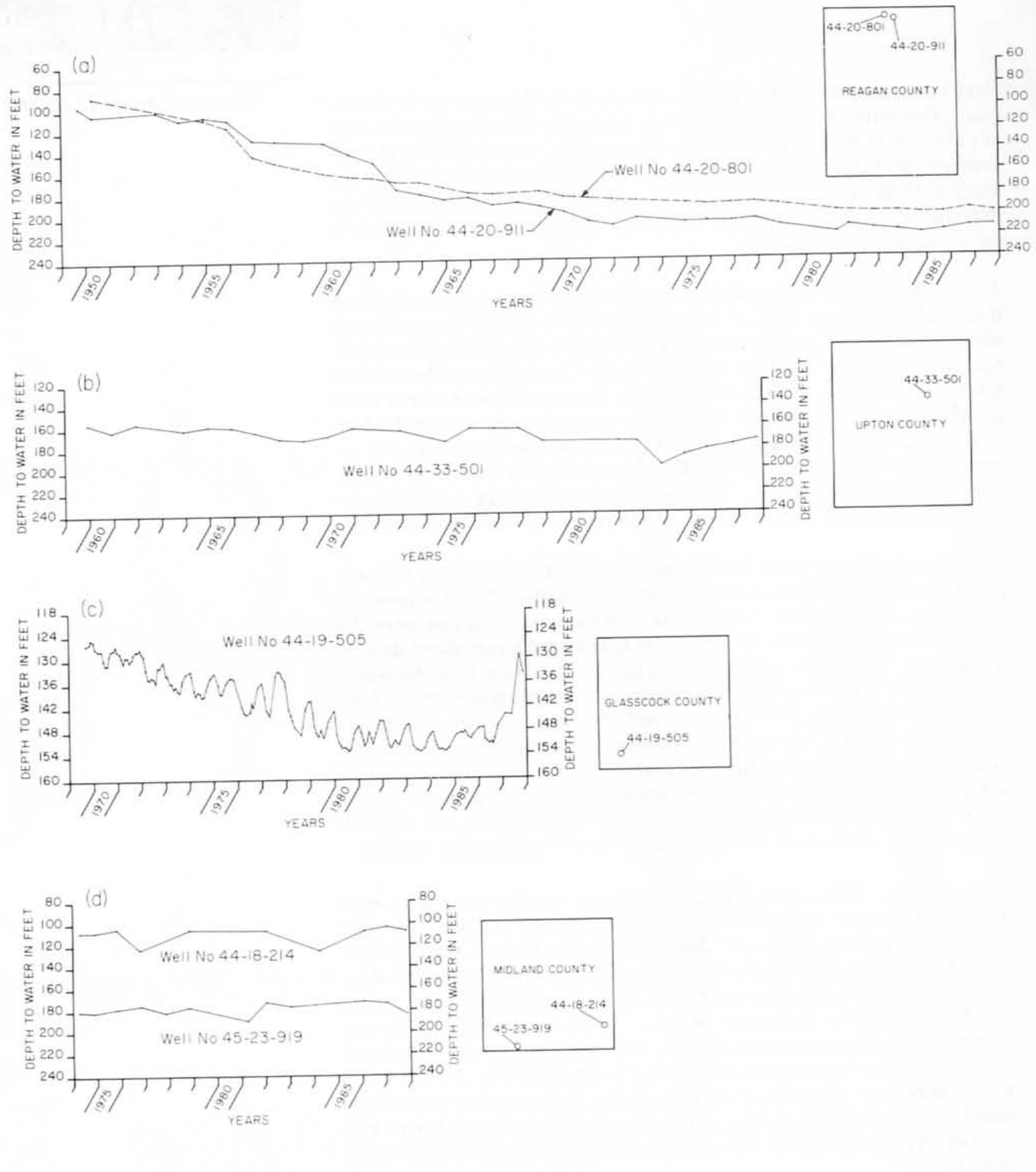


Figure 16
Hydrographs of Water Levels in Selected Wells

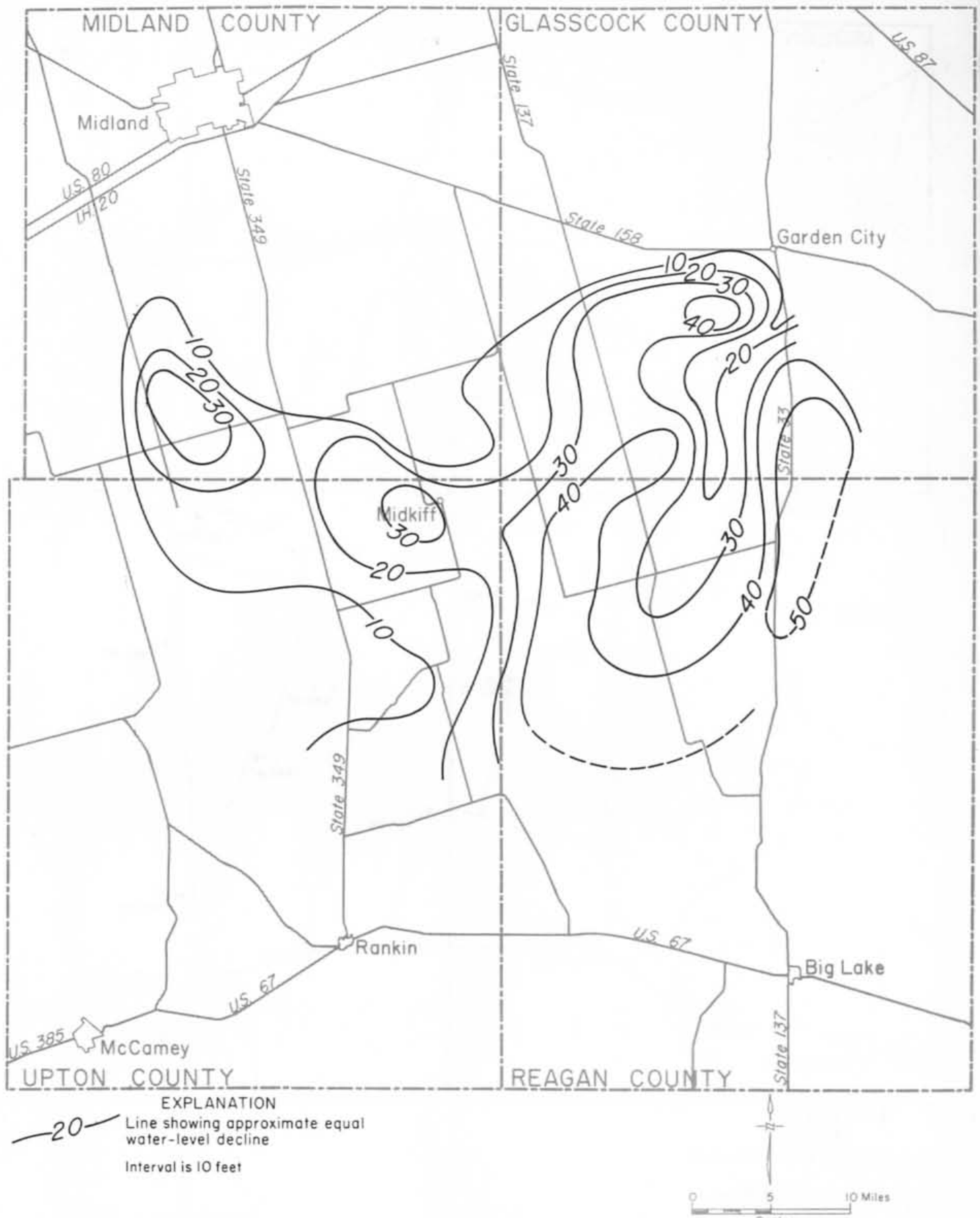


Figure 17

Water-Level Declines in the Edwards-Trinity (Plateau) Aquifer, 1970-87

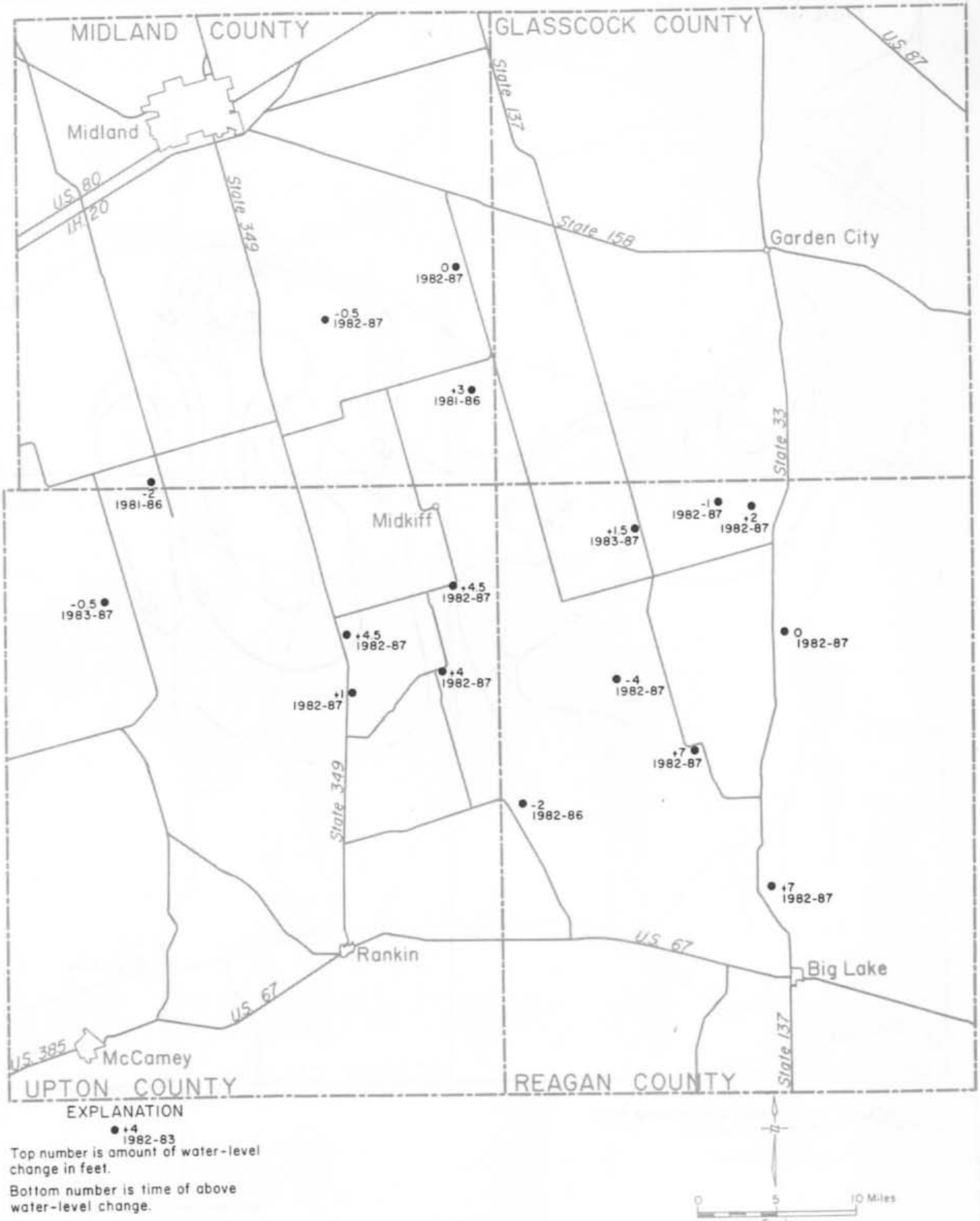


Figure 18
Water-Level Change in the Edwards-Trinity (Plateau) Aquifer since 1981

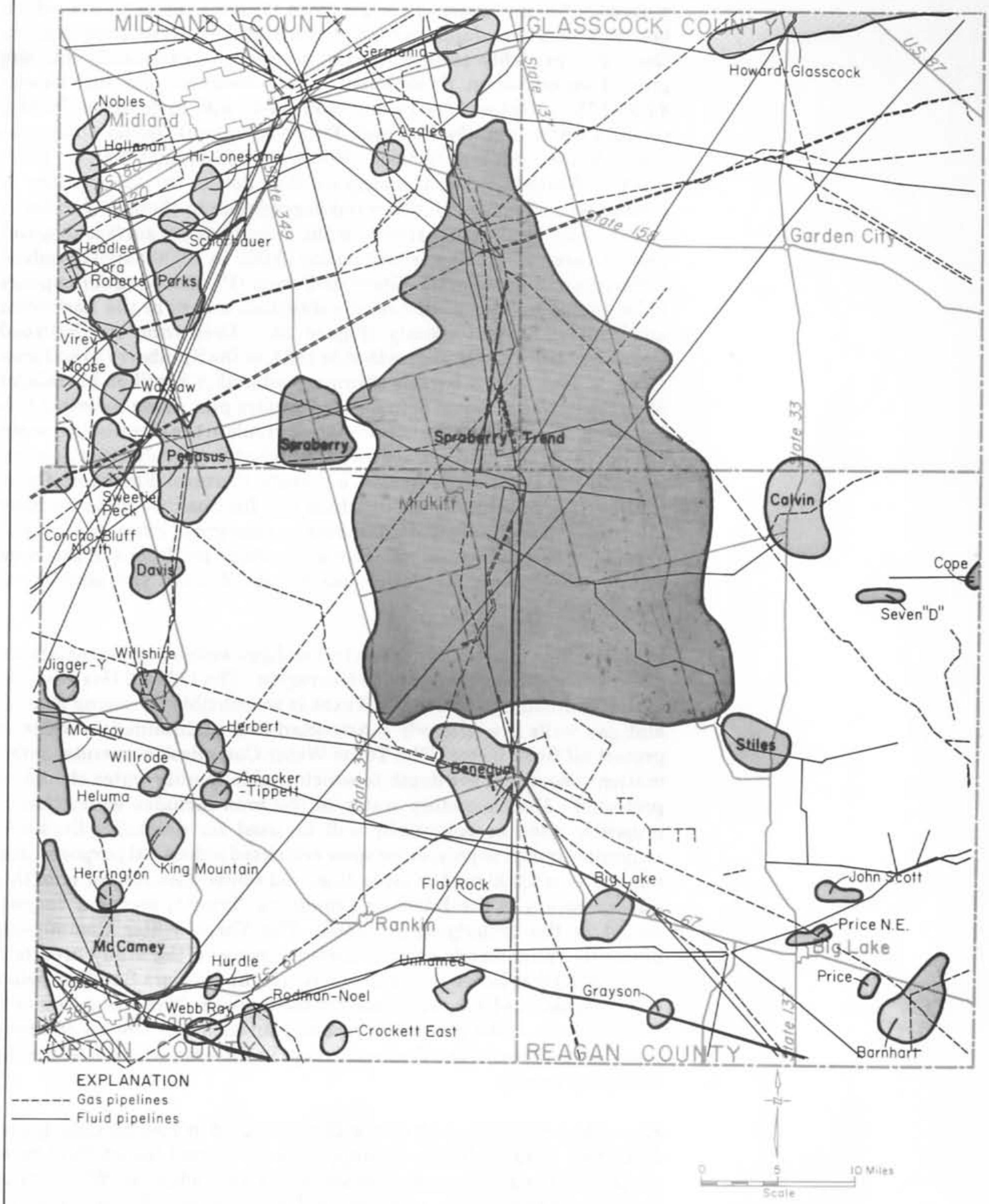


Figure 19
Oil Fields and Pipelines

The disposal of brines (water containing greater than 35,000 mg/l dissolved solids) into unlined surface pits was common 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. Some water wells located near pits, such as well 44-26-513 in Upton County and well 44-43-805 in Reagan County, produce water from the Edwards-Trinity (Plateau) aquiferwhich contains elevated levels of chloride (White, 1968 p. 41; and Walker, 1979, p.100). White (1968, p.41) suggests that due to the low velocity of ground-water movement, a marked degradation in chemical quality is usually only local in occurrence in the vicinity of old surface disposal pits. An area where moderately saline (3,000 to 10,000 mg/l dissolved solids) ground water in the Edwards-Trinity (Plateau) aquifer appears to be spreading in a southeasterly direction occurs in the northwest quadrant of Reagan County (Figure 13). Data from the Railroad Commission ofTexas indicate that in 1961, in the Spraberry Trend area alone, of 10.3 million barrels of brine produced ,8.8 million barrels, or 85 percent, was disposed of in unlined surface pits. Even if most of this water was evaporated, the accumulation of salt in the pits would remain as a threat to the land surface and the underlying fresh water aquifer. In 1983 the Legislature passed a statute (Natural Resources Code, Chapter 91, Subchapter K) in which the Railroad Commission may allow use of a disposal pit on a temporary, emergency basis, or allow use of an impervious disposal pit. Surface geologic conditions in this area are generally not suitable for use of pits without the addition of impervious liners.

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 information 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, and may contain 5,000 mg/l or more dissolved solids. Ground water of this quality occurs in the Edwards Limestone, Trinity, and to a varying extent in the underlying Dockum. The Texas Water Commission presently recommends setting surface casing in the study area to a depth of 50 feet below the base of Cretaceous (Antlers Sand) or below any recognizable fresh-water sand in the Dockum. The Water Commission does not make protection recommendations for the lower sandy unit (Santa Rosa) of the Dockum except in the area where it abuts the overlying Trinity.

Some older oil fields, such as the Big Lake field in Reagan County and McCamey field in Upton County, were developed before field rules pertaining to surface-casing requirements were adopted. While investigating contamination problems in Upton County, White (1968) revealed that these earlier wells were inadequately cased and had little or no cement around the casing, which apparently has resulted in extensive contamination of the fresh water aquifer in their vicinity (Figure 13). The large Spraberry Trend field that occupies much of the central part of the study area originally had field rules requiring a minimum of only 120 feet of surface casing.

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 wells may be inadequately cased. In 1967 more than 15 million barrels of brine was injected into wells in the Spraberry Trend area alone. Brine production and method of disposal data were taken from Railroad Commission of Texas 1967 saltwater production and disposal questionnaires and illustrated in Walker (1979).

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. 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 that are no longer visible at the surface may go undetected.

Abandoned and improperly completed water wells are also potential sources of contamination. Well records in agency files indicate that many older water wells have very little if any cemented casing at the surface. Bacterial contamination is most common in shallow wells and in wells where surface runoff is allowed to enter the borehole, especially near septic tanks. Pesticides also can reach the aquifer when irrigation runoff is allowed to flow down the borehole or outside of inadequately cemented casing. The Texas Water Commission is presently engaged in a program of locating abandoned water wells and having them plugged.

Another potential source of contamination exists with the numerous buried pipelines that transport both gas and fluid petroleum products across the region (Figure 19). A major spill could seep downward into the aquifer, especially in areas where the pipeline is underlain by fractured rock. Even small, undetected leaks can have a detrimental effect in time.

Natural water in the Edwards-Trinity (Plateau) aquifer is generally characterized by a low (less than 1:1) chloride to sulfate ratio (White, 1968; Walker, 1979). However, water samples from 16 wells had ratios ranging from 3:1 to 39:1. Quality diagrams of selected wells (Figure 20) illustrate the change in quality over time. High chloride to sulfate ratios and elevated levels of chloride often occur in ground water in the local vicinity of areas that were used to dispose of brine in unlined surface evaporation pits (White, 1968; Walker, 1979). The aquifer in these areas, although small in areal extent, has been most severely altered.

Increased levels of sulfate are fairly widespread, especially in Reagan and Upton Counties. High levels of sulfate may be the result of a mixing of water derived from Triassic and Permian formations with fresh water in the Trinity. This mixing may occur when the deeper water flows upward and then laterally into the fresh water zone, often under induced pressure from nearby injection wells. Another possible source of increased sulfate in the ground water is from natural gas, which occurs in lower oil producing zones, that escapes upward around the outside of casing that is not sufficiently cemented to form a seal.

The effect of irrigation pumpage has not generally added to the water quality deterioration, but may be responsible for increasing the spread of existing contamination by increasing the rate of ground-water movement. With declining water levels in the area, some wells have been deepened and may be encountering thin sand lenses in the upper part of the Dockum. Water from these lenses is generally of poorer although usable quality.

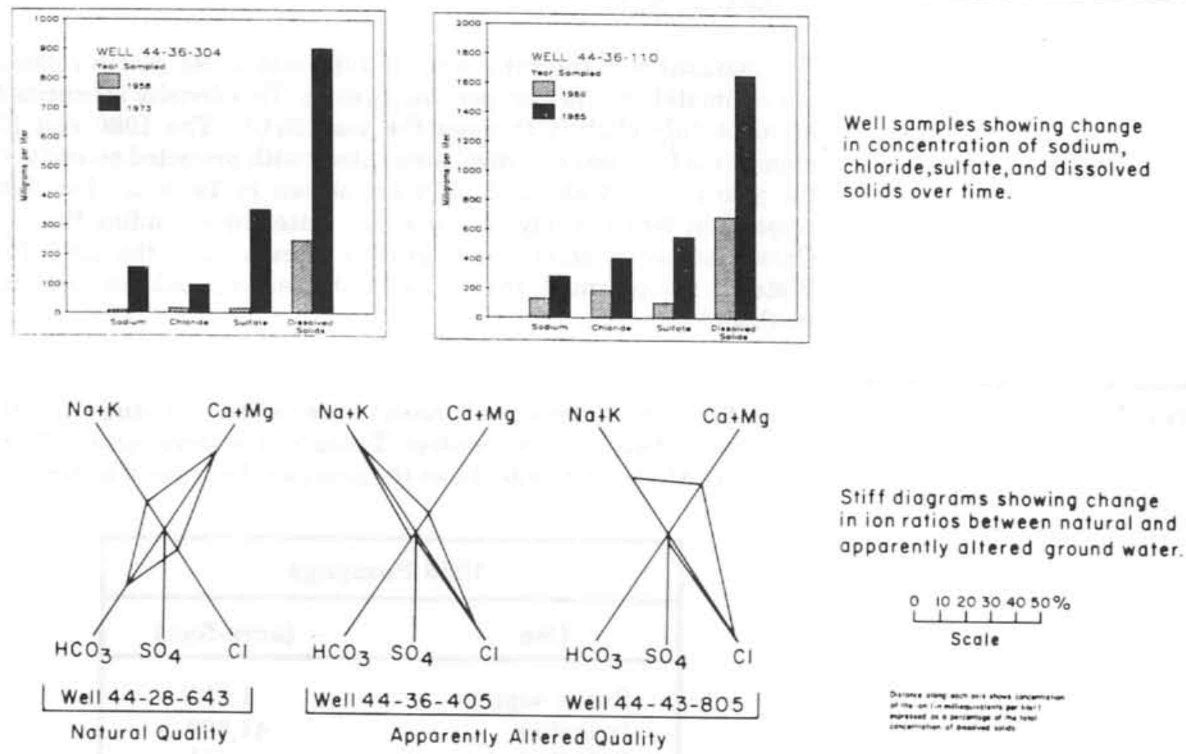


Figure 20
Chemical-Quality Diagrams Showing Change Over Time in Concentration and Ratio of Constituents in Water from Selected Wells

Projected Water Demand

Population

The regional population is generally sparse and depends heavily on the economic conditions in both the agricultural and petroleum related industries. Only the cities of Big Lake and Rankin occur within the study area (Figure 1) and have a combined population of 5,484 in 1985, which represents an increase of approximately 19 percent over the 1980 level. The population for the two cities is projected to increase to 8,249 by the year 2010.

The population of the rural area in 1985 was 1,798, which relates to approximately one person per square mile. This density is expected to increase only slightly 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 2. 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

In 1985 the total pumpage of ground water within the study area (Figure 1) was about 43,628 acre-feet (Texas Water Development Board , 1988). The following table shows the pumpage by types of water use for that year.

1985 Pumpage	
Use	**(acre-feet)**
Public supply	1,092
Irrigation	41,899
Industry	151
Domestic	280
Livestock	206
Total	**43,628**

Source: Texas Water Development Board 1988 Revised Data Series

Public Supply

The municipal water needs of the cities of Big Lake and Rankin are provided by the only two public supply water systems within the primary study area and both rely entirely on ground water from the Edwards-Trinity (Plateau) aquifer. The city of McCamey, in the southwest corner of Upton County and outside of the primary study area, obtains its water from a well field located in Pecos County. In Glasscock County, citizens in the community of Garden City obtain their water supply from private wells. The calculated amount of ground water pumped for public supply use within the study area in 1985 was about 1,092 acre-feet, which was about 2.5 percent of the total pumpage from the aquifer.

Table 2. Current and Projected Population of Study Area [1]

County [2]	Year	Cities [3]	Rural [4]	Total
Midland	1980	-0-	366	366
	1985	-0-	449	449
	1990	-0-	555	555
	2000	-0-	733	733
	2010	-0-	773	773
Reagan	1980	3,404	599	4,003
	1985	4,067	762	4,829
	1990	4,790	878	5,668
	2000	5,508	878	6,386
	2010	6,060	921	6,981
Upton	1980	1,216	435	1,651
	1985	1,417	587	2,004
	1990	1,485	675	2,160
	2000	1,852	685	2,537
	2010	2,189	733	2,922
Total	1980	4,620	1,400	6,020
	1985	5,484	1,798	7,282
	1990	6,275	2,108	8,383
	2000	7,360	2,296	9,656
	2010	8,249	2,427	10,676

[1] 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.

[2] Population estimates are for the area in each county that falls within the 1969 underground water reservoir delineation (Figure 1).

[3] The term "Cities" includes Big Lake in Reagan County and Rankin in Upton County.

[4] The term "Rural" includes unincorporated areas and all rural population.

The city of Big Lake originally operated seven wells within the city. When these wells could no longer meet the city's needs, the Reagan County Water Supply District was formed and developed a well field consisting of 11 wells located about five miles northeast of the Stiles area. In time, these wells were abandoned because of declining water levels and deteriorating water quality, and a new field was developed about 17 miles north of Big Lake and east of Highway 33. Since 1982, 19 wells have been drilled in this field. In 1985, the Reagan County Water Supply District pumped 822 acre-feet of ground water (Texas Water Development Board, 1988).

Windmill wells supplied the water needs of the residents of Rankin until 1939, when the city installed a municipal water system consisting of one well (White, 1968). The city added a second well in 1948 and a third in 1951. In 1965, Rankin was supplied by ten wells owned by the county in a well field two and a half miles northeast of the city, and by three wells in the municipal system. Pumping in 1965 amounted to 94 million gallons (288.5 acre-feet), or slightly more than 225,000 gallons per day (White, 1968). The county currently operates 21 wells and also receives water from two wells owned by the Upton County Water District. Wells in the municipal system are no longer used. Two hundred and seventy acre-feet of ground water was pumped by the county for public supply use in 1985 (Texas Water Development Board, 1988).

Irrigation

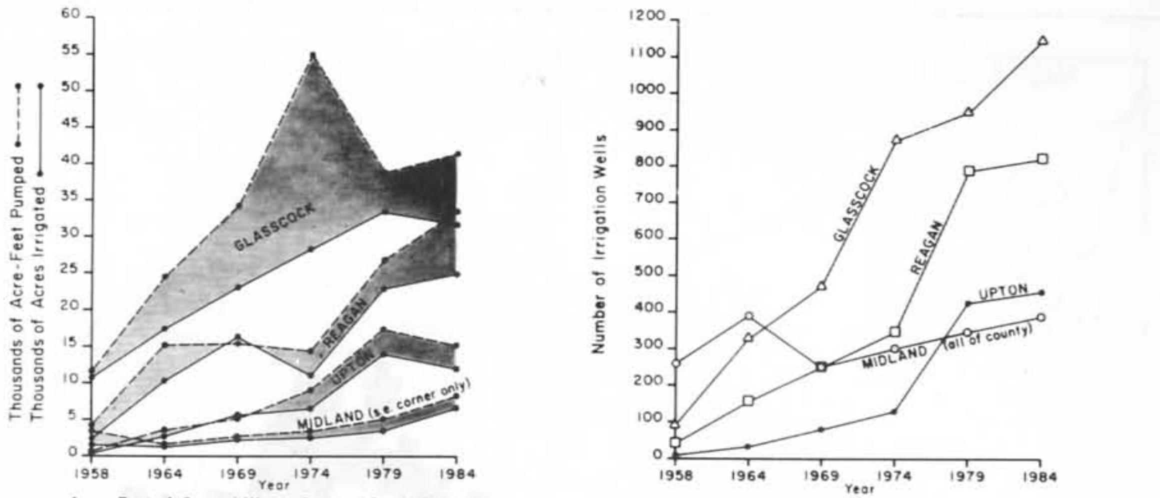
Irrigation represents the largest use of ground water in the study area. In 1985 approximately 41,899 acre-feet of ground water was pumped for irrigation, which represents about 96 percent of all ground water pumped in the study area (Texas Water Development Board, 1988).

Development of ground water for irrigation began in the late 1940's and increased substantially in the 1960's and 1970's (Figure 21). Since about 1979, the amount of ground water used for irrigation has increased very little. Agricultural economic downtrends, escalating fuel cost, and declining water levels are the primary reasons for the leveling out of irrigation growth. Additionally, substantial acreage has been 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.

Between 1958 and 1984, the amount of ground water pumped for irrigation increased from 4,968 to 48,956 acre-feet in Reagan and Upton Counties. During the same period, the number of acres irrigated increased from 3,170 to 37,084 (Figures 22). The number of irrigation wells actually in operation increased from 49 to 1,285 between 1958 and 1984 (Figure 21). In southern Glasscock County 11,597 acre-feet was pumped for irrigation in 1984 from the same aquifer (Texas Water Development Board, 1986).

Industrial

Industrial pumpage of ground water from the Edwards-Trinity (Plateau) and Dockum aquifers in the area is almost exclusively related to the petroleum industry, including such operations as water flooding for secondary recovery, operation of gasoline plants and compressor stations, and drilling oil and gas wells. Approximately 151 acre-feet of



Acre-Feet of Ground Water Pumped for Irrigation and Acres Irrigated with Ground Water
(Data from Texas Water Development Board Rept.294)

Operable Irrigation Wells
(Data from Texas Water Development Board Rept.294)

Figure 21
Irrigation Development

ground water was pumped from the area in 1985 for all industrial uses, including manufacturing and mining (Texas Water Development Board, 1988). This amount represents about 0.3 percent of the total pumpage from the aquifers.

Salt water, a byproduct of oil and gas recovery, is subsequently injected back into deep formations for disposal or secondary recovery operations. Paleozoic rocks underlying fresh-water formations are the producing zones for the petroleum industry in the study area. Most production has been from the Spraberry Trend of Permian age. Additional production, primarily in the western half of Upton County, has been from the Cisco, Bend, and Strawn Groups of Pennsylvanian age; Devonian age formations; and the Ellenberger Group of Ordovician age (Midland Map Co., 1985). The Salado Formation of Permian age is the primary source of brine production.

Domestic and Livestock

The rural population in the area is quite sparse, and in 1985 pumped approximately 280 acre-feet for domestic use (Texas Water Development Board , 1988). Ground-water pumpage for livestock use in the same year was approximately 206 acre-feet, much of which was pumped by windmills. An additional 51 acre-feet of surface water for livestock use represents the only recognized surface-water use in the study area.

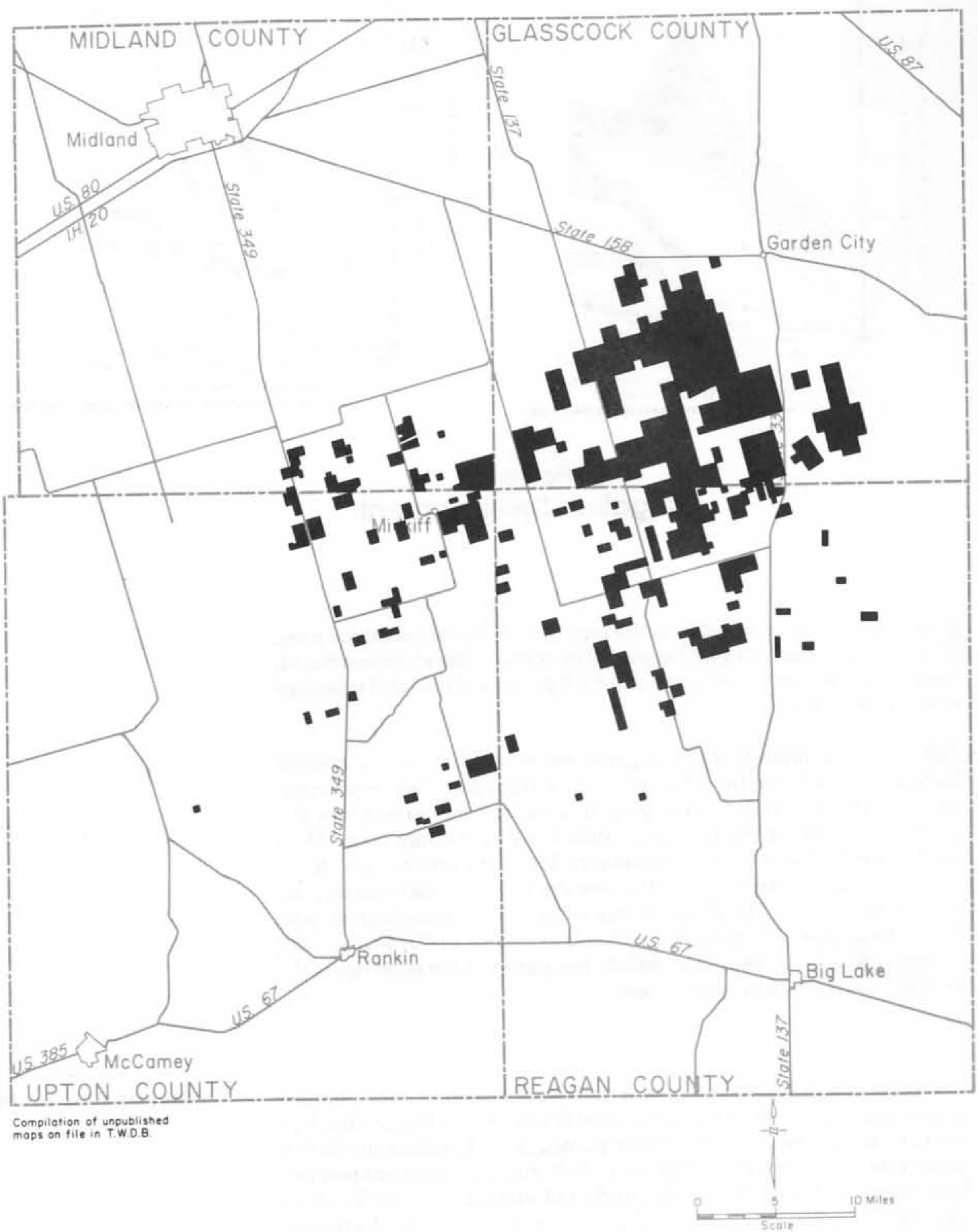


Figure 22
Irrigated Acreage in 1984

Projected Water Demands, 1990-2010

The total amount of water used in the study area (Figure 1) during 1980 and 1985, respectively, is estimated to have been 47,948 and 43,679 acre-feet, all of which was ground water from the Edwards-Trinity (Plateau) aquifer except for 76 and 51 acre-feet, which was surface water, respectively (Texas Water Development Board , 1988). Ninety-six percent of the 1985 amount was used for irrigation purposes.

Current and projected water demands by use category are shown in Table 3. Projections of future municipal and rural requirements are based upon 1988 Texas Water Development Board Revised Data Series population projections and projected high series per capita water use. Future projections of irrigation, industrial, and livestock use are based upon high series 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. All future water requirements are expected to be drawn from ground-water supply, except for a minor amount of surface water projected for livestock use.

Under high series projection conditions, the total annual water requirement for the study area is expected to increase by 16 percent from 1985 to the year 2010, at which time the annual demand is estimated to be 50,663 acre-feet. Municipal and rural requirements are projected to increase to 2,184 acre-feet annually during this period. The major projected increase under these conditions is with irrigation use, which will increase 14 percent by 1990 to 47,914 acre-feet annually and then remain constant through the year 2010. Livestock use is projected to increase only slightly, while industrial use is expected to decline. Again, these projections are based on drought condition requirements. Actual water demand may not reach this level. The estimated annual effective recharge to the aquifer of 30,000 acre-feet is less than the amount needed to meet present and future demands; therefore, the water supply for the study area will continue to be drawn partially from storage within the aquifer.

Table 3. Current and Projected Water Demand by Use in Study Area [1]
(Units in Acre-Feet)

County [2]	Year	Public Supply [3]	Irrigation	Industrial	Domestic [4]	Livestock [5]	Total
Midland	1980	-0-	5,531	171	63	75	5,840
	1985	-0-	8,662	151	92	63	8,968
	1990	-0-	6,359	124	89	88	6,660
	2000	-0-	6,359	77	112	102	6,650
	2010	-0-	6,359	68	112	102	6,641
Reagan	1980	781	23,000	-0-	70	226	24,077
	1985	822	22,750	-0-	102	139	23,813
	1990	1,093	29,333	-0-	161	264	30,851
	2000	1,193	29,333	-0-	152	303	30,981
	2010	1,241	29,333	-0-	152	303	31,029
Upton	1980	394	17,500	-0-	50	87	18,031
	1985	270	10,487	-0-	86	55	10,898
	1990	445	12,222	-0-	93	81	12,841
	2000	527	12,222	-0-	89	92	12,930
	2010	589	12,222	-0-	90	92	12,993
Total by Use	1980	1,175	46,031	171	183	388	47,948
	1985	1,092	41,899	151	280	257	43,679
	1990	1,538	47,914	124	343	433	50,352
	2000	1,720	47,914	77	353	497	50,561
	2010	1,830	47,914	68	354	497	50,663

[1] 1980 and 1985 water demand is based on reported and site-specific computed use. 1990, 2000, and 2010 water demand is based on 1988 TWDB Revised High Series projections. All amounts are ground water, except for a minor amount of surface water used for livestock.

[2] Water demand estimates are for the area in each county that falls within the 1969 underground water reservoir delineation (Figure 1).

[3] Public Supply includes projected demands for the cities of Big Lake in Reagan County and Rankin in Upton County.

[4] Domestic includes unincorporated areas and all rural population use. In 1985, 26.5 percent of rural water use in the Reagan County area was supplied by Big Lake, and 22.6 percent in Upton county was supplied by Rankin.

[5] Livestock includes a minor amount of surface water.

Availability of Water

Current Availability of Ground Water

The amount of fresh to slightly saline ground water available on a perennial basis within the 1969 delineation area is approximately 30,000 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 (43,628 acre-feet in 1985) exceeds this available quantity, thus resulting in the water-level decline shown in Figure 17.

Ground water in transient storage in the Edwards-Trinity (Plateau) aquifer only within the primary study area (Figure 1), or the farming district, is approximately 7.5 million acre-feet. This estimate is based on the volume of saturated thickness shown on Figure 23 and an average specific yield of 0.074.

Potential for Conjunctive Use of Ground and Surface Water

Surface water, at this time, is not a viable alternative source of water supply. Except for a minor amount of water held temporarily in surface depressions, virtually all water used in the study area is derived from underground aquifers. Surface water storage of significant quantity is questionable in the area due to low annual rainfall, high evaporation rate, and existence of only ephemeral streams. The nearest river, the Pecos, is located a short distance to the south of the study area, but is too saline for most practical uses.

No unallocated surface water presently exists in area lakes, although excess supplies could feasibly be available through such entities as the city of Midland and the Colorado River Municipal Water District, especially after the completion of the Stacy Reservoir project. The basic cost of this water plus the construction of a pipeline to transport the water would make its use economically impractical for irrigation use. For these reasons, practically no surface water use is projected for the study area through the year 2010 (Texas Water Development Board , 1988). A study was made in the early 1980's by various entities in Crane, Reagan, and Upton Counties to determine the feasibility of building a pipeline from Lake J. B. Thomas in Borden and Scurry Counties to supplement public supply sources. The result of the study indicated that the project would be economically unfavorable.

Potential for Additional Ground-Water Development

Areas most favorable for additional ground-water development are dependent on saturated thickness, history of water-level decline, and chemical quality. The primary study area, which consists mostly of the farming district, is presently near, or at, maximum development. Additional pumpage will accelerate the rate of water-level decline. Also, this area contains slightly saline (poorer quality) water.

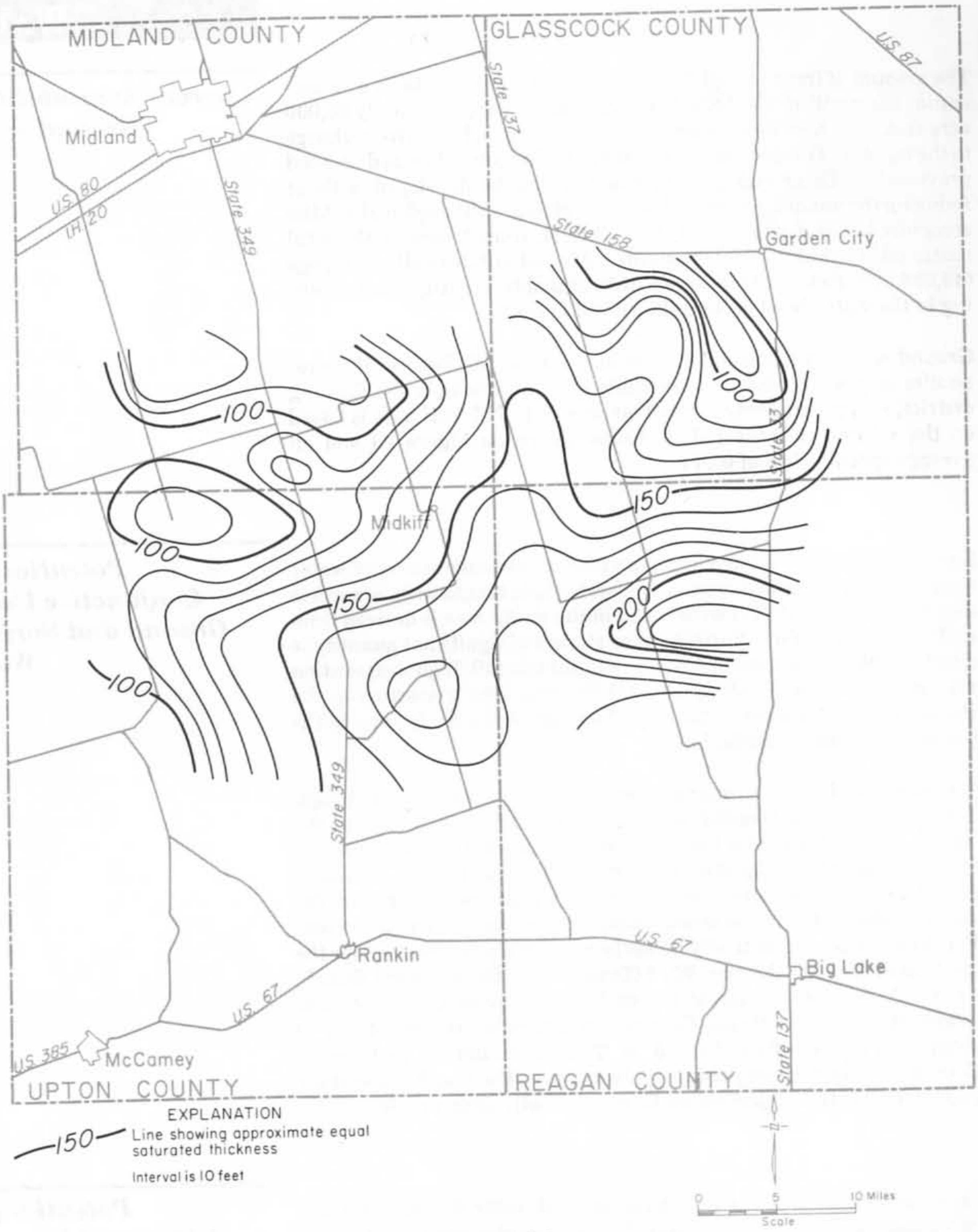


Figure 23
Approximated Saturated Thickness of the Edwards-Trinity (Plateau) Aquifer, 1987

An area in the east-central part of Reagan County appears to have the best conditions for additional development including 150 to over 200 feet of saturated thickness in the Antlers Sand and a water quality of better than 1,000 mg/l. This area is east of Highway 33, north of Big Jim Draw, and extends several miles north of Centralia Draw and eastward into Irion County. Large- scale farming is not possible in this area due to the lack of a sufficient thickness of surface soil. The Reagan County Water Supply District well field is located in this area north of Centralia Draw.

Additional saturated thickness can be obtained from the Dockum sand unit which abuts the Antlers Sand in much of this area. Water in at least the upper part of this zone should be usable for many purposes, although it may not meet public supply standards.

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.

Numerous methods of artificially recharging aquifers have been studied (O'Hare and others, 1986), but the following discussion will focus on methods applicable to the primary study area (Figure 1) which consists mostly of the flat upland farming region of southeast Midland, northwest Reagan, and northeast Upton Counties. Increased recharge would benefit this area by increasing the amount of water in storage in the aquifer in an area that has experienced significant water-level declines. In addition, an increase of fresh water entering the aquifer would enhance the quality of the ground water.

Surface Depressions

The first consideration toward increasing aquifer recharge should address methods of enhancing the amount of infiltration of surface water derived from precipitation. Unfortunately, very little surface water is available for recharge because of low annual rainfall and high evaporation. The average annual rate of evaporation is more than five times greater than the average annual rate of precipitation (Figure 2), thus creating a prevailing low soil moisture content. Surface drainage is predominantly inward, accumulating in the numerous surface depressions. Soils within these depressions contain impermeable clays which retard downward percolation. In time, most of this water is lost to evaporation. The vertical permeability, or infiltration capacity, of these depressions can be improved by breaking up the clay soil bottom by deep chiseling. This process will probably need repeating each time the basin dries. Additionally, digging a trench in the basin will not only remove a portion of the clay soil, but will also concentrate the water such that less surface area is exposed to evaporation. Precaution should be taken with depressions that were historically used as salt-water disposal pits. These basins usually contain a high salt content in their soil, which can leach out and percolate downward into the aquifer.

Brush Clearing

Transpiration is the emission of water vapor to the atmosphere by plants. The greatest loss of water by transpiration in the study area occurs on rangeland that contains large concentrations of brush and woody plants, mesquite being the most dominant. A mesquite stand that has a canopy shading 50 percent of the soil can use as much as nine inches of water per month during the growing season (Hoffman, 1967). According to Rechenthin and Smith (1967), "a grassland restoration program, involving the control of undesirable plants and replacing them with grass, would result in a saving of water, most of which would be available for deep percolation into underground aquifers and as return flow to streams."

An illustration of the effect resulting from the removal of woody plants from a watershed can be seen along West Rocky Creek in Irion County immediately east of Reagan County (U. S. Soil Conservation Service, 1986). Between about 1915 and 1935 the creek, which had historically flowed, gradually dried up. About 70 percent of the mesquite was removed in the 1950's and by 1967, springs feeding the creek reappeared. Brush clearing in the study area may not have as dramatic an affect, but a significant increase in recharge should occur.

Runoff-Control Structures

Another method of maximizing the recharge potential of the temporarily available surface water is by the construction of runoff-control structures. There are two considerations concerning the location of such structures. First, these structures should be located such that the water that is retained behind the dam will cover soils with the best permeability for rapid infiltration. A second consideration is the placement of a structure upstream from the best recharge area. The retained storm runoff is then released at a controlled rate comparable to the maximum potential recharge rate of the downstream area. This would minimize storage detention time, thus reducing evaporation losses, and allow maximum storage availability for the next storm.

Sewage Effluent on Spreading Basins

An additional source of surface water that might be available for infiltration through spreading basins is sewage effluent from the various municipal water systems. Such a process is presently occurring in an area near the Glasscock and Midland County line, where treated effluent from the city of Midland is being spread on the land surface. Factors that must be carefully analyzed before using this process include: (1) the cost of transporting the effluent to the spreading basin, (2) the infiltration capability of the spreading basin, and (3) the chemical quality effect that the effluent will have on the present quality of the ground water and on the land surface.

Recharge Wells

Recharge wells have successfully been used to inject water directly into underground water-bearing zones. Water sources, such as treated sewage effluent in El Paso, storm-runoff near Dell City, and playa lakes near Lubbock, along with an understanding of the geohydrological characteristics of the formation into which the water will be injected, determines the technology necessary to construct recharge wells. In the study area, water collected in surface depressions and storm-runoff structures represents the most viable source for injection. Precaution must be given to injecting only water that is silt free and chemically fresh. Recharge wells completed in the Edwards-Trinity (Plateau) aquifer will probably operate with only moderate success because of the low transmissibility of the Antlers Sand formation and limited storage capacity of the Edwards Limestone. Water injected into the formation will remain near the recharge well and probably will not spread laterally for a significant distance during the life of the well.

Projected Availability

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 most 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 below, by the year 2010 approximately seven percent of the water held in storage in the aquifer will have been used with approximately 7,004,000 acre-feet remaining.

Year	Water Demand[1]	Average Annual Effective Recharge	Storage[2] Depletion	Water remaining in the Aquifer
1985	43,679	30,000	13,679	7,500,000
1990	50,352	30,000	20,352	7,414,923
2000	50,561	30,000	20,561	7,210,358
2010	50,663	30,000	20,663	7,004,238

Water quantity in acre-feet.
[1] From Table 3.
[2] Pumpage minus recharge.

Well fields producing water for the cities of Big Lake and Rankin should not be overly affected by irrigation pumpage and, therefore, should have adequate supplies through the year 2010 considering required expansion of the fields to accommodate projected population growth. 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 Edwards-Trinity (Plateau) aquifer is the sole source of water for public supply and irrigation use in the study area with pumpage for irrigation representing 96 percent of the total ground-water use. Current and projected water demands are slightly in excess of the estimated annual recharge rate of 30,000 acre-feet. By the year 2010, approximately seven percent of the water currently held in storage in the aquifer is projected to have been withdrawn, with approximately 7,004,000 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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