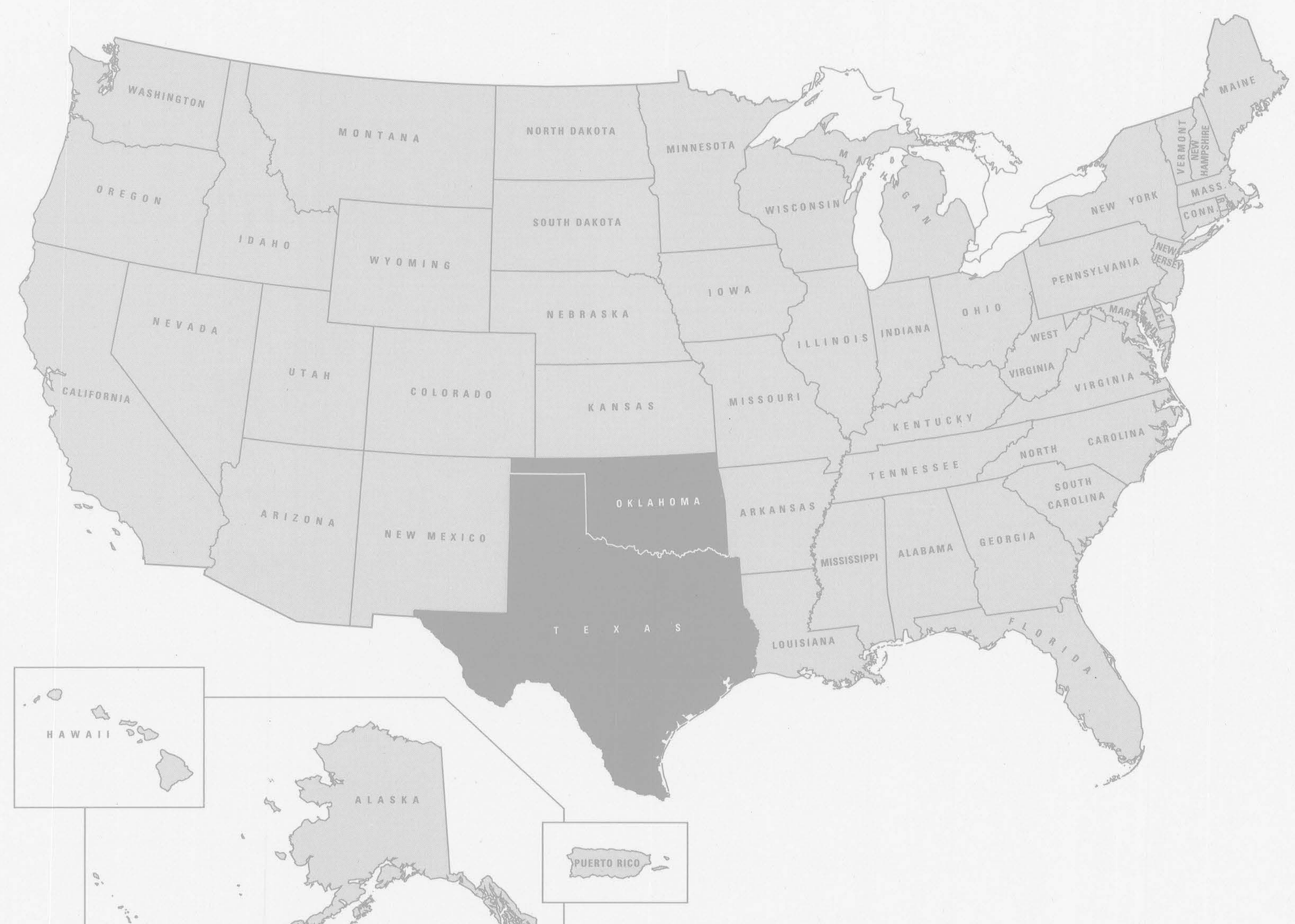
GROUND WATER ATLAS OF THE UNITED STATES

SEGMENT 4
Oklahoma
Texas



HYDROLOGIC INVESTIGATIONS ATLAS 730–E
U.S. Geological Survey

Reston, Virginia
1996

GROUND WATER ATLAS OF THE UNITED STATES

Hydrologic Investigations Atlas 730–E

FOREWORD

The Ground Water Atlas of the United States presents a comprehensive summary of the Nation's ground-water resources, and is a basic reference for the location, geography, geology, and hydrologic characteristics of the major aquifers in the Nation. The information was collected by the U.S. Geological Survey and other agencies during the course of many years of study. Results of the U.S. Geological Survey's Regional Aquifer-System Analysis Program, a systematic study of the Nation's major aquifers, were used as a major, but not exclusive, source of information for compilation of the Atlas.

The Atlas, which is designed in a graphical format that is supported by descriptive discussions, includes 13 chapters, each representing regional areas that collectively cover the 50 States and Puerto Rico. Each chapter of the Atlas presents and describes hydrogeologic and hydrologic conditions for the major aquifers in each regional area. The scale of the Atlas does not allow portrayal of minor features of the geology or hydrology of each aquifer presented, nor does it include discussion of minor aquifers. Those readers that seek detailed, local information for the aquifers will find extensive lists of references at the end of each chapter.

An introductory chapter presents an overview of ground-water conditions Nationwide and discusses the effects of human activities on water resources, including saltwater encroachment and land subsidence.

Gordon P. Eaton

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, *Secretary*

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, *Director*

CONVERSION FACTORS

For readers who prefer to use the International System (SI) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply inch-pound units	*By*	*To obtain metric units*
	Length	
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
billion gallons per day (Bgal/d)	3.785	million cubic meters per day (Mm^3/d)
acre-foot per year	0.00003909	cubic meter per second (m^3/s)
acre-foot	1,233	cubic meter (m^3)
	Temperature	
degree Fahrenheit (°F)	5/9 (°F–32)=°C	degree Celsius (°C)

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

ATLAS ORGANIZATION

The Ground Water Atlas of the United States is divided into 14 chapters. Chapter A presents introductory material and nationwide summaries; chapters B through M describe all principal aquifers in a multistate segment of the conterminous United States; and chapter N describes all principal aquifers in Alaska, Hawaii, and Puerto Rico.

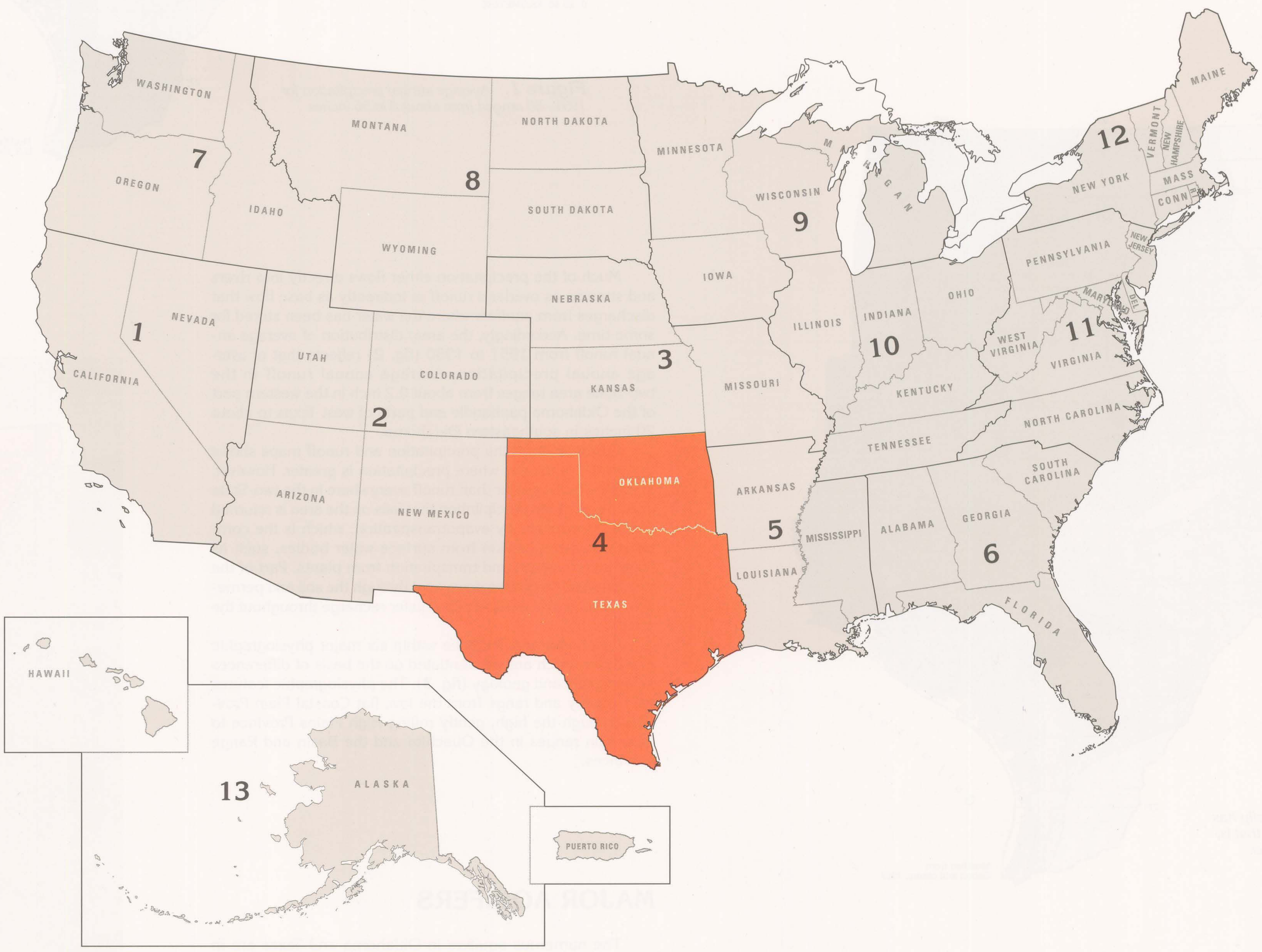
Segment Number	*Chapter content*	*Hydrologic Atlas Chapter*
—	Introductory material and nationwide summaries	730–A
1	California, Nevada	730–B
2	Arizona, Colorado, New Mexico, Utah	730–C
3	Kansas, Missouri, Nebraska	730–D
4	Oklahoma, Texas	730–E
5	Arkansas, Louisiana, Mississippi	730–F
6	Alabama, Florida, Georgia, South Carolina	730–G
7	Idaho, Oregon, Washington	730–H
8	Montana, North Dakota, South Dakota, Wyoming	730–I
9	Iowa, Michigan, Minnesota, Wisconsin	730–J
10	Illinois, Indiana, Kentucky, Ohio, Tennessee	730–K
11	Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia	730–L
12	Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont	730–M
13	Alaska, Hawaii, Puerto Rico	730–N

Ground Water Atlas of the United States

Segment 4

Oklahoma, Texas

By Paul D. Ryder



CONTENTS

Cartographic design and production by Gary D. Latzke, Bruce R. Droster, and Wendy J. Danchuk

Regional summary

INTRODUCTION

The two States, Oklahoma and Texas, that compose Segment 4 of this Atlas are located in the south-central part of the Nation. These States are drained by numerous rivers and streams, the largest being the Arkansas, the Canadian, the Red, the Sabine, the Trinity, the Brazos, the Colorado, and the Pecos Rivers and the Rio Grande. Many of these rivers and their tributaries supply large amounts of water for human use, mostly in the eastern parts of the two States. The large perennial streams in the east with their many associated impoundments coincide with areas that have dense populations. Large metropolitan areas such as Oklahoma City and Tulsa, Okla., and Dallas, Fort Worth, Houston, and Austin, Tex., are supplied largely or entirely by surface water. However, in 1985 more than 7.5 million people, or about 42 percent of the population of the two States, depended on ground water as a source of water supply. The metropolitan areas of San Antonio and El Paso, Tex., and numerous smaller communities depend largely or entirely on ground water for their source of supply. The ground water is contained in aquifers that consist of unconsolidated deposits and consolidated sedimentary rocks. This chapter describes the geology and hydrology of each of the principal aquifers throughout the two-State area.

Precipitation is the source of all the water in Oklahoma and Texas. Average annual precipitation ranges from about 8 inches per year in southwestern Texas to about 56 inches per year in southeastern Texas (**fig. 1**). In general, precipitation increases rather uniformly from west to east in the two States.

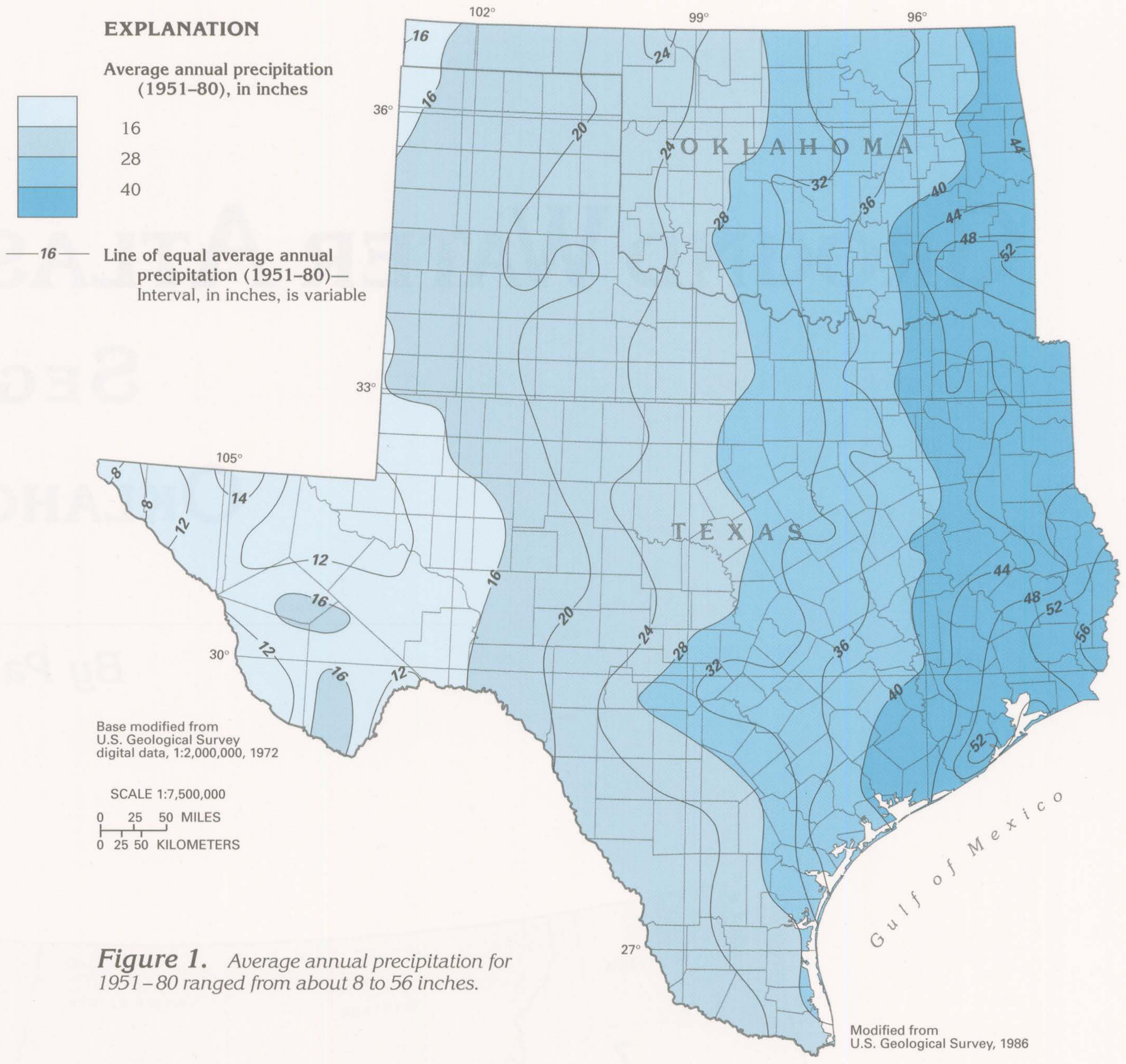


Figure 1. Average annual precipitation for 1951–80 ranged from about 8 to 56 inches.

Much of the precipitation either flows directly into rivers and streams as overland runoff or indirectly as base flow that discharges from aquifers where the water has been stored for some time. Accordingly, the areal distribution of average annual runoff from 1951 to 1980 (**fig. 2**) reflects that of average annual precipitation. Average annual runoff in the two-State area ranges from about 0.2 inch in the western part of the Oklahoma panhandle and parts of west Texas to about 20 inches in southeastern Oklahoma.

Comparison of the precipitation and runoff maps shows that runoff is greater where precipitation is greater. However, precipitation is greater than runoff everywhere in the two-State area. Much of the precipitation that falls on the area is returned to the atmosphere by evapotranspiration, which is the combination of evaporation from surface-water bodies, such as lakes and marshes, and transpiration from plants. Part of the precipitation percolates downward through the soil and permeable rocks and is available for aquifer recharge throughout the area.

Oklahoma and Texas lie within six major physiographic provinces which are differentiated on the basis of differences in landforms and geology (**fig. 3**). The physiographic features vary greatly and range from the low, flat Coastal Plain Province through the high, gently rolling High Plains Province to mountain ranges in the Ouachita and the Basin and Range Provinces.

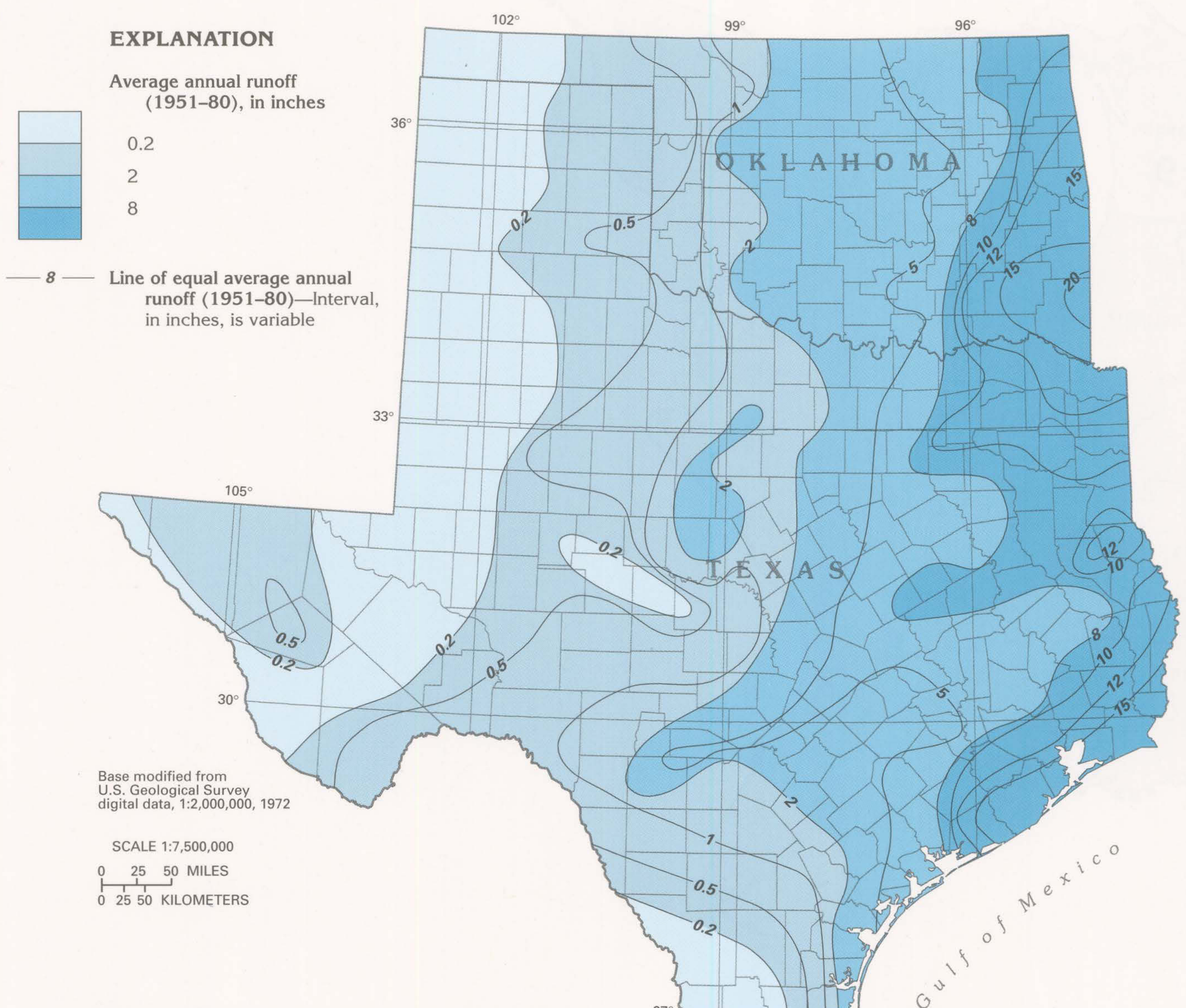


Figure 2. Average annual runoff generally has the same areal distribution as precipitation; that is, runoff is greater where precipitation is greater.

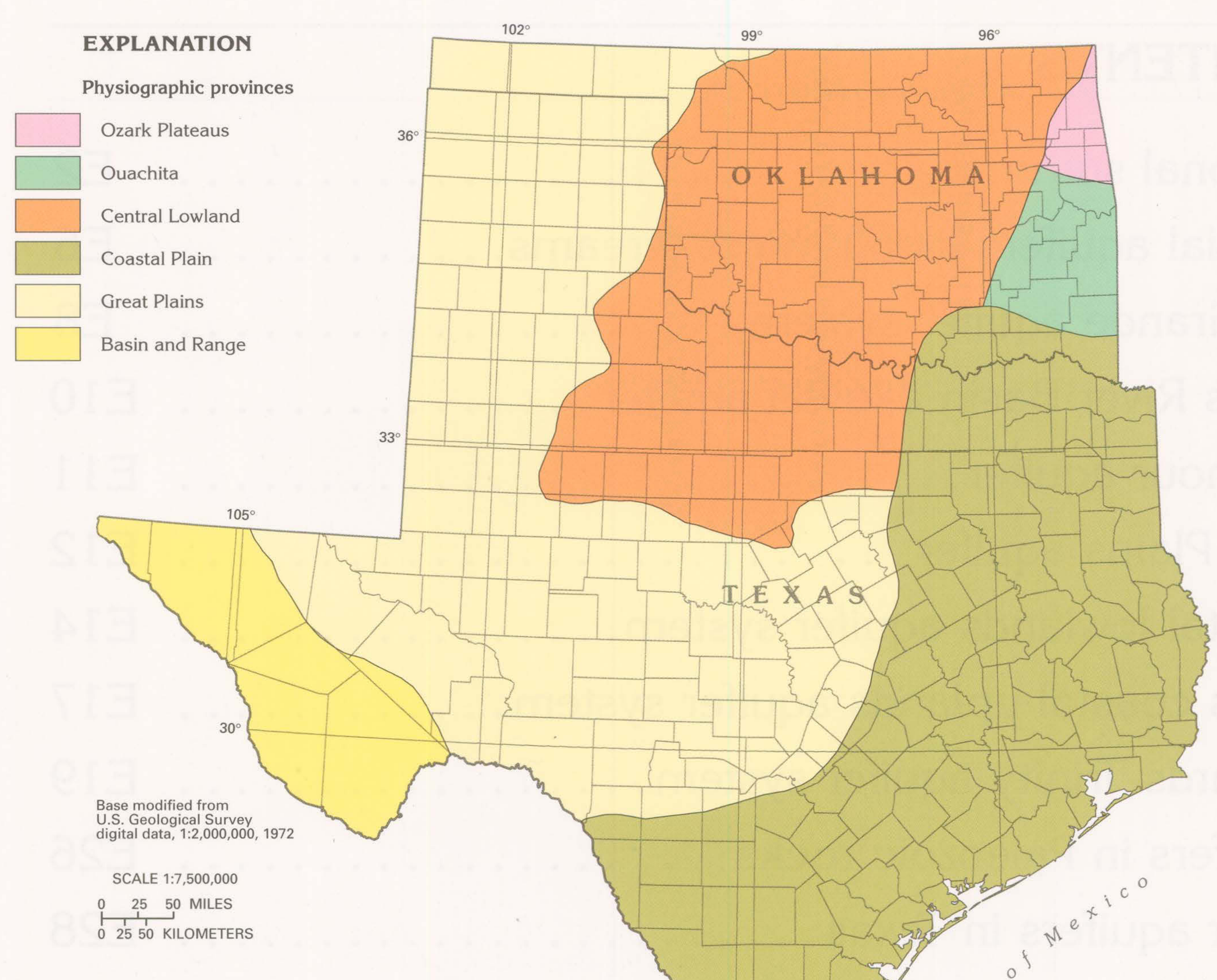


Figure 3. Oklahoma and Texas can be divided into six physiographic provinces on the basis of differences in landforms and geology. The physiographic features vary greatly in altitude and relief.

MAJOR AQUIFERS

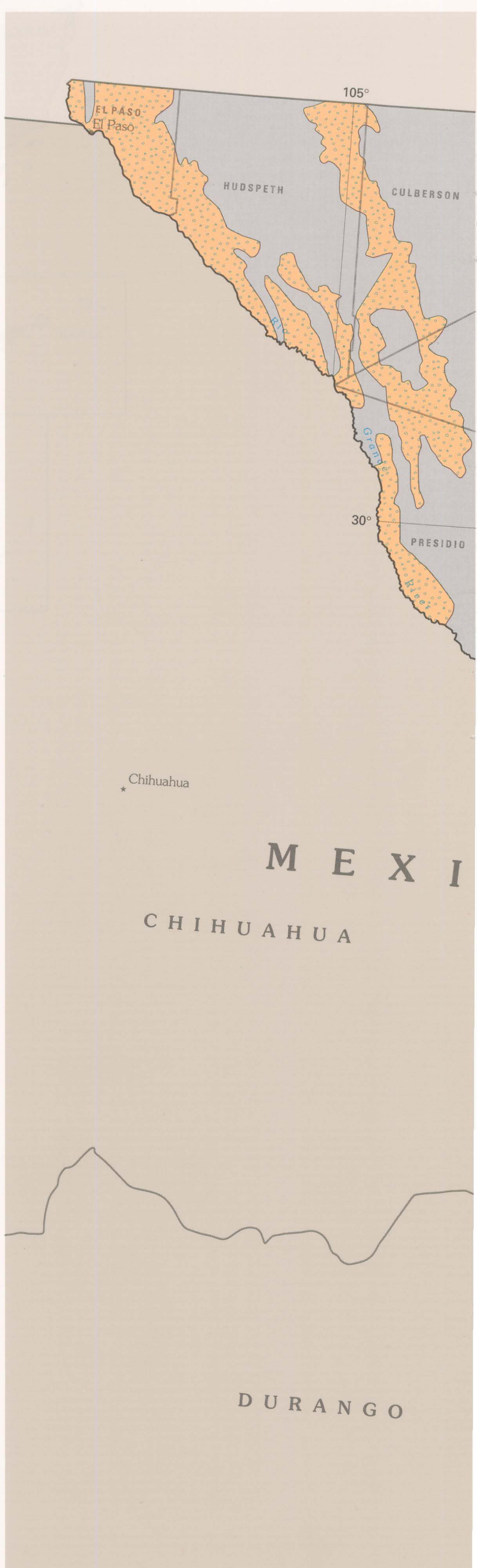
The numerous aquifers in Oklahoma and Texas are in geologic units that range from unconsolidated sand along major streams to consolidated carbonate rocks and sandstones that extend over wide areas. These aquifers are grouped into 16 major aquifers or aquifer systems on the basis of differences in their rock types and ground-water flow systems. An aquifer system is a grouping of two or more aquifers and can be of two types. One type consists of vertically stacked aquifers that are separated by confining units but are hydraulically connected—that is, their flow systems function in a similar manner, and a change in conditions in one aquifer affects the other aquifer(s). The second type is a set of aquifers that are not physically connected but share common geologic and hydrologic characteristics and can thus be studied and described together. Both types of aquifer systems are in Segment 4.

The approximate areal extent of 15 of the major aquifers or aquifer systems at the land surface is shown in **figure 4**: the 16th category, alluvial aquifers along major streams, is not shown in the figure. Where they are exposed at the land surface, the aquifers generally contain water that is fresh to slightly saline. The aquifers in this chapter generally are mapped only where they contain fresh to moderately saline water, except where physical boundaries determine the aquifer limits. Salinity in this report refers to the concentration of dissolved solids in water, which commonly is used as an indicator of the general suitability of the water for human use. Recommendations by the U.S. Environmental Protection Agency state that the dissolved-solids concentration in drinking water should not exceed 500 milligrams per liter. Water that has considerably greater concentrations can be suitable for other uses.

The terms used in this report to describe water with different concentrations of dissolved solids are as follows:

	Dissolved-solids concentration, in milligrams per liter
Freshwater	Less than 1,000
Slightly saline water	1,000 to 3,000
Moderately saline water	3,000 to 10,000
Very saline water	10,000 to 35,000
Brine	Greater than 35,000

The general term saline is used to describe water that is not fresh.



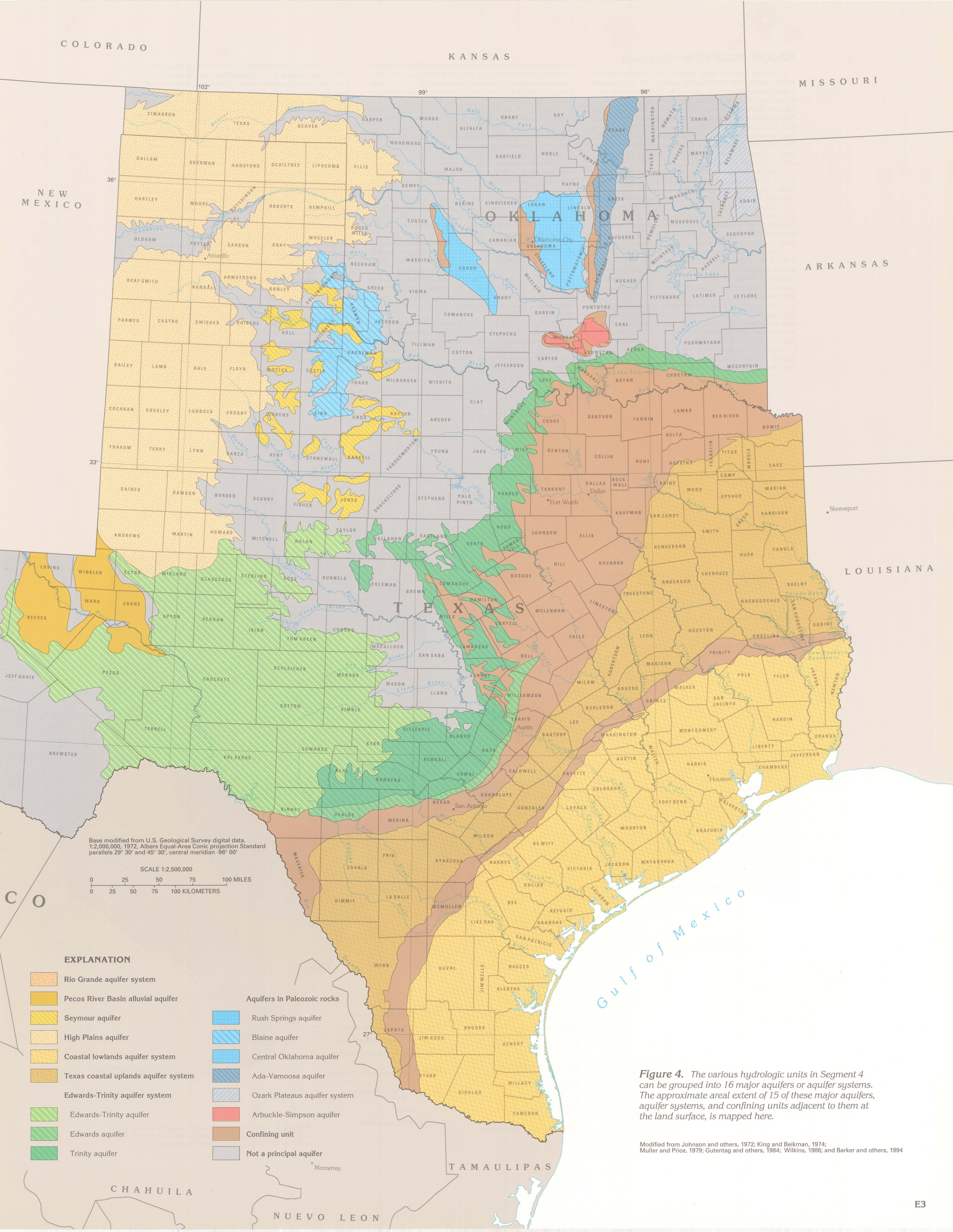


Figure 4. *The various hydrologic units in Segment 4 can be grouped into 16 major aquifers or aquifer systems. The approximate areal extent of 15 of these major aquifers, aquifer systems, and confining units adjacent to them at the land surface, is mapped here.*

Modified from Johnson and others, 1972; King and Beikman, 1974; Muller and Price, 1979; Gutentag and others, 1984; Wilkins, 1986; and Barker and others, 1994

MAJOR AQUIFERS—Continued

In some areas, a deep aquifer that contains fresh to slightly saline water underlies the outcrop of a major aquifer mapped here, For example, parts of the Edwards–Trinity aquifer are covered by the Pecos River Basin alluvial aquifer in northern Reeves and Pecos Counties, Tex. and by the High Plains aquifer in northern Ector, Midland, and Glasscock Counties, Tex. In addition, in some areas, alluvial aquifers along large streams cover small areas of underlying major aquifers. The rocks not classified as a major aquifer either yield little water or yield sufficient water for most uses but the areal extent of the water-yielding rocks is small.

Alluvial aquifers, which are discussed later in this chapter, are along major streams in Oklahoma and Texas. These aquifers consist of deposits of alluvium in and along stream channels, alluvial terraces that are remnants of older alluvium, and overlying windblown deposits. The deposits consist of clay, silt, sand, and gravel; only the sand and gravel yield water. The deposits range in age from Tertiary to Quaternary and are a few feet to more than 100 feet thick. The alluvial aquifers generally contain water under unconfined conditions.

The Rio Grande aquifer system in westernmost Texas is in the Basin and Range Physiographic Province (**fig. 3**). The aquifer system consists of thick deposits of unconsolidated basin-fill material, which is mostly sand but may include a variety of rock types and particle sizes that range from clay to boulders.

The Pecos River Basin alluvial aquifer is in the Great Plains Physiographic Province. The aquifer consists of unconsolidated sand and gravel, some of which was deposited by streams and some by wind. The deposits locally include clay, silt, and boulders. Small amounts of gypsum and caliche, which are formed by chemical processes, are in the Pecos River Basin alluvial aquifer. The Seymour aquifer is in the Great Plains and Central Lowland Physiographic Provinces. The aquifer consists mainly of scattered erosional remnants of the alluvial Seymour Formation of Pleistocene age. Saturated thickness of the scattered alluvial deposits is generally less than 100 feet, but large well yields are locally obtainable. The water is used mainly for agricultural purposes.

The High Plains aquifer is in the Great Plains Physiographic Province. The aquifer is in northwestern Oklahoma and west-central and northwestern Texas and consists of unconsolidated clay, silt, and sand, with some gravel and caliche. The aquifer provides large amounts of irrigation water and is the most intensively pumped aquifer in Oklahoma and Texas.

The coastal lowlands aquifer system contains numerous local aquifers in a thick sequence of mostly unconsolidated Coastal Plain sediments of alternating and interfingering beds of clay, silt, sand, and gravel. The sequence is generally wedge-shaped and dips and thickens toward the Gulf of Mexico. The local aquifers consist of sand and gravel and have been grouped into five permeable zones of regional extent. Large amounts of water are withdrawn from the aquifer system for municipal, industrial, and irrigation needs.

The Texas coastal uplands aquifer system is similar in configuration and composition to the coastal lowlands aquifer system. The two aquifer systems, which are situated in the Coastal Plain Physiographic Province, are hydraulically separated by clays of the Vicksburg and the Jackson Groups of Tertiary age, which compose a thick and effective confining unit. Large amounts of irrigation water are withdrawn from the Texas coastal uplands aquifer system in the agricultural Winter Garden area of Texas.

The Edwards–Trinity aquifer system is in rocks of Cretaceous age that are in a wide, looping band that extends across central Texas and into the southeastern corner of Oklahoma. The aquifer system is divided into three parts. In the western part of the Great Plains Physiographic Province, the Edwards–Trinity aquifer consists mostly of sandstone, sand, dolomite, and clay of Early Cretaceous age. In the south, at the contact of the Great Plains and the Coastal Plain Physiographic Provinces, the Edwards aquifer consists of limestone, dolomite, and marl. The rocks are extensively faulted, fractured, and cavernous, thus allowing the largest individual freshwater well yields in Texas and Oklahoma. The Edwards aquifer is the water supply for the city of San Antonio. The Trinity aquifer extends from the southeastern corner of Oklahoma southwestward into Uvalde County in southern Texas. The aquifer spans three physiographic provinces—the Central Lowland, the Coastal Plain, and the Great Plains. The rocks that compose the aquifer are mostly of Early Cretaceous age. In order of dominance, they consist of sandstone, sand, clay, conglomerate, caliche, shale, limestone, and dolomite.

Several aquifers and one aquifer system in Oklahoma and northern Texas are in Paleozoic rocks; generally, they yield small amounts of water to wells. The Rush Springs aquifer in west-central Oklahoma consists of fine-grained sandstone and is used primarily for irrigation. The Blaine aquifer in southwestern Oklahoma and northern Texas consists of fractured and cavernous gypsum and associated dolomite, and supplies water for irrigation. The Central Oklahoma aquifer consists of fine-grained sandstone, shale, and siltstone; it is an important source of water for suburban communities in the Oklahoma City area. The Ada–Vamoosa aquifer in east-central Oklahoma consists of sandstone and provides water for public and industrial use. The Rush Springs, the Blaine, the Central Oklahoma, and the Ada–Vamoosa aquifers are in the Central Lowland Physiographic Province. The Arbuckle–Simpson aquifer in south-central Oklahoma is in the Central Lowland Physiographic Province and consists of limestone, dolomite, and sandstone. The Ozark Plateaus aquifer system in northeastern Oklahoma is in the Ozark Plateaus Physiographic Province and consists of an upper aquifer in cavernous limestone and a lower aquifer in fractured dolomite with sandy zones.

GEOLOGY

Two general categories of sedimentary rocks comprise most of the rocks that underlie Oklahoma and Texas—mostly consolidated rocks of Paleozoic and Mesozoic age, and semiconsolidated to unconsolidated rocks of Cenozoic age. The Paleozoic (Cambrian through Permian) and Mesozoic (Triassic through Cretaceous) sedimentary rocks crop out mostly in Oklahoma and northern, central, and westernmost Texas. Cenozoic (Paleocene and younger) rocks underlie the Great Plains in the northwestern parts of Texas and Oklahoma; they also underlie the Coastal Plain where they form a broad, arcuate, coast-parallel band. Both categories of rocks have been divided into numerous formations, as shown on the correlation charts that accompany the discussions of the major aquifers in the following sections of this chapter.

The majority of the water-yielding Paleozoic and Mesozoic rocks are limestone and dolomite; however, sandstone formations are productive aquifers, especially in Oklahoma, and some water also is obtained locally from fractured shale, siltstone, and gypsum. Most Cenozoic aquifers are in clastic rocks.

The geologic and hydrogeologic nomenclature used in this report differs from State to State because of independent geologic interpretations and varied distribution and lithology of rock units. A fairly consistent set of nomenclature, however, can be derived from the most commonly used rock names. Therefore, the nomenclature used in this report is basically a synthesis of that of the U.S. Geological Survey, the Texas Bureau of Economic Geology, and the Oklahoma Geological Survey. Individual sources for nomenclature are identified on the figures prepared for this report.

The geologic map (**fig. 5**) shows the distribution of rocks by major age category. Numerous geologic features, such as faults and lineaments, are not shown on the geologic map for the sake of simplicity. Where these features are important hydrologically, they will be depicted and discussed in later sections of this chapter. The geologic sections (**figs. 6 through 8**) show some of the major subsurface structures in Oklahoma and Texas.

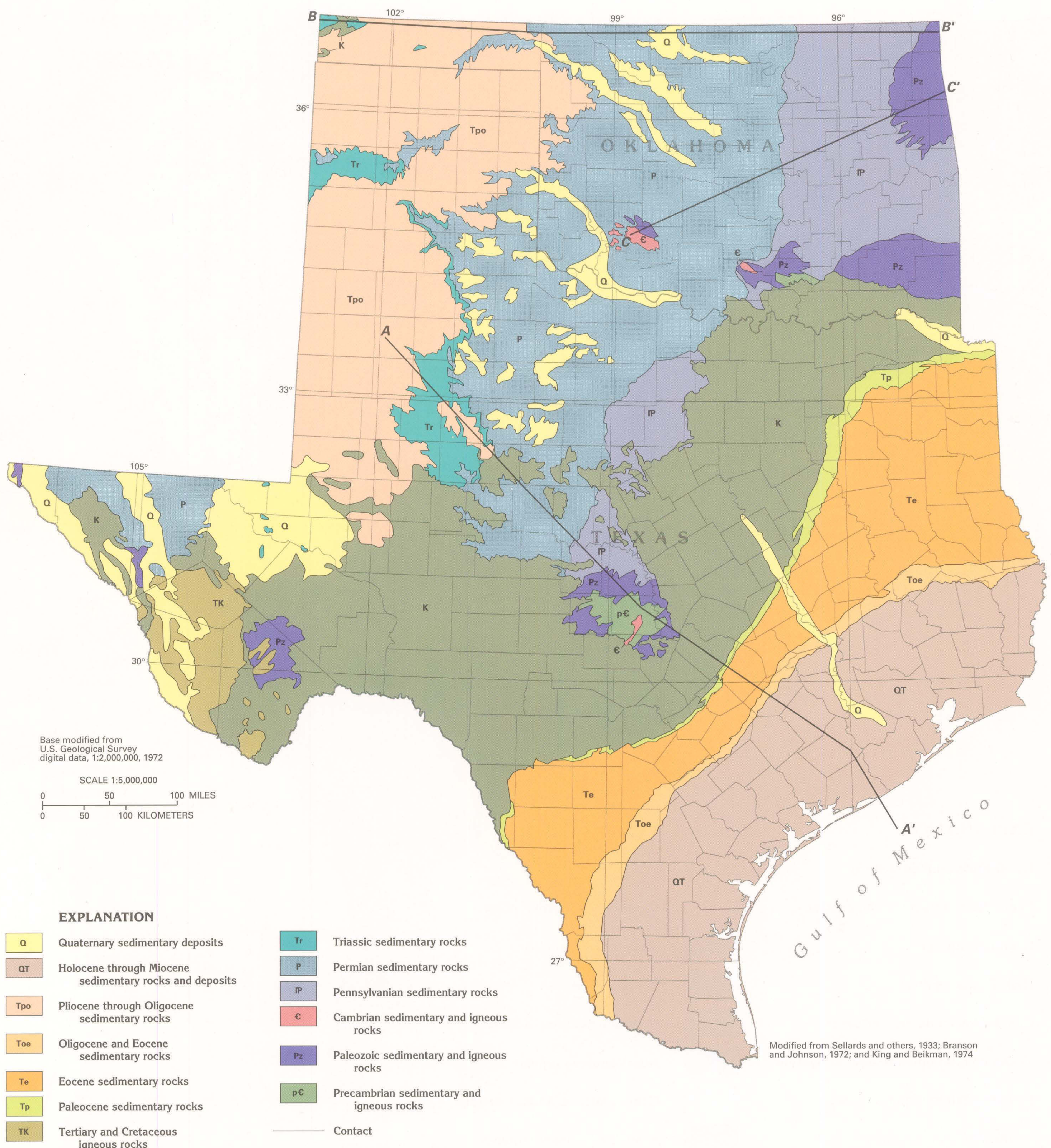


Figure 5. A simplified geologic map shows the extent of the major rock units and unconsolidated deposits in Segment 4. The rocks and deposits range in age from Precambrian to Holocene.

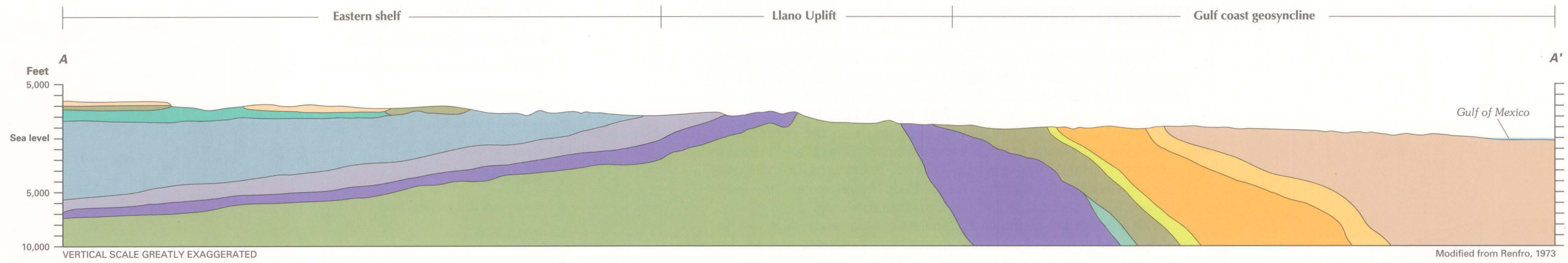


Figure 6. A geologic section through Texas shows that Precambrian rocks are exposed in the vicinity of the Llano Uplift. Rocks of Paleozoic through Tertiary age have relatively shallow dips on the northwest flank of the uplift. On the southeast flank of the uplift, the rocks dip rather steeply toward and under the Gulf of Mexico.

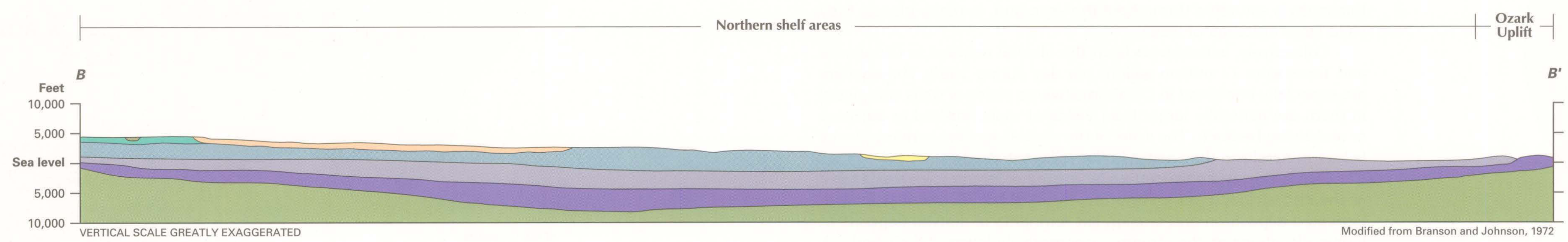


Figure 7. A geologic section across northernmost Oklahoma shows relatively flat-lying strata. The rocks that are exposed range in age from Paleozoic to Quaternary.

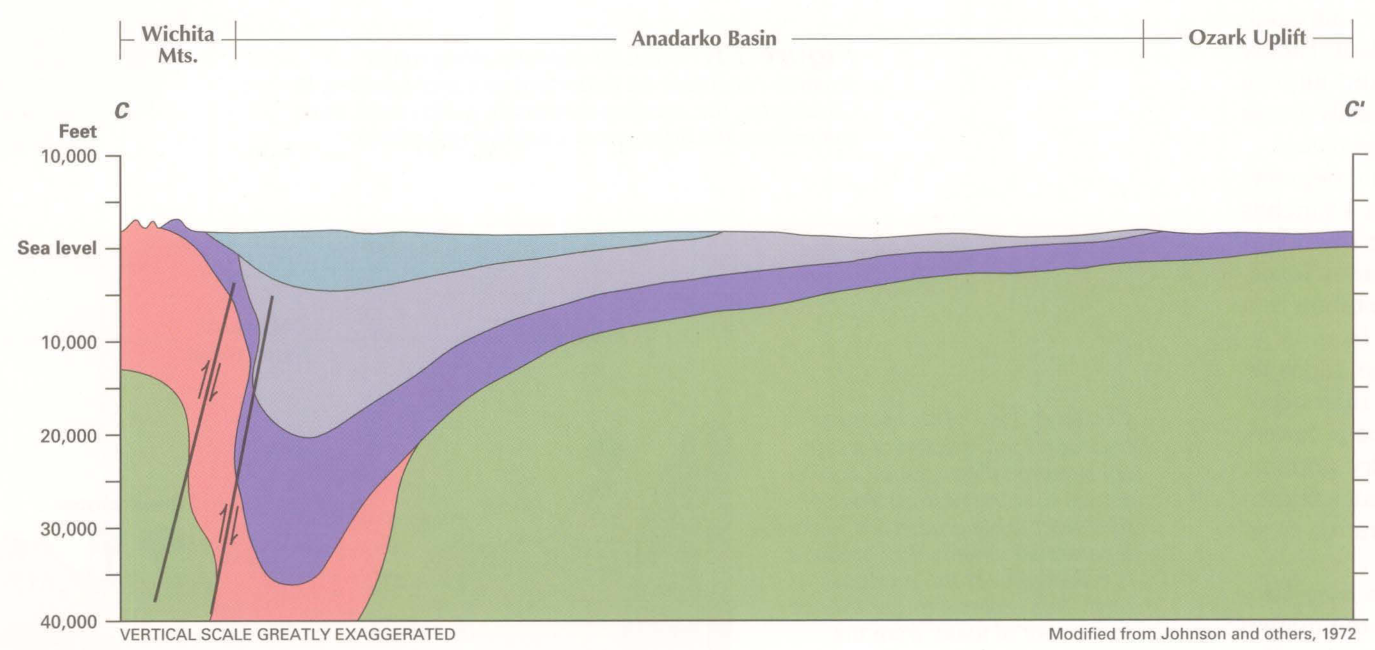
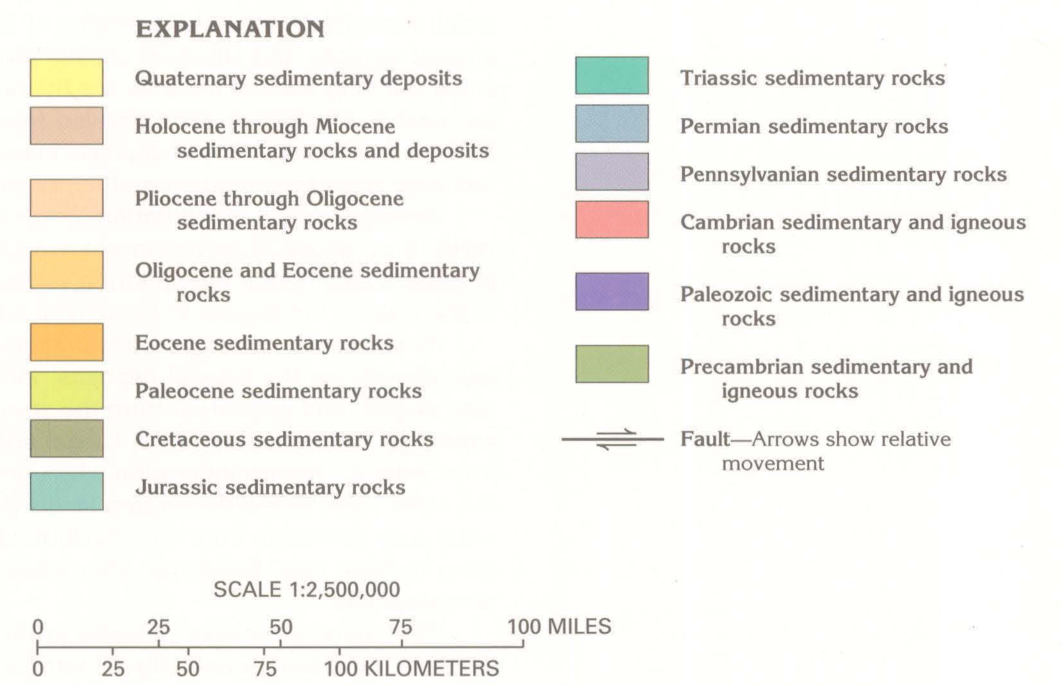


Figure 8. A geologic section through central Oklahoma shows that Cambrian rocks are exposed in the Wichita Mountains. On the flank of the Wichita Mountain Uplift, a great thickness of Paleozoic rocks has accumulated in the Anadarko Basin. The rocks rise gradually toward the Ozark Uplift.



FRESH GROUND-WATER WITHDRAWALS

Ground water is the source of water supply for more than 7.5 million people, or about 42 percent of the population in the two-State area. About 7,300 million gallons per day was withdrawn from all the principal aquifers during 1985; 80 percent of this amount was used in rural areas for agricultural, domestic, and commercial supplies. Withdrawals for public supplies were small and accounted for only about 16 percent of the total water withdrawn.

Total freshwater withdrawals during 1985, by county, are shown in **figure 9**. Counties with the largest withdrawals are those with large irrigated acreage and large population centers. About 94 percent of the ground water was withdrawn in Texas, and the remainder was withdrawn in Oklahoma. Locally, slightly saline ground-water withdrawals are included in the mapped amounts.

Total withdrawals of freshwater (including slightly saline water) during 1985 from each of the principal aquifers in the two-State area are shown in **figure 10**. The largest withdrawal, 4,508 million gallons per day, was from the High Plains aquifer; this is about four times as much water as was withdrawn from the second most used aquifer, the coastal lowlands aquifer system (1,090 million gallons per day), and more than 2.5 times as much water as was withdrawn from all the other principal aquifers combined. The Edwards aquifer was the third most used aquifer with a withdrawal rate of 467 million gallons per day; more than one-half was withdrawn in Bexar County, Tex., where ground water is the source of water supply for the city of San Antonio.

About 397 million gallons per day was withdrawn from the Texas coastal uplands aquifer system, the fourth most used aquifer, during 1985. During the same year, the Trinity aquifer provided 182 million gallons per day, and 145 million gallons per day was withdrawn from the Edwards–Trinity aquifer. Withdrawals from the Rio Grande aquifer system and the Seymour aquifer during 1985 were 126 and 121 million gallons per day, respectively. The Pecos River Basin alluvial aquifer and the alluvial aquifers along major streams accounted for withdrawals of 80 and 71 million gallons per day, respectively, during 1985. Withdrawals from the mostly indurated aquifers in Paleozoic rocks in Oklahoma and northern Texas were small; during 1985, the Rush Springs, the Central Oklahoma and the Ada–Vamoosa, the Blaine, the Ozark Plateaus, and the Arbuckle–Simpson aquifers accounted for 52, 48, 24, 9, and 8 million gallons per day, respectively.

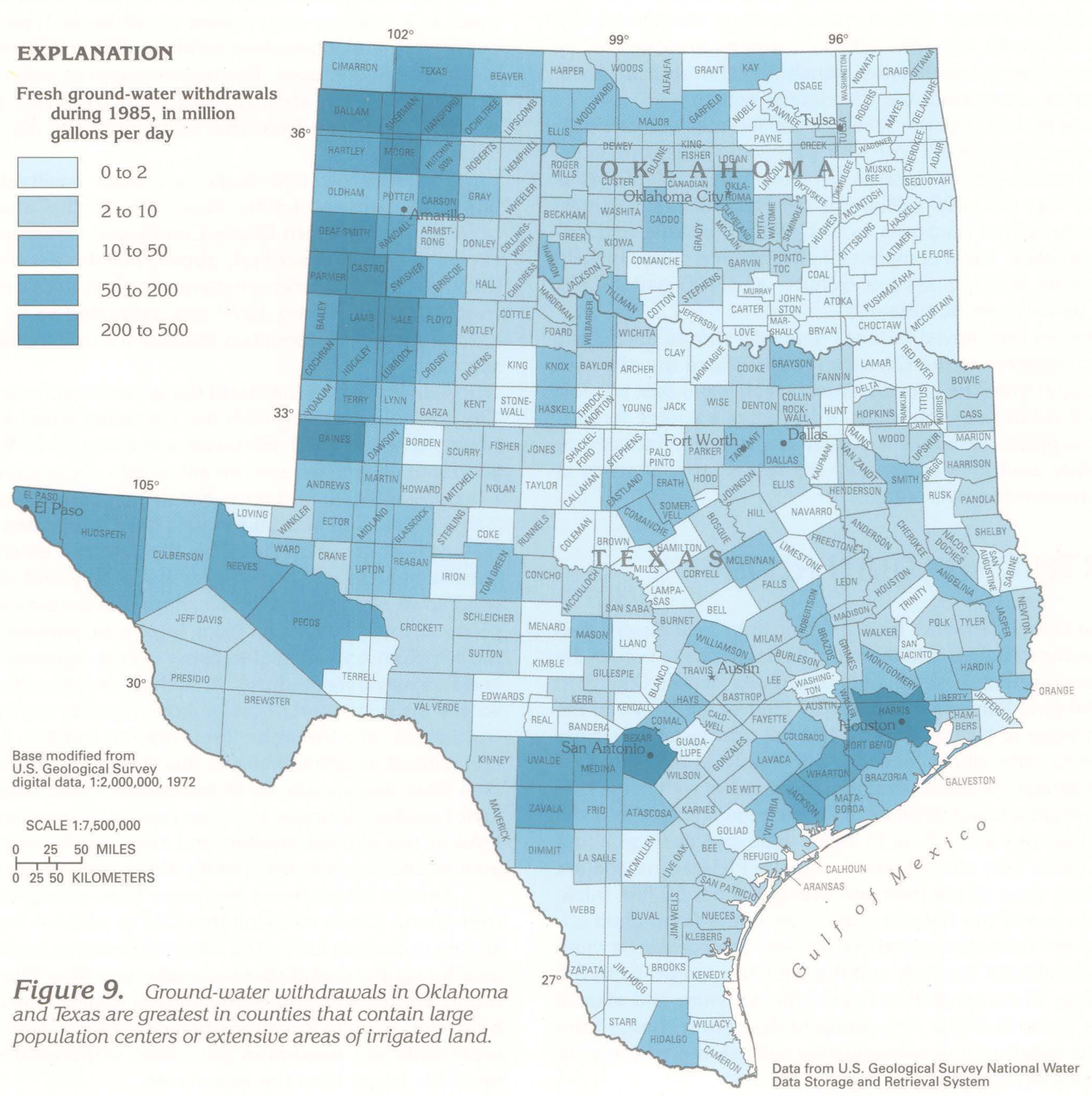


Figure 9. Ground-water withdrawals in Oklahoma and Texas are greatest in counties that contain large population centers or extensive areas of irrigated land.

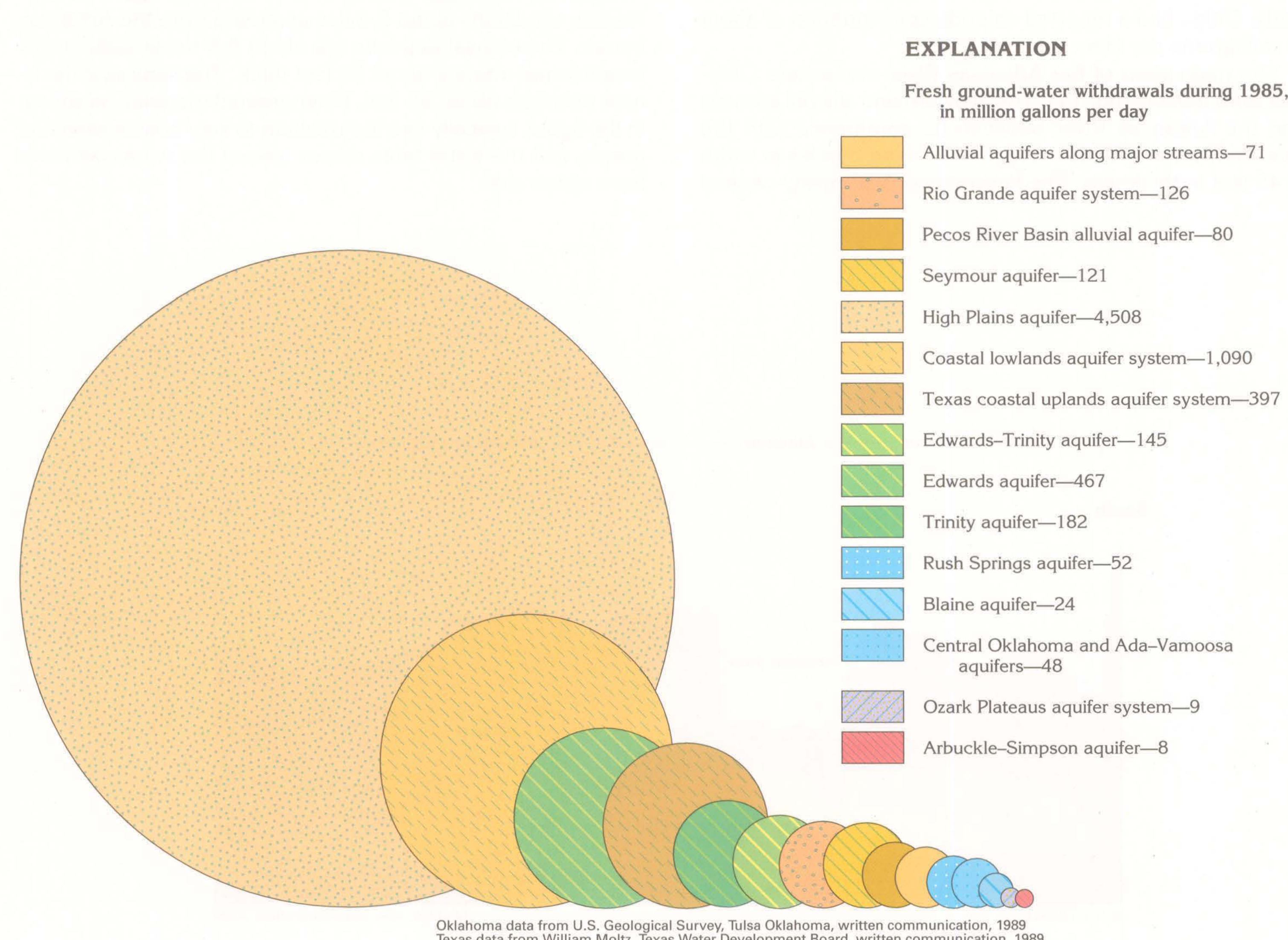


Figure 10. The High Plains aquifer was the source of about 62 percent of the fresh ground-water withdrawals in the two-State area during 1985; about 15 percent of the freshwater was withdrawn from the coastal lowlands aquifer system, the second most used aquifer.

Alluvial aquifers along major streams

INTRODUCTION

Alluvial aquifers of major importance are along many of the larger streams in the two-State area (**fig. 11**). These streams are the Salt Fork Arkansas and the Arkansas, the Cimarron, the North Canadian, the Canadian, the Washita, the North Fork Red and the Red, the Brazos and the Neosho Rivers. The alluvial deposits, with the exception of those along the Brazos and the lower Arkansas Rivers, are limited to the Central Lowland Physiographic Province. The Brazos River deposits are in the Great Plains and the Coastal Plain Provinces, and the lower Arkansas River deposits are in the Ouachita Province.

The aquifers are generally in deposits of Quaternary age, are unconfined, and consist of sand and gravel with some clay and silt. Locally, they include deposits of Tertiary age. The aquifer materials are commonly segregated by size into lenses and beds, which can affect the movement and availability of water. Beds and lenses of sand, gravel, or mixtures of the two yield most of the water. The deposits may be more than 100 feet thick and several miles wide, much of their total thickness is saturated throughout the year, and, in many places, they yield large amounts of water.

Collectively, withdrawals from the alluvial aquifers in Oklahoma and Texas were 71 million gallons per day during 1985. The aquifers are especially important in Oklahoma, where yields of wells completed in them are generally larger than yields of wells finished in adjacent or underlying bedrock. The water in the alluvial aquifers in many places is less mineralized than water in the adjacent streams.

Deposition and downcutting by the major streams were extensive at the end of the Tertiary Period and during the Quaternary Period. Repeated deposition and erosion left remnants of alluvial deposits at higher elevations as the streams progressively lowered their beds. A series of alluvial terraces was often the result, the youngest of which might be only a few feet higher than the present-day flood plain. Alluvium, as distinguished from alluvial terraces, is the most recent material deposited within the confines of the present flood plain. The alluvial terraces and alluvium usually form a single aquifer, although some outlying alluvial terraces are hydraulically independent. Highly permeable windblown sand derived from the alluvium and alluvial terraces overlies the alluvial deposits in many places and readily stores recharge from precipitation and conducts the recharge downward.

Average annual precipitation in the areas of the alluvial deposits varies from about 22 inches in western Oklahoma to about 44 inches in eastern Oklahoma. Precipitation varies from about 32 to 46 inches in the area of the Brazos River alluvial aquifer in southeastern Texas.

Most natural recharge to the aquifers occurs as precipitation that falls directly on the alluvial deposits, infiltration of runoff from adjacent slopes, and infiltration from the streams that cross the deposits, especially during higher flows. Large, additional recharge may occur from induced stream infiltration when ground-water pumpage lowers the water table below the stream levels (**fig. 12**). During dry periods, water may discharge from the alluvium into the streams, thus contributing to base flow. Discharge also takes place as transpiration from phreatophytes.

The chemical quality of water in the alluvial deposits may vary between the alluvium and alluvial terraces, thus reflecting the quality of the major source of recharge. The source of recharge for the alluvium may be the river and that for the alluvial terraces may be precipitation and leakage from underlying or adjacent aquifers.

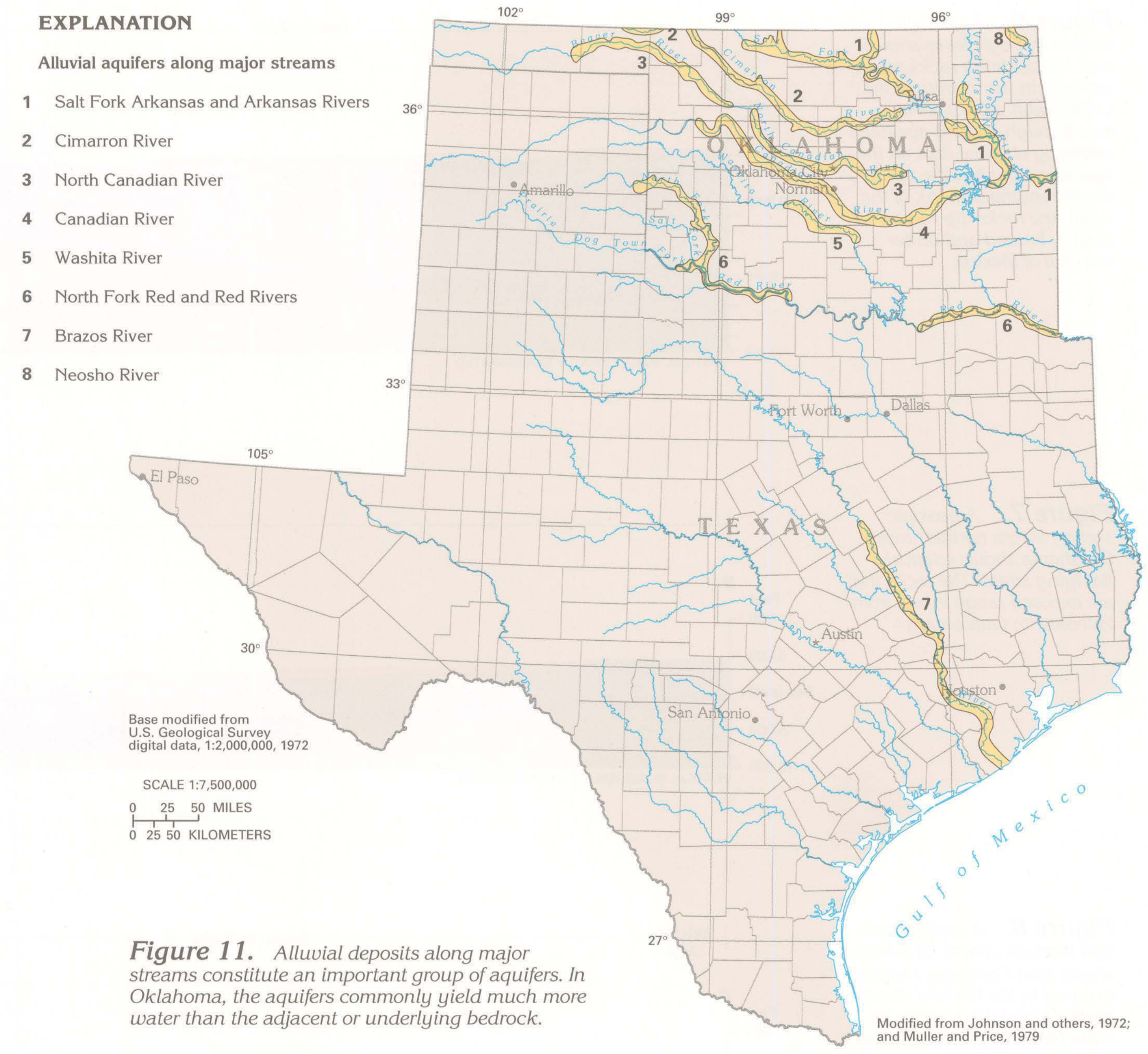


Figure 11. *Alluvial deposits along major streams constitute an important group of aquifers. In Oklahoma, the aquifers commonly yield much more water than the adjacent or underlying bedrock.*

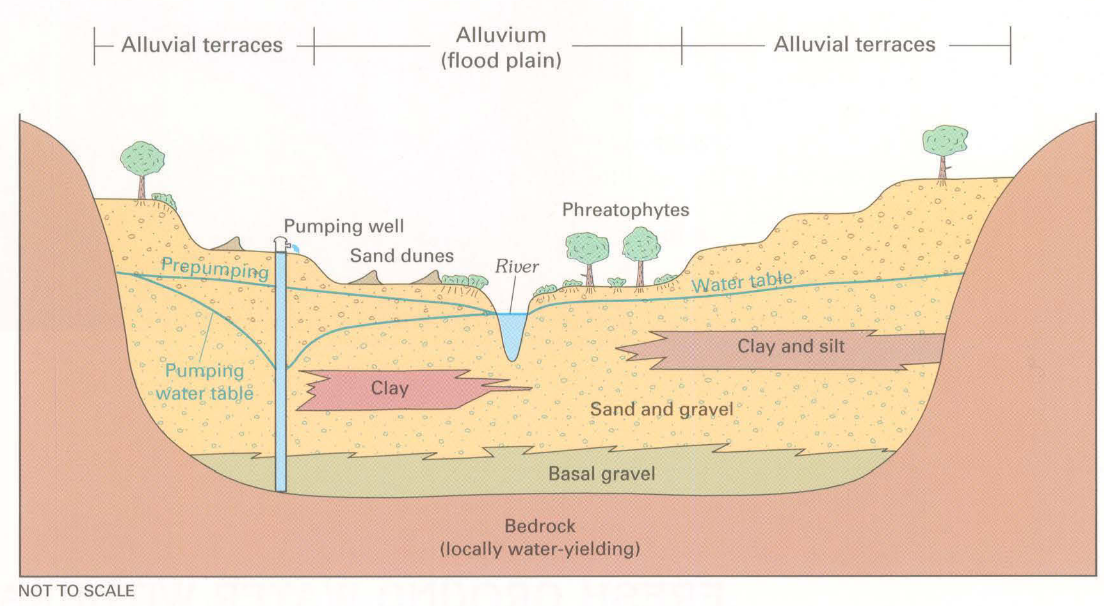


Figure 12. *This idealized hydrogeologic section of a typical stream-valley alluvial aquifer shows that the natural slope of the water-table gradient is toward a perennial stream. The gradient is reversed near the pumping well. This reversal might induce movement of water from the stream toward the well.*

SALT FORK ARKANSAS RIVER AND ARKANSAS RIVER

The Salt Fork Arkansas River originates in the so-called gypsum hills of southern Kansas and contains water with large concentrations of calcium sulfate as it enters Woods County, Okla. The river then receives large amounts of sodium chloride downstream from natural brine springs and salt plains in Alfalfa County, Okla. The river contains saline water, which is unsuitable for most uses, downstream to its junction with the Arkansas River.

Alluvium and alluvial terrace deposits as much as 10 miles wide and 150 feet thick are located along the entire length of the Salt Fork Arkansas River. Water in alluvium close to the river can reflect the chemical quality of the river water. For example, the water in the alluvium that formerly supplied a small city in Woods County, Okla., is a hard, calcium sulfate type. Downstream from the salt plain in Alfalfa County, water from the alluvium that supplies a small city in Grant County, Okla., had a reported chloride concentration of about 370 milligrams per liter.

The main stem of the Arkansas River also enters Oklahoma from Kansas (**fig. 11**). The alluvium and alluvial terraces along the Arkansas River between its confluence with the Cimarron River and Tulsa average more than 5 miles in width and 45 feet in thickness. The deposits consist mostly of sand and gravel, and the water table is generally less than 20 feet below land surface. Wells constructed mostly for irrigation use yield as much as 600 gallons per minute and average 350 gallons per minute.

Between about the mouth of the Cimarron River and the mouth of the Canadian River, the alluvial aquifer consists mostly of sand and gravel about 40 feet thick. The water table is generally from 10 to 20 feet below land surface. Direct recharge from precipitation results in ground water with smaller concentrations of dissolved solids than the river water. Yields of wells constructed mostly for irrigation purposes commonly are 300 to 500 gallons per minute.

Between the Canadian River junction and the Arkansas State line, the alluvium and alluvial terraces along the Arkansas River are about 40 feet thick and consist mostly of sand and gravel. The diagrammatic section shown in **figure 13** represents conditions about 5 miles upstream from the Arkansas border. The alluvial deposits are about 5.5 miles wide at this location and average about 50 feet thick. The saturated thickness averages about 35 feet. Finer grained material, as shown in the figure, typically overlies medium to very coarse sand and gravel, and the water table slopes toward the Arkansas River from either side.

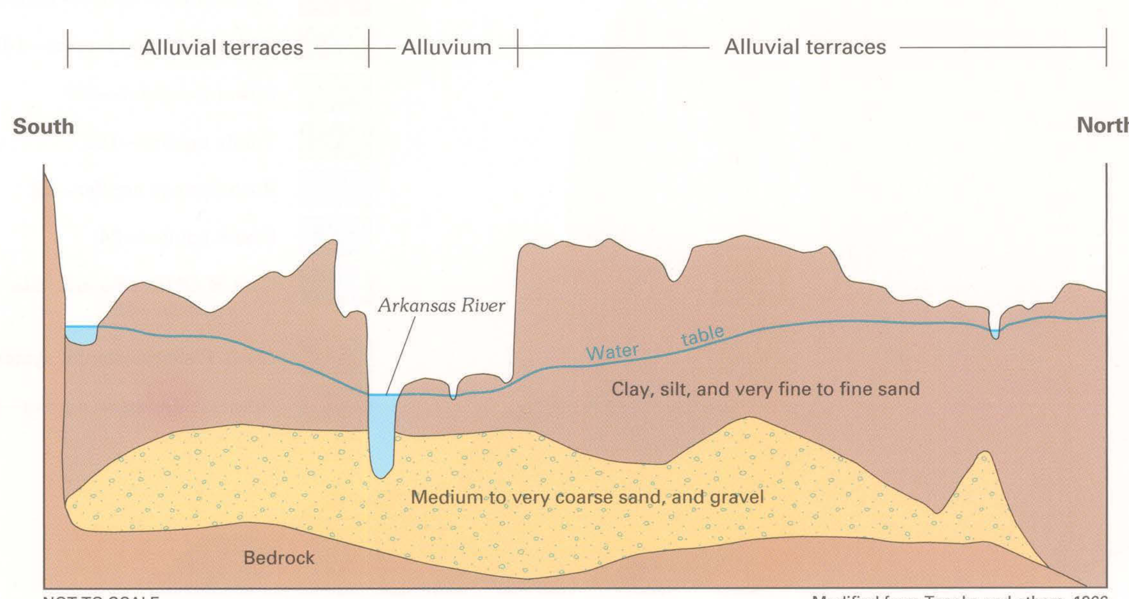


Figure 13. *An idealized hydrogeologic section of the alluvial aquifer adjacent to the Arkansas River just upstream from the Oklahoma–Arkansas State line shows that finer grained alluvial material typically overlies coarser deposits. The average long-term water table slopes from both sides toward the river.*

CIMARRON RIVER

The Cimarron River enters Oklahoma from Kansas (**fig. 11**) and flows across Permian red beds in Harper, Major, and Woodward Counties. The red beds contain thick layers of salt and gypsum that are easily dissolved and are responsible for highly mineralized surface waters and ground water in the alluvium. The alluvium on the southwestern side of the Cimarron River in these counties is a poor source of ground water. The limited supplies taht can be pumped are highly mineralized (calcium sulfate and sodium chloride); some of the water is suitable for livestock, but not for human consumption. However, the alluvial terraces on the northeastern side of the river compose one of the best aquifers in Oklahoma. The alluvial terraces extend for 110 miles from southern Woods County to western Logan County and range from 3 to 15 miles in width; average width is about 10 miles. The terraces consist of sand and gravel with some clay and sandy clay and have an average thickness of about 60 feet and an average saturated thickness of about 40 feet. The alluvial terraces are overlain by windblown sands that readily transmit recharge from local precipitation downward into the alluvial aquifer.

Water in the Cimarron River alluvial terraces is a calcium-magnesium bicarbonate type with dissolved-solids concentrations of about 400 milligrams per liter or less. Hardness is generally less than 200 milligrams per liter. The water is suitable for municipal purposes as well as for domestic and irrigation supplies. Wells completed in the terrace deposits yield as much as 600 gallons per minute, and 100 gallons per minute usually can be obtained.

Water in the alluvial terraces generally moves toward the alluvium adjacent to the Cimarron River. Where the alluvium is recharged from the alluvial terraces with water that has low dissolved-solids concentrations, it becomes a source for municipal supplies. Wells in the alluvium that are intensively pumped or are too near the river are subject to infiltration of highly mineralized river water.

NORTH CANADIAN RIVER

The North Canadian River originates in New Mexico and flows eastward across Oklahoma. Alluvial deposits border the river from western Texas County to eastern Beaver County in the Oklahoma Panhandle but supply little water. Between the western edge of Harper County and the northwestern corner of Blaine County, alluvial deposits are mainly on the north side of the river and consist of sand and basal gravel with some clay and silt. High alluvial terraces of Pleistocene age on the north side of the river are 1.5 to 11 miles wide and average about 70 feet thick. Low alluvial terraces of late Pleistocene age are along both sides of the river and average about 50 feet thick; the thickness of the Holocene alluvium in the flood plain adjacent to the river averages about 30 feet. The combined width of the low alluvial terraces and the alluvium ranges from 0.5 to 2 miles. Dune sands that overlie the alluvium and alluvial terraces in much of the area temporarily store recharge from local precipitation and subsequently release the recharge to the underlying deposits.

The water table in the alluvial deposits between western Harper County and northwestern Blaine County ranges from about 20 to 80 feet below land surface. The general direction of ground-water flow is toward the North Canadian River. Specific yield of the deposits is estimated to average 0.29. Specific yield is the volume of water that will drain by gravity from a given volume of soil or rock. It can be expressed as a percentage; in this example, 29 percent of the water in each volume of saturated alluvial material will drain under the influence of gravity alone. Hydraulic conductivity is a measure of the rate at which water will pass through an aquifer—the higher the hydraulic conductivity, the more permeable the aquifer. Hydraulic conductivity of the aquifer is as much as 160 feet per day and averages 59 feet per day. Recharge by infiltration from precipitation is on the order of 1 inch per year. Wells completed in the deposits yield as much as 1,000 gallons per minute. The water is a calcium-magnesium bicarbonate type, has small concentrations of dissolved solids, and is suitable for municipal and irrigation uses. The aquifer supplies water for several small towns in the area. An estimated 18 million gallons per day was withdrawn from this segment of the alluvial aquifer during 1977.

The lithologic, hydrologic, and water-quality characteristics of the alluvial aquifer along the North Canadian River between northwestern Blaine County and Oklahoma City are similar to those described, above, but the areal extent and thickness of the aquifer are somewhat less in this reach of the river. Pumpage during 1977 was estimated to be 12 million gallons per day, or about two-thirds of the rate for the upstream segment.

Alluvium along the North Canadian River from Oklahoma City to its confluence with the Canadian River in McIntosh County is about 2 to 3 miles wide and about 30 to 40 feet thick. Scattered alluvial terraces on either side of the alluvium reach a maximum width of 8 miles but usually have a width of from 2 to 3 miles. The alluvial terraces have a reported maximum thickness of about 80 feet. The alluvium and alluvial terraces consist of sand and gravel with some clay and silt. Locally, windblown sand covers the alluvium and terraces and acts to promote rapid infiltration from local precipitation. In places, the alluvium and alluvial terraces overlie aquifers in Permian and Pennsylvanian bedrock. In such places, the alluvial deposits and the upper part of the bedrock aquifers are hydraulically continuous, and the water levels are the same in the bedrock and alluvial aquifers. Water in this stretch of the North Canadian River is generally more mineralized than water in the alluvial aquifer. At times, the river level is higher than the water level in the alluvial aquifer, and river water could enter the aquifer and degrade the quality of the ground water.

Annual estimates of recharge from precipitation range from about 1 inch at Oklahoma City to about 4 inches downstream at Eufaula Lake. The water table slopes toward the river, and the aquifer contributes to stream base flow. The withdrawal rate from this segment of the alluvial aquifer was reported to be about 19 million gallons per day during 1982. This rate represents the maximum permitted withdrawal rate and is probably larger than the actual rate.

CANADIAN RIVER

The Canadian River enters Texas from New Mexico and flows eastward across the Texas Panhandle. Alluvium and alluvial terraces are located along the river from Dewey County, Okla., southeastward and eastward to the western part of McIntosh County, Okla.

Wells completed in the alluvium and alluvial terraces yield as much as 500 gallons per minute. Where the ground water is not highly mineralized, the aquifer is a source of supply for various uses. However, the chemical quality of the water is variable, and, although the aquifer can be used locally, it has little potential for wide-scale development.

Results of a study of the potential of the alluvial aquifer along the Canadian River near Norman, Okla. (**fig. 14**), indicate that the alluvial terraces contain a large amount of potable water. The alluvial terraces are about 50 feet above the flood plain. The alluvium and alluvial terraces consist of clay, silt, sand, and basal gravel and are as much as 80 feet thick. Dune sands that cover the alluvial terraces and alluvium in many places allow the ready infiltration of precipitation. Under natural conditions, movement of water in the aquifer is from recharge areas where precipitation infiltrates the alluvial terraces downgradient to discharge into the river as base flow.

Ground-water recharge in the Norman area is about 8 inches per year, or about one-fourth of normal annual precipitation. The specific yield of the saturated deposits is estimated to be 15 percent, and the average hydraulic conductivity of the aquifer is 134 feet per day.

Water in the terrace deposits is less mineralized than that in the alluvium. In places, more mineralized river water can infiltrate the alluvium, which causes sulfate, chloride, and dissolved-solids concentrations in the ground water to exceed the limits recommended for drinking water by the U.S. Environmental Protection Agency.

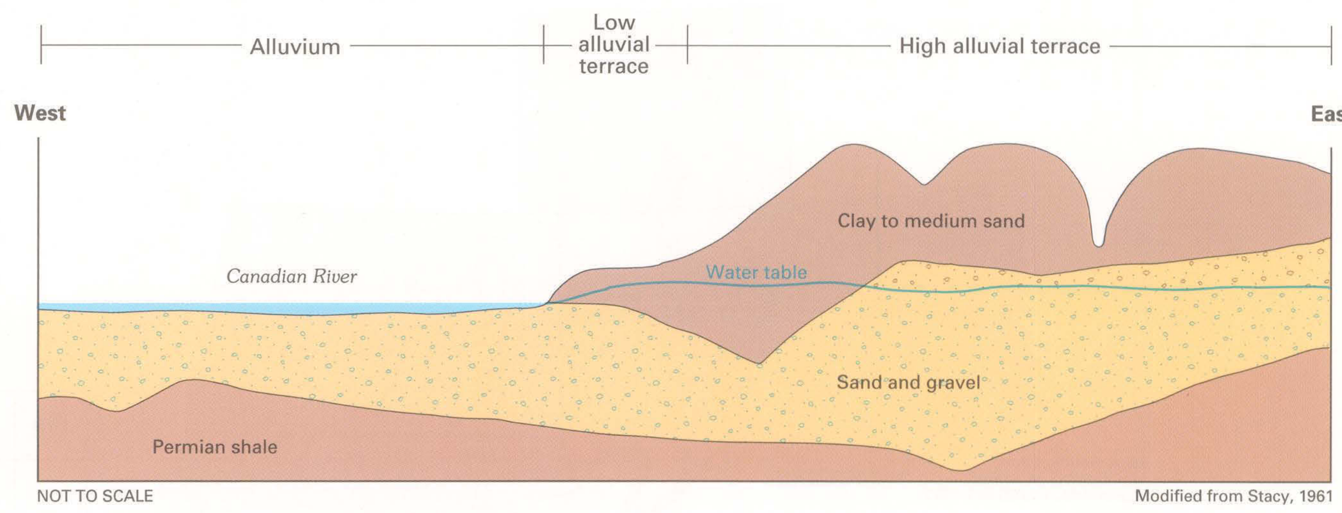


Figure 14. *This generalized hydrogeologic section shows that the alluvial aquifer adjacent to the Canadian River in the Norman, Okla., area consists of fine grained deposits overlying coarse sand and gravel. The water table in the deposits east of the river slopes gently toward the river.*

WASHITA RIVER

The Washita River originates in the Texas Panhandle and flows eastward into Oklahoma and then southeastward to discharge into the Red River. Alluvium and alluvial terraces are along the Washita River mainly in Grady and Garvin Counties, Okla.

Between the Caddo–Grady County line and southeastern Garvin County, the alluvial valley averages about 2 miles in width and has a maximum width of 3 miles. The alluvium has an average thickness of about 64 feet and a maximum thickness of 120 feet. Depth to water in the alluvium is generally less than 20 feet. Maximum thickness of the alluvial terraces is 50 feet. Wells are commonly between 50 and 100 feet in depth. Yields are about 100 to 300 gallons per minute from wells completed in the alluvium and 20 to 100 gallons per minute from wells completed in the alluvial terraces.

Recharge to the older alluvial terraces is mainly from local precipitation and runoff from adjacent uplands; generally, the older terraces are not hydraulically continuous with the younger terraces and alluvium. Discharge from the alluvium contributes to the base flow of the Washita River. During high river stages, the normal hydraulic gradient can be reversed, and river water can enter the alluvium.

Water from the alluvium and alluvial terraces is used for municipal, industrial, and irrigation supplies. The water is generally a calcium-magnesium bicarbonate type with dissolved-solids concentrations usually less than 1,000 milligrams per liter.

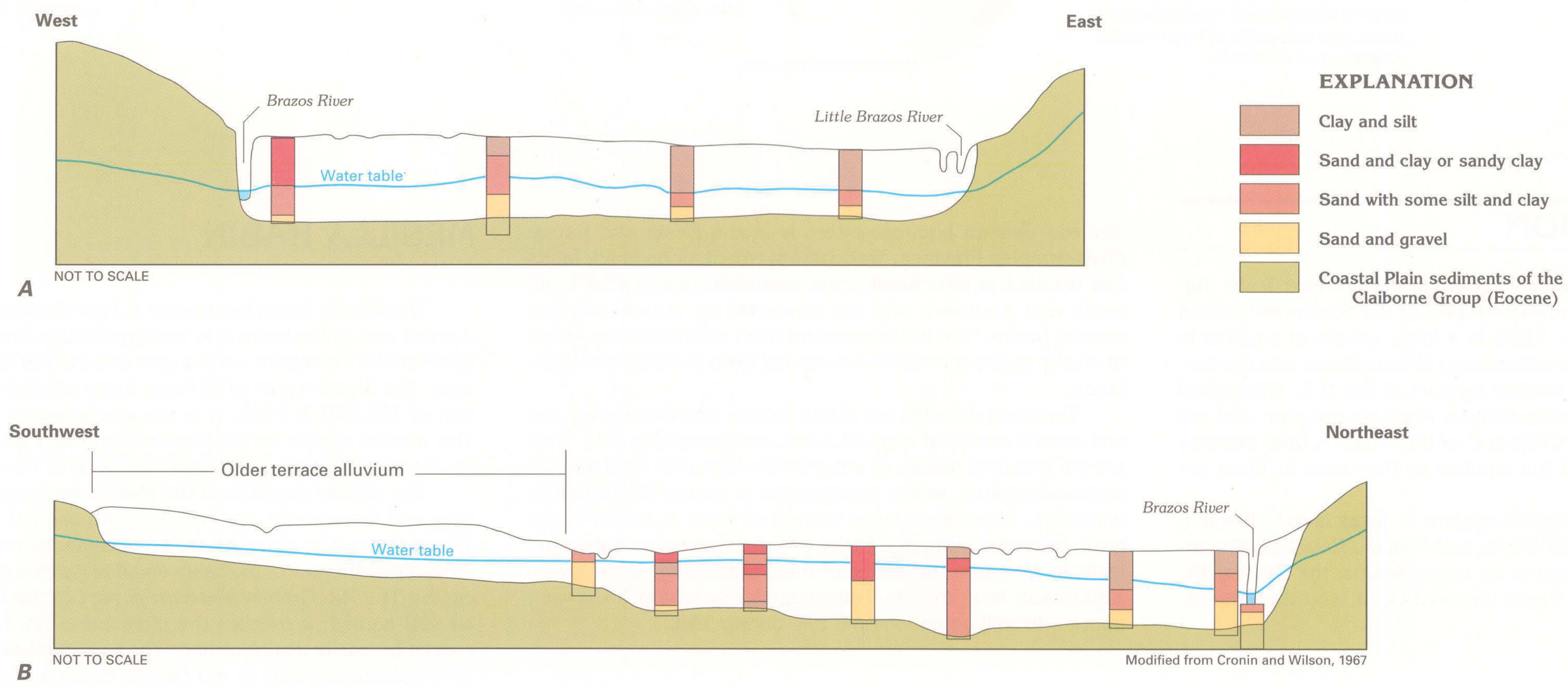


Figure 15. *These idealized hydrogeologic sections of the alluvial aquifer along the Brazos River Valley show that fine grained material overlies coarser alluvial materials (A). Alluvial terraces (B) are at higher altitudes relative to the younger alluvium in the flood plain. The water table generally slopes toward the Brazos River.*

NORTH FORK RED RIVER AND RED RIVER

The North Fork Red River heads just east of Amarillo in the Texas Panhandle and flows eastward into Oklahoma. Quaternary alluvium and alluvial terraces compose an aquifer of major importance along the North Fork Red River from Beckham County, Okla. at the border of the Texas Panhandle to its junction with the Red River and along the Red River eastward to Jefferson County, Okla. Alluvium and alluvial terraces are covered by dune sands in most of the area. The Quaternary deposits are underlain by poorly permeable Permian bedrock.

In central Beckham County, the extensive alluvial terraces, which consist of varying proportions of clay, silt, sand, and gravel, are mainly south of the river's flood plain. The maximum width of the saturated part of the deposits is about 7 miles. The terraces range from 18 to 195 feet in thickness, and average about 70 feet; the saturated part averages about 33 feet in thickness. The water table in the alluvial terraces of central Beckham County slopes toward the North Fork Red River, and water discharges from the aquifer to the river.

Wells completed in the moderately to highly permeable terrace deposits supply water for municipal, industrial, rural domestic, and agricultural uses. The common range of well yields is from 200 to 500 gallons per minute. The water is slightly saline, and concentrations of dissolved solids range from 1,000 to 2,000 milligrams per liter.

Another area of alluvium and extensive terraces is at the junction of the North Fork Red River and the Red River in western Tillman County. Alluvium and alluvial terraces in this area consist of sand and gravel with some clay and sandy clay. The alluvium has an average thickness of about 34 feet, and the alluvial terraces average about 42 feet in thickness. The alluvium along the east side of the North Fork Red River and on the north side of the Red River is generally less than 2 miles wide; the adjoining alluvial terraces are 8 to 10 miles wide. Permian red beds that have low permeability underlie and adjoin the unconsolidated deposits. The alluvial aquifers in Cotton County, Okla., and in Wilbarger, Wichita, and Clay Counties, Tex., apparently supply only small quantities of water.

The water table in the alluvial deposits in western Tillman County, Okla., and northern Wilbarger County, Tex., generally slopes toward the North Fork Red and Red Rivers. Recharge to the terrace deposits from local precipitation is estimated to be about 3 inches per year. Well yields, water quality, and water use are similar to those discussed for the aquifer in Beckham County.

BRAZOS RIVER

The Brazos River heads in New Mexico and flows southeastward across Texas to discharge into the Gulf of Mexico. Large quantities of water are available in the alluvial aquifer along the river between northern McLennan and central Fort Bend Counties, Tex. In this reach, the alluvium and alluvial terraces are as much as 8 miles wide. The alluvial terraces, which are of much less significance as a source of water than the flood-plain alluvium, are as much as 75 feet thick and consist of clay, silt, sand, and gravel. The flood-plain alluvium consists predominantly of gravel and fine to coarse sand, with lesser amounts of clay and silt. Generally, coarser-grained material is present in the lower part of the alluvium. Maximum thickness of the alluvium is about 100 feet, and average thickness is about 45 feet.

The deposits that compose the alluvial aquifer are of Quaternary age and are underlain by rocks that range in age from Late Cretaceous to Quaternary. The underlying rocks dip toward the Gulf of Mexico and contain several major aquifers that crop out in bands parallel to the coast. Where the Brazos River crosses these aquifers, the alluvial aquifer is hydraulically connected to them.

Hydraulic conductivity values determined by laboratory tests on samples of the alluvium are as great as 2,400 feet per day for gravel. Estimated transmissivity values average about 5,600 feet squared per day, and the average specific yield is estimated to be about 15 percent. Transmissivity is a measure of the ease with which water will pass through an aquifer; transmissivity is hydraulic conductivity multiplied by aquifer thickness. The higher the transmissivity, the more productive the aquifer.

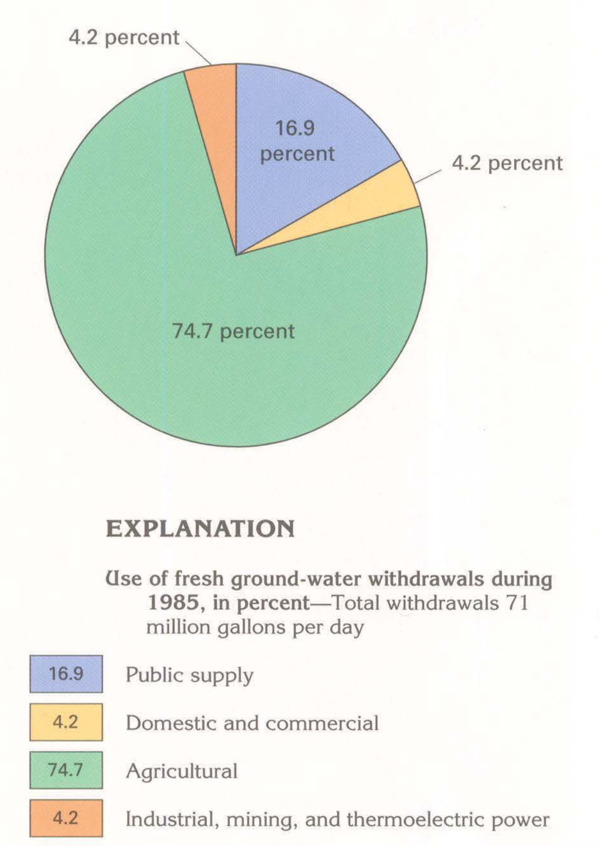
The water table in the alluvium ranges from less than 10 to nearly 50 feet below land surface. The water table slopes toward the river, and seepage from the alluvium contributes to stream base flow. Recharge to the alluvial aquifer is mainly from precipitation that falls directly on the flood plain and alluvial terraces; estimates of recharge range from 2 to 5 inches per year.

Diagrammatic sections for the area where the Brazos River is the boundary between Burleson and Brazos Counties, Tex. are shown in **figure 15**. In west-central Brazos County and east-central Burleson County, the saturated part of the alluvial aquifer is about 8 miles wide, and the saturated thickness of the basal sand and gravel is as much as 50 feet (**fig. 15*A***).

Water from most wells completed in the alluvial aquifer is used for irrigation. In addition to irrigation, the chemical quality of the water is generally suitable for domestic and livestock watering purposes, although concentrations of dissolved solids in the water commonly exceed 1,000 milligrams per liter and the water is classified as hard. An estimated 1,000 irrigation wells pump water from the alluvial aquifer; yields of most of the wells range from 250 to 500 gallons per minute. An estimated 30 million gallons per day was pumped from the Brazos River alluvial aquifer during 1985.

FRESH GROUND-WATER WITHDRAWALS

Withdrawals of fresh and slightly saline water from the collective alluvial aquifers in Oklahoma and Texas totaled about 71 million gallons per day during 1985 (**fig. 16**). About 53 million gallons per day was withdrawn for agricultural purposes, the principal water use. Withdrawals for public supply were about 12 million gallons per day. About 3 million gallons per day was withdrawn for domestic and commercial uses; withdrawals for industrial, mining, and thermoelectric-power uses were also about 3 million gallons per day.



Data from N.L. Barber and D.L. Lurry, U.S. Geological Survey, written communication, 1989; U.S. Geological Survey, Tulsa Oklahoma, written communication, 1989; and William Moltz, Texas Water Development Board, written communication, 1989

Figure 16. *Most of the freshwater withdrawn from the alluvium and terrace deposits along major streams during 1985 was used for agricultural purposes.*

Rio Grande aquifer system

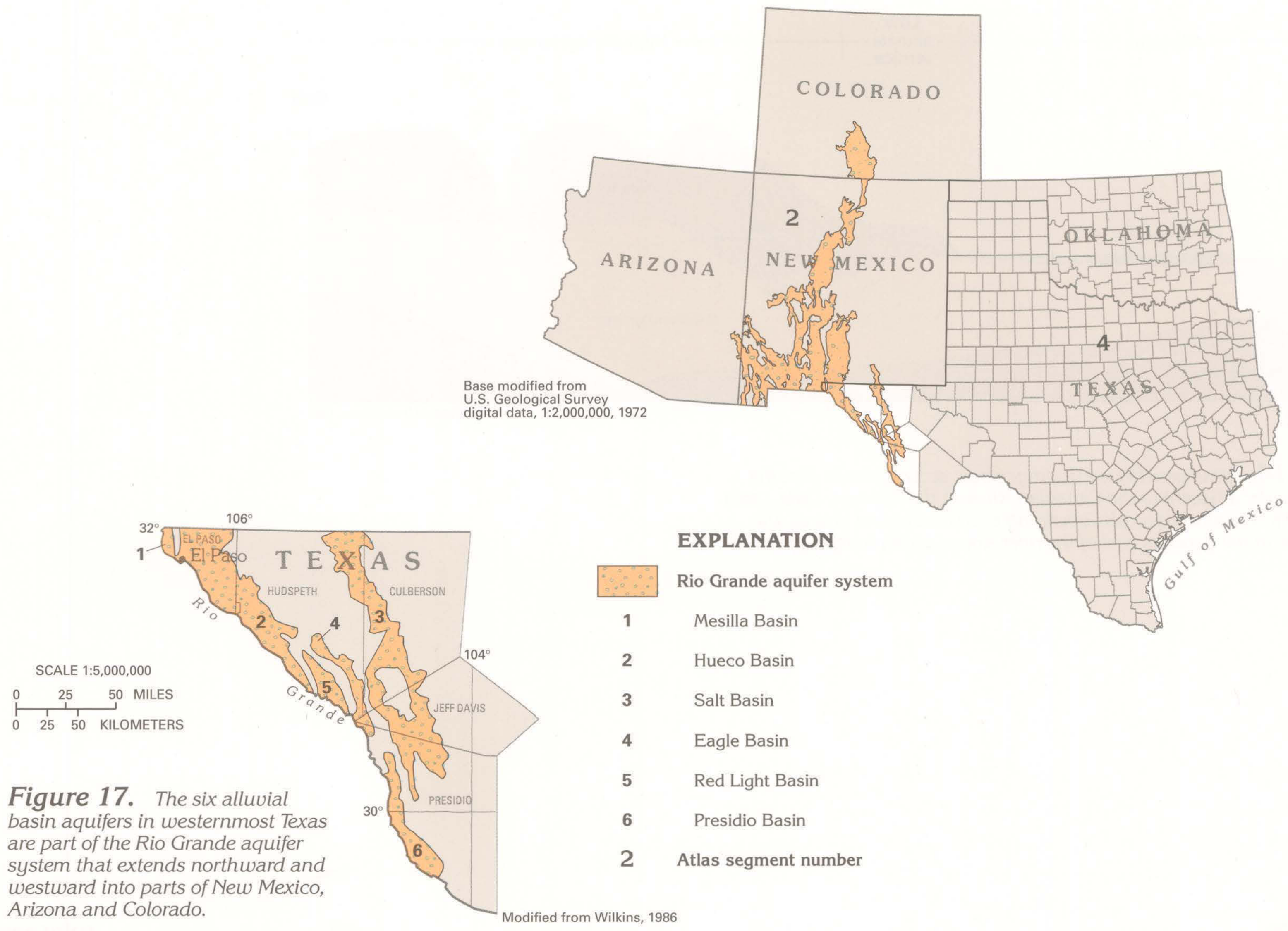


Figure 17. *The six alluvial basin aquifers in westernmost Texas are part of the Rio Grande aquifer system that extends northward and westward into parts of New Mexico, Arizona and Colorado.*

Era	System	Stratigraphic unit	Lithology	Hydrogeologic unit
Cenozoic	Quaternary	Rio Grande alluvium and alluvium of tributary streams	Gravel, sand, silt, and clay deposited by the Rio Grande and its tributaries; up to 200 feet thick at some locations. Locally contains caliche	Rio Grande aquifer system
	Quaternary and Tertiary	Basin-fill deposits	Gravel, sand, silt, and clay deposited by the ancestral Rio Grande or streams local to individual basins; commonly 1,000 feet thick, up to 9,000 feet thick in Hueco Basin	
	Tertiary	Volcanic / clastic and volcanic deposits	Reworked tuffs and alluvial deposits that consist almost exclusively of volcanic / clastic deposits interbedded with ash-fall tuffs and volcanic flows or ash-flow tuffs; up to 6,000 feet thick in southern Salt Basin	

Modified from Gates and others, 1980

Figure 18. *Unconsolidated basin-fill deposits of late Tertiary and Quaternary age are the principal water-yielding units of the Rio Grande aquifer system. The aquifers also may include overlying Rio Grande alluvium and underlying volcanic deposits.*

INTRODUCTION

The Rio Grande aquifer system in westernmost Texas (**fig. 17**) corresponds to the eastern part of the Southwest alluvial basins aquifer system, which is a large system of aquifers in alluvial basins in the southwestern United States and Mexico. These aquifers were studied as part of the U.S. Geological Survey's Regional Aquifer-System Analysis program and are discussed in detail in Chapter C of this Atlas. A brief description and discussion of the aquifers as they exist in Texas are presented here.

The Rio Grande aquifer system in Texas is in Culberson, El Paso, Hudspeth, Jeff Davis, and Presidio Counties. The alluvial aquifers are found in six major basins: the Mesilla, the Hueco, the Salt, the Eagle, the Red Light, and the Presidio (**fig. 17**).

The Rio Grande aquifer system is in the Basin and Range Physiographic Province. Vertical movement along block faults has resulted in structurally high mountain ranges that trend south and southeast and are separated by structurally low parallel basins. The basin areas are filled with thick sequences of clastic sediments that have eroded from the adjacent highlands.

The basin deposits are of late Tertiary and Quaternary age and consist mostly of clay, silt, sand, and gravel (**fig. 18**). They are the principal source of water for the city of El Paso and the surrounding area, where precipitation is sparse (8–12 inches annually). Although a large volume of water is stored in the basin deposits, pumpage easily exceeds natural recharge and leads to long-term depletion of the stored water. Collectively, withdrawals from the Rio Grande aquifer system in Texas were about 126 million gallons per day during 1985.

MESILLA BASIN

The Mesilla Basin lies largely in New Mexico and Mexico. A small part of the basin is in western El Paso County between the Franklin Mountains on the east and the Rio Grande on the west. The western part of El Paso, a city which had a population of 464,000 in 1985, is in the southern end of the basin. The alluvial aquifer in the Mesilla Basin is a source of water for the municipal and industrial needs of El Paso.

The alluvial deposits of the Mesilla Basin are of late Tertiary and Quaternary age and are composed of gravel, sand, silt, and clay. The deposits are predominantly coarse grained around the margins of the basin and fine grained near the basin center. The Rio Grande alluvium is part of the Mesilla Basin alluvial aquifer; it overlies the older basin fill, from which it cannot be easily distinguished. The total thickness of the unconsolidated deposits in the Mesilla Basin is estimated to be at least 2,000 feet, and the thickness of the Rio Grande alluvium is 150 feet or less.

The chemical quality of the water in the shallower part of the aquifer is influenced by the quality of the water in the Rio Grande. The water in the shallower part of the aquifer is generally more mineralized than that in the deeper part. Concentrations of dissolved solids in the shallower ground water locally are as much as several thousand milligrams per liter, whereas water from the deeper part of the aquifer commonly has dissolved-solids concentrations that are less than 300 milligrams per liter. The depth of freshwater extends to as much as 1,400 feet below land surface. Water in the southern one-half of the basin deposits is more mineralized than elsewhere. This could be due, in part, to the narrow valley outlet at El Paso that restricts ground-water outflow and prevents flushing of water with greater dissolved-solids concentrations.

Wells completed in the Mesilla Basin alluvial aquifer yield as much as 3,000 gallons per minute. Transmissivity of the aquifer is several thousand feet squared per day. The aquifer receives recharge by infiltration of runoff around the basin margins, and from seepage from the Rio Grande, ephemeral streams, canals, and excess irrigation water. During 1980, about 21 million gallons per day was pumped from the Mesilla Basin alluvial aquifer, nearly all for municipal and industrial uses. Before development, water levels in wells completed in the deeper parts of the aquifer were at land surface or a few feet above land surface, and ground water moved upward from the deeper to the shallower zones. After development, water-level gradients were reversed, and water from the Rio Grande alluvium and shallower zones within the basin deposits now leaks downward. This vertical percolation from the shallower deposits has apparently replenished deeper permeable zones in the aquifer and has caused long-term water-level changes to stabilize.

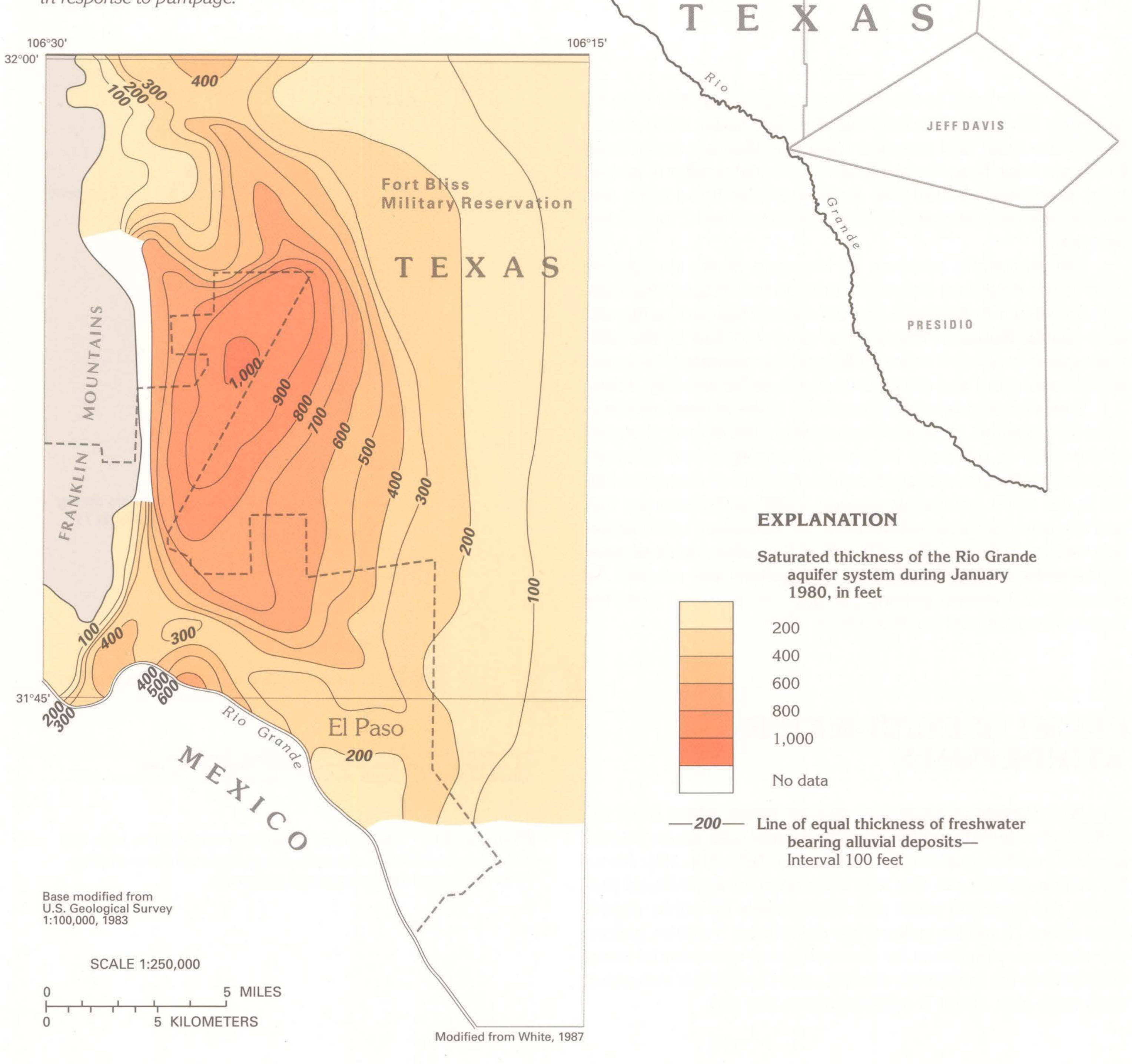
Assuming a specific yield of 10 percent for the unconsolidated deposits in the Texas portion of the Mesilla Basin and the adjacent mesa to the east, about 820,000 acre-feet of freshwater is estimated to be in storage in the deposits. The volume of slightly saline water stored in the Rio Grande alluvium is estimated to be about 300,000 acre-feet. (One acre-foot is the volume of water that will cover 1 acre of land to a depth of 1 foot, or about 43,560 cubic feet of water.) Although these volumes of water may be recoverable in theory, the volume of water that can be recovered in practice may be substantially less.

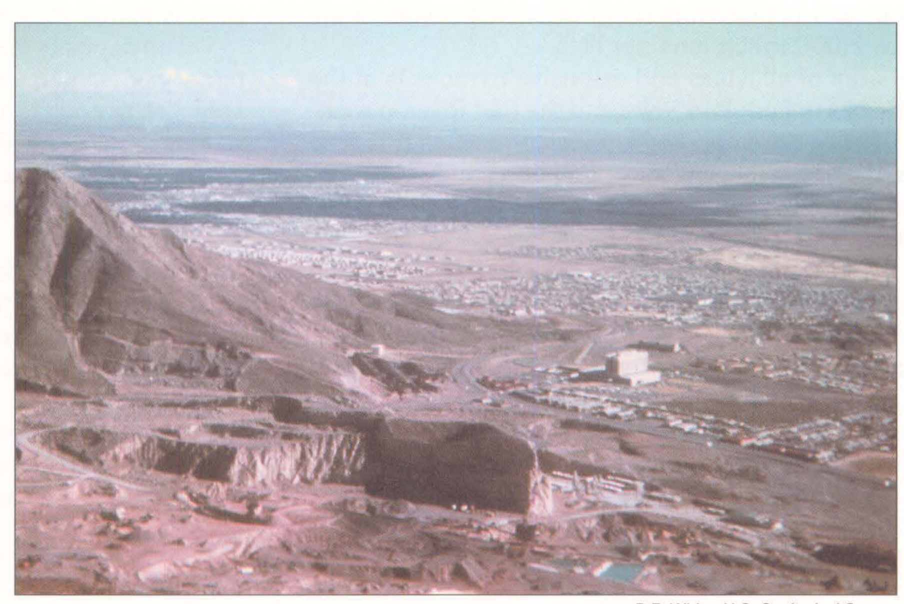
HUECO BASIN

The Hueco Basin is situated in parts of New Mexico, Texas, and Mexico. In Texas, the northern part of the basin lies between the Franklin Mountains on the west and the Hueco Mountains on the east. The unconsolidated alluvial deposits in the Hueco Basin consist of gravel, sand, silt, and clay. The deposits locally are as much as 9,000 feet thick in a deep trough adjacent and parallel to the Franklin Mountains. The deposits that compose the Hueco Basin alluvial aquifer include the Rio Grande alluvium, which is probably not more than 200 feet thick.

Between the Texas–New Mexico border on the north and the city of El Paso, the deposits of the Hueco Basin contain about 10 million acre-feet of freshwater in an approximately 7-mile-wide area adjacent and parallel to the Franklin Mountains. A map of the saturated thickness of the freshwater-bearing alluvial deposits is shown in **figure 19**. In January 1980, these saturated deposits were more than 1,000 feet thick about midway between the Texas–New Mexico border and the Rio Grande at El Paso. An additional large amount of slightly saline water is available in deposits that underlie and adjoin the freshwater-bearing deposits to the east. Relatively rapid recharge to the aquifer by runoff from the Franklin Mountains into alluvial-fan deposits makes this a favorable area for ground-water development. During 1980, about 66 million gallons per day were withdrawn from the Hueco Basin alluvial aquifer in the El Paso–Fort Bliss Military Reservation area (**fig. 20**) for municipal, military, and industrial supplies.

Figure 19. *Alluvial deposits that contain freshwater in the Hueco Basin were more than 1,000 feet thick in January 1980. Although the thickness of the alluvial deposits does not change with time, the amount and thickness of freshwater in the deposits vary seasonally and in response to pumpage.*





D.E. White, U.S. Geological Survey

Figure 20. *The northeastern part of the city of El Paso and the Fort Bliss Military Reservation are in the Hueco Basin. The city and the reservation depend on the Hueco Basin alluvial aquifer for water supply. The view is from the Franklin Mountains looking northeast.*

HUECO BASIN—Continued

Under natural conditions, ground-water movement is toward the Rio Grande and in a down-valley direction. In developed areas, ground water moves toward centers of pumpage. Natural hydraulic gradients have been reversed in intensively pumped artesian areas, and water in the shallow alluvium moves downward across local confining units to replenish water that is pumped from deeper zones. Water-level declines have been large near municipal well fields. Net water levels declined more than 100 feet between 1903 and 1989 in the downtown areas of El Paso and Ciudad Juarez, Mexico, as shown in **figure 21**.

Where the alluvial deposits contain water under unconfined (water-table) conditions, the specific yield of the aquifer is estimated to be between 16 and 30 percent, and the transmissivity of the aquifer is estimated to range from 1,300 to 37,000 feet squared per day. Where local confining units create artesian conditions, the storage coefficient of the aquifer is about 0.0004 and the estimated transmissivity ranges from 6,700 to 16,000 feet squared per day. The storage coefficient and transmissivity for the deposits in the southeastern part of the Hueco Basin probably are substantially smaller. Wells completed in the aquifer yield as much as 3,000 gallons per minute.

The basin fill in the southeastern part of the Hueco Basin is mostly fine grained and probably consists largely of playa deposits. Field data suggest that the thickness of the deposits in this area ranges from 1,000 to 3,000 feet. Sand and gravel are substantial only in the upper 200 to 400 feet, which includes the Rio Grande alluvium. The ground water generally becomes more mineralized with depth from the northern part of the basin toward the southeast. This is shown by a water-quality profile along a line that approximately follows the course of the Rio Grande from El Paso southeastward to about Fort Hancock in Hudspeth County (**fig. 22**). Water with less than 1,000 milligrams per liter dissolved solids is contained in deposits that are more than 400 feet thick in the vicinity of El Paso, but the freshwater diminishes rapidly toward the southeast. Although water with dissolved-solids concentrations of less than 1,000 milligrams per liter is desired for most public and industrial uses, waters with greater concentrations are acceptable for such uses as livestock watering and irrigation, and the southeastern part of the Hueco Basin alluvial aquifer is a valuable source of water for these purposes.

The city of El Paso's demands for fresh ground water are currently (1996) resulting in depletion of water in storage in parts of the Hueco Basin alluvial aquifer. Results of intensive pumping include declining water levels, decreased well yields, and deteriorating water quality. City planners anticipate that the demand for water in El Paso will soon exceed supply. To reduce demands and to increase future supplies, El Paso city officials are implementing conservation practices and artificial recharge programs.

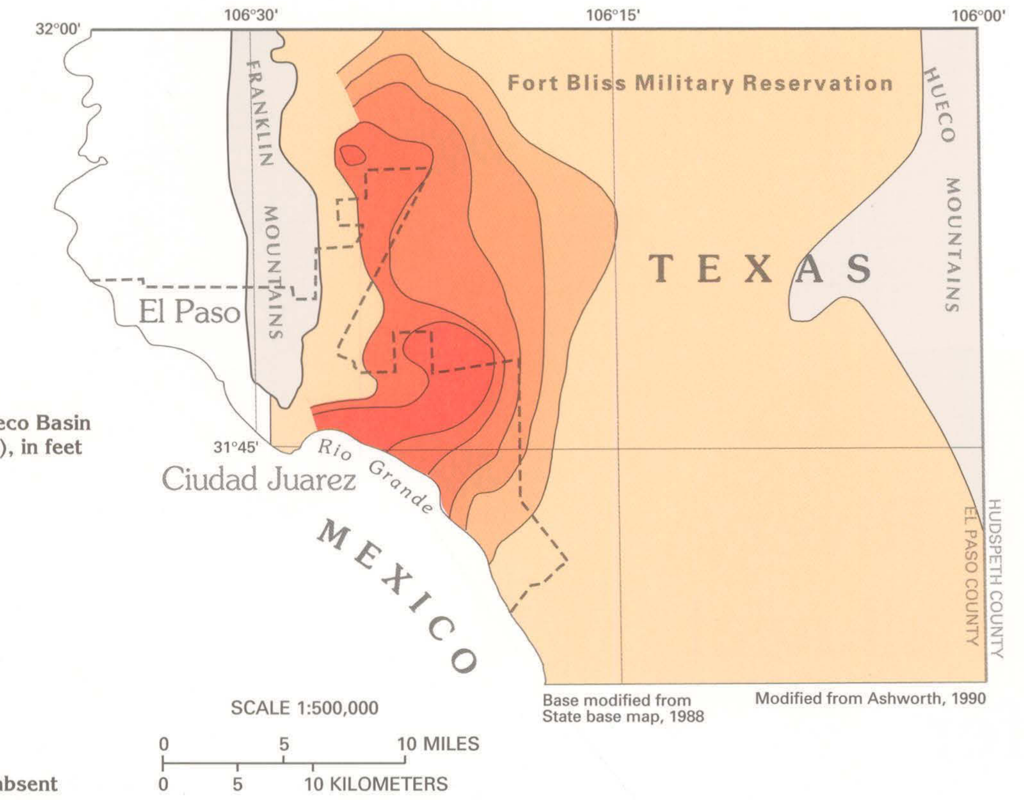


Figure 21. In 1989, pumpage in the El Paso area caused the potentiometric surface in the Hueco Basin alluvial aquifer to decline more than 100 feet below the 1903 surface in part of El Paso. The largest declines are near municipal well fields.

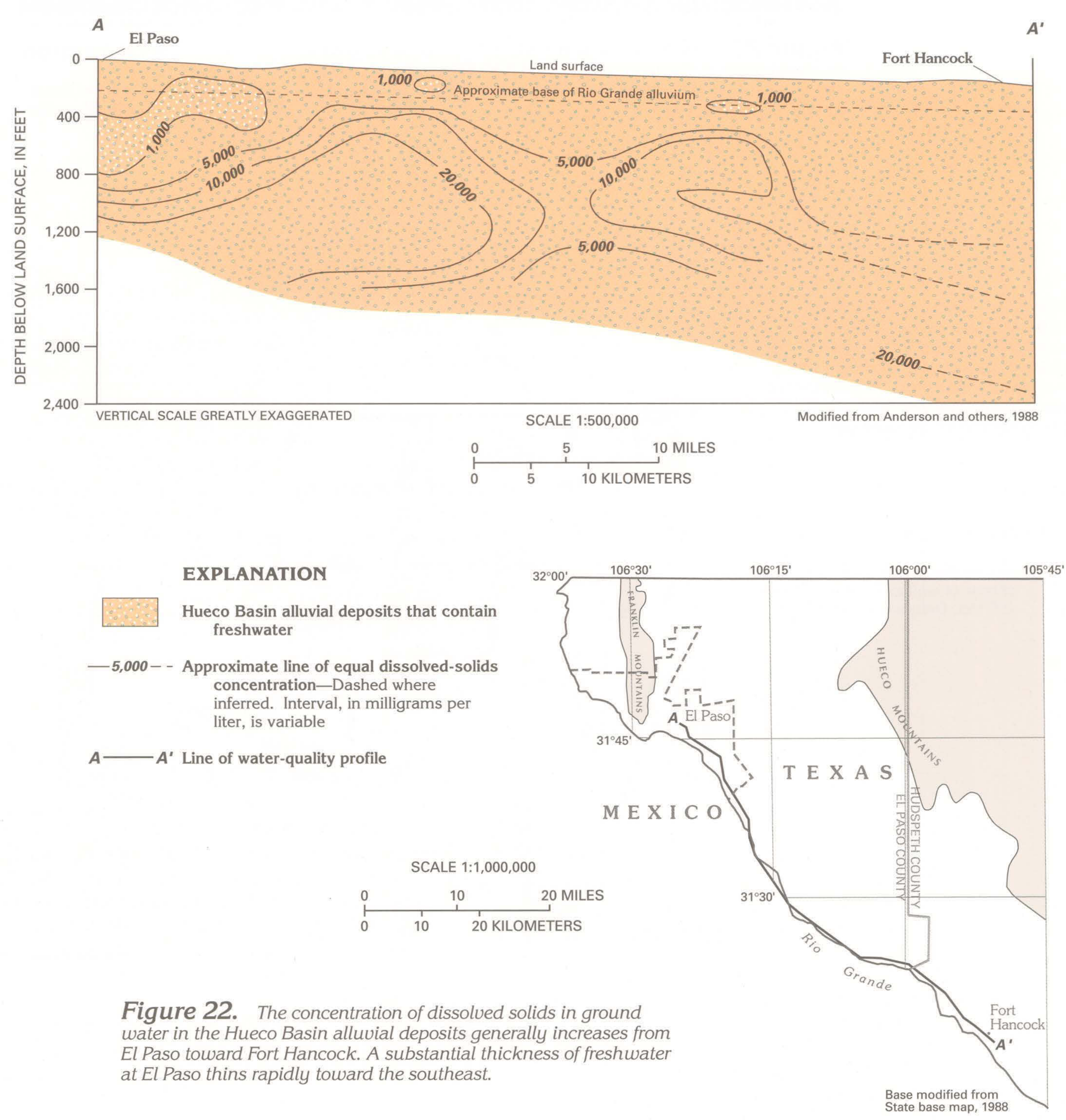


Figure 22. The concentration of dissolved solids in ground water in the Hueco Basin alluvial deposits generally increases from El Paso toward Fort Hancock. A substantial thickness of freshwater at El Paso thins rapidly toward the southeast.

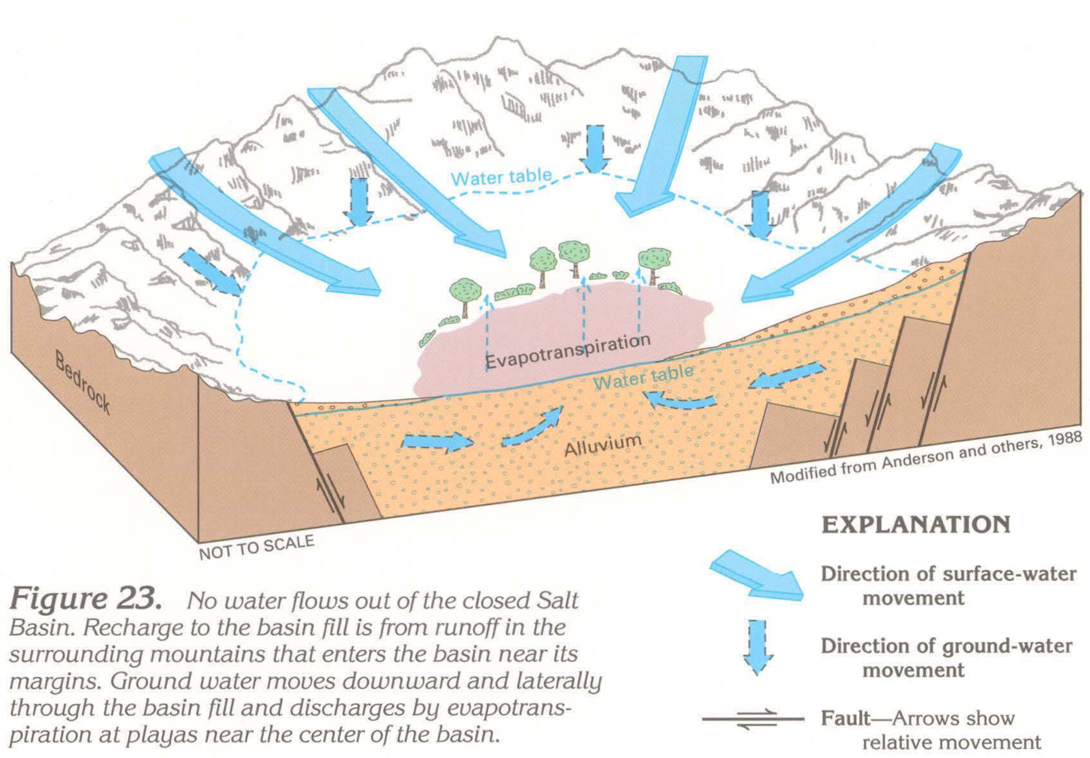


Figure 23. No water flows out of the closed Salt Basin. Recharge to the basin fill is from runoff in the surrounding mountains that enters the basin near its margins. Ground water moves downward and laterally through the basin fill and discharges by evapotranspiration at playas near the center of the basin.

SALT BASIN

The Salt Basin lies mostly in Texas, but a small part of the basin extends northward into New Mexico (**fig. 17**). From the New Mexico–Texas border into Presidio County, the width of the Salt Basin ranges from 5 to 20 miles, and the length is about 140 miles. The basin is bounded by various mountain ranges.

The deposits in the Salt Basin consist of clay, sand, gravel, caliche, and, in places, volcanic rocks and volcanic/clastic deposits (**fig. 18**). The Salt Basin is a closed basin; that is, no surface drainage leaves the basin. Recharge to the basin fill is mainly by runoff from the bordering mountains into alluvial fans. The water moves laterally and downward into the basin fill and then upward toward playa areas near the center of the basin where it is discharged mainly by evapotranspiration (**fig. 23**).

In the northern part of the basin, ground water moves upward toward playas that contain salt deposits. The alluvium in this part of the basin is relatively fine grained and mostly contains highly mineralized water. The water is slightly saline around the basin margin, moderately saline along the axis of the basin, and very saline to briny beneath the playa areas. Salt deposits that formed in the playas as a result of precipitation of minerals from ground water were commercially mined from 1863 until the early 1950's. Wells completed in the deposits yield as much as 1,200 gallons per minute. An average of about 4.5 million gallons per day was withdrawn from the Salt Basin alluvial aquifer from 1951 to 1972, primarily for irrigation in the northern part of the basin.

The deposits in the central part of the basin are coarse grained and are composed primarily of volcanic rocks and volcanic/clastic deposits. Fresh to slightly saline ground water is in this part of the basin, where the basin-fill deposits are as much as 2,400 feet thick. Estimates of specific yield for the deposits in the central part of the basin range from 5 to 10 percent. Large-capacity irrigation wells completed in the deposits yield from 400 to more than 1,000 gallons per minute. Water levels in the central part of the basin declined as much as 6.5 feet per year from 1951 to 1973.

Little ground-water development has occurred in the southern part of the basin, but sparse data indicate that well yields range from about 250 to 1,400 gallons per minute. The amount of freshwater in storage in the Salt Basin alluvial aquifer is estimated to be 6.5 million acre-feet; the estimated volume of slightly saline water in storage is 1.0 million acre-feet. About 75 percent of the total water is assumed to be recoverable. During 1960, about 32 million gallons per day was pumped from the Salt Basin alluvial aquifer.

EAGLE BASIN

The Eagle Basin is bounded by various mountain ranges. The southern part of the basin extends to the Rio Grande. The width of the basin ranges from 2 to 10 miles, and the length is about 60 miles. Most of the basin is in Hudspeth County, although the southern end extends into Culberson, Jeff Davis, and Presidio Counties.

The deposits in the basin consist of clay, silt, sand, gravel, volcanic rocks, and volcanic/clastic deposits. The deposits are more than 2,000 feet thick in the central part of the basin and in the southern part of the basin near the Rio Grande. Most wells completed in the basin-fill deposits are used for watering livestock and have small yields. Some irrigation wells reportedly yield between 1,000 and 1,500 gallons per minute. Specific-capacity data indicate a transmissivity of as much as 13,000 feet squared per day for the Eagle Basin alluvial aquifer in the Rio Grande Valley. Most of the recharge to the alluvial basin aquifer enters at the margins of the basin as runoff from the surrounding mountains. Ground water moves toward the axis of the basin and then southward to discharge to the Rio Grande.

RED LIGHT BASIN

The Red Light Basin is located in southeastern Hudspeth County. It is bounded on the north, west, and east by various mountains, and extends southward to the Rio Grande. The basin is filled with alluvium which consists of clay, silt, sand, and gravel, combined with volcanic rocks and volcanic/clastic deposits. The basin-fill deposits thicken toward the south and are more than 3,000 feet thick at the Rio Grande. The deposits contain at least some freshwater in most of the basin; however, substantial quantities of freshwater are available only in the central part. Only a few wells which have small yields and are used primarily for livestock watering have been completed in the deposits.

PRESIDIO BASIN

The Presidio Basin is in the western part of Presidio County and contains the southernmost aquifer of the Rio Grande aquifer system in Texas (**fig. 17**). The Rio Grande forms the western boundary for the basin; it is bounded on the east by mountains. The width of the basin ranges from 4 to 10 miles, and the length is about 70 miles. The basin contains great thicknesses of fine-grained alluvial deposits, volcanic rocks, and volcanic/clastic deposits. The basin-fill deposits are as much as 5,000 feet thick along the axis of the basin near the Rio Grande.

Ground water has been developed along the flood plain of the Rio Grande, where it is used mostly for irrigation; in other parts of the basin, ground water is pumped only for livestock watering and domestic use. Large-diameter irrigation wells in the flood plain of the Rio Grande at the southern end of the basin yield from 300 to 800 gallons per minute. Specific-capacity data indicate a transmissivity of about 5,000 to 21,000 feet squared per day for the alluvial aquifer in the Rio Grande Valley. Recharge to the basin fill is mainly along the bordering mountains where small streams enter the basin. Ground water flows from the basin margins to the Rio Grande, where it is discharged either by evapotranspiration or by seepage to the river.

In the Rio Grande Valley in the central part of the basin, an estimated 5 million gallons per day of ground water was withdrawn for irrigation during 1960. An estimated 800,000 acre-feet of freshwater is in storage in the Presidio Basin alluvial aquifer; of this amount, an estimated 75 percent can be recovered.

FRESH GROUND-WATER WITHDRAWALS

An estimated 126 million gallons per day of freshwater was withdrawn from the Rio Grande aquifer system during 1985. About 77 million gallons per day was withdrawn for public supply, the principal use (**fig. 24**). About 30 million gallons per day was withdrawn for agricultural purposes, and about 10 million gallons per day was pumped for industrial, mining, and thermoelectric-power uses. About 9 million gallons per day was withdrawn for domestic and commercial uses.

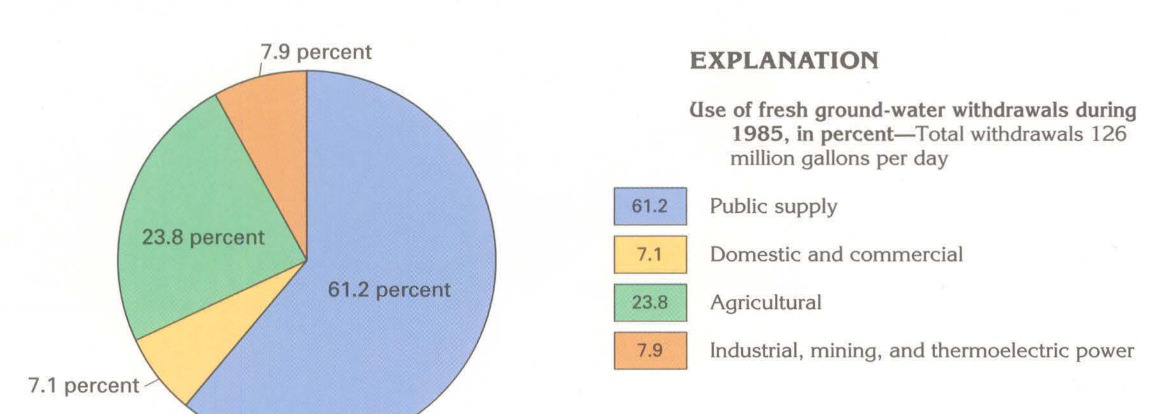


Figure 24. Most of the freshwater withdrawn from the Rio Grande aquifer system during 1985 was used for public supply and agricultural purposes.

Pecos River Basin alluvial aquifer

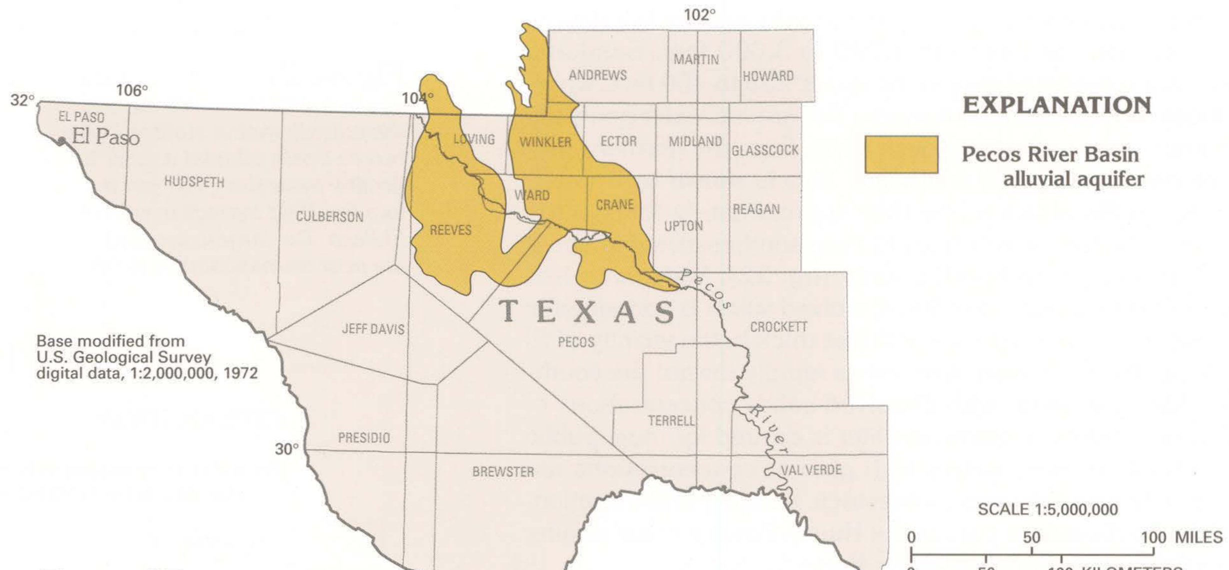


Figure 25. Thick alluvial deposits in the Pecos River Basin yield large quantities of water mostly to irrigation wells.

INTRODUCTION

Thick and extensive alluvial deposits of Cenozoic age compose the Pecos River Basin alluvial aquifer in western Texas (**fig. 25**). The aquifer is in the Great Plains Physiographic Province and underlies approximately 5,000 square miles in parts of Andrews, Crane, Ector, Loving, Pecos, Reeves, Ward, and Winkler Counties. The topography in the area consists mostly of flat to rolling plains that slope gently toward the Pecos River. Ground water in the Cenozoic alluvium is of major importance in this area where average annual rainfall is less than 12 inches.

Era	System	Stratigraphic unit	Lithology	Hydrogeologic unit
Cenozoic	Quaternary	Dune sand	Fine to very fine grained, gray to red-brown sand	Pecos River Basin alluvial aquifer
	Quaternary and Tertiary	Alluvium	Generally unconsolidated, poorly to moderately sorted gravel, sand, silt, and clay with some caliche	

Modified from Brown and others, 1965

Figure 26. Cenozoic alluvium and dune sand in the Pecos River Basin compose a major water-yielding unit in Texas.

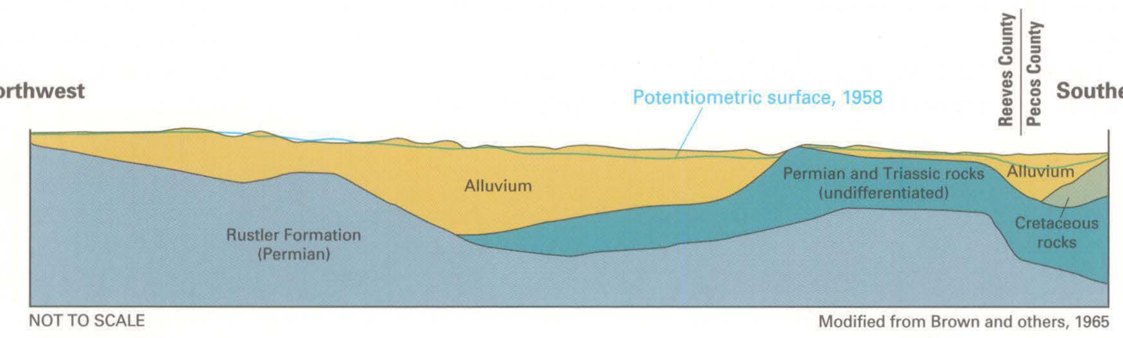


Figure 27. The thickness of the alluvial aquifer varies greatly, as shown by this diagrammatic section approximately parallel to the course of the Pecos River. In northeastern Reeves County, the aquifer is about 1,500 feet thick.

EXPLANATION

Pecos River Basin alluvial aquifer

HYDROGEOLOGY

During late Tertiary and Quaternary time, streams that flowed across the area laid down thick, extensive deposits of alluvium. Prevailing winds subsequently deposited a cover of sand in the eastern part of the area. The alluvial deposits, in order of abundance, consist of gravel, sand, silt, and clay; the deposits contain some caliche (**fig. 26**). The alluvium generally ranges from 100 to 300 feet in thickness; in places, it is as much as 1,500 feet thick.

The alluvium overlies Permian, Triassic, and Cretaceous rocks as shown by a diagrammatic section that extends from northern Reeves County to northern Pecos County approximately parallel to the Pecos River (**fig. 27**). In places, these underlying rocks can yield substantial quantities of water and may be in hydraulic connection with the overlying alluvium. The maximum thickness of the alluvium in the section is about 1,500 feet in northeastern Reeves County near the Pecos River. Dissolution of evaporites in underlying Permian rocks has resulted in subsidence and the formation of deep troughs in Reeves County and in Winkler and Ward Counties; thick deposits of Cenozoic alluvium have accumulated in the troughs, which are evident in the base-of-aquifer map shown in **figure 28**. The altitude of the base ranges from less than 1,400 feet to more than 3,000 feet above sea level.

Water in the alluvium is generally unconfined; however, confined conditions prevail in local areas where a clay confining unit is present. Under natural conditions, ground water generally moves from recharge areas near the margins of the alluvium toward the Pecos River. However, pumpage for irrigation in such areas as central Reeves and northern Pecos Counties has caused hydraulic gradients to reverse; consequently, water moves toward these areas from all directions (**fig. 29**). The saturated thickness of the aquifer, based on the altitude of the 1989 potentiometric surface, ranged from 0 to more than 1,000 feet (**fig. 30**).

Recharge to the alluvium is by direct precipitation, infiltration from intermittent streamflow, return irrigation water, and subsurface flow from older formations. Recharge by precipitation is especially effective in an area that is covered with sand dunes and extends from southwestern Andrews County through parts of Winkler, Ector, and Ward Counties into central Crane County.

The natural concentration of dissolved solids in water in the alluvial aquifer commonly exceeds 1,000 milligrams per liter. The salinity, which has increased substantially in some areas of intense pumpage, is caused primarily by induced infiltration of highly mineralized water from the Pecos River and return flow of irrigation water that has high mineral content caused by concentration by evapotranspiration and leaching of salts and fertilizers from the soil.

Ground water in the alluvial aquifer is used principally for irrigation. Irrigation wells completed in the aquifer generally yield between 200 and 2,500 gallons per minute and average about 1,000 gallons per minute. Aquifer tests in Reeves, Pecos, Winkler, Ward, and Crane Counties show a large variability in the transmissivity of the alluvial aquifer, with values that range from 2,500 to 12,000 feet squared per day.

Annual pumpage from the alluvial aquifer is much greater than annual recharge. In an intensively irrigated area of central Reeves County, water levels declined more than 190 feet between 1951 and 1960.

Some of the area underlain by the alluvial aquifer is not suitable for irrigation from wells because either the terrain is too rough or the saturated thickness of the aquifer is not great enough to sustain well yields. 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. If substantial water-quality degradation by migration of undesirable water is to be avoided, then only about 9.5 million acre-feet, or 32 percent, of this water can be pumped.

Figure 28. The base of the Pecos River Basin alluvial aquifer has an irregular configuration, with a deep depression in east-central Reeves County and western Ward County. The altitude of the base generally ranges from about 1,400 to 3,000 feet above sea level.

EXPLANATION

—1800— **Base-of-aquifer contour**—Shows altitude of base of aquifer. Contour interval 400 feet. Datum is sea level

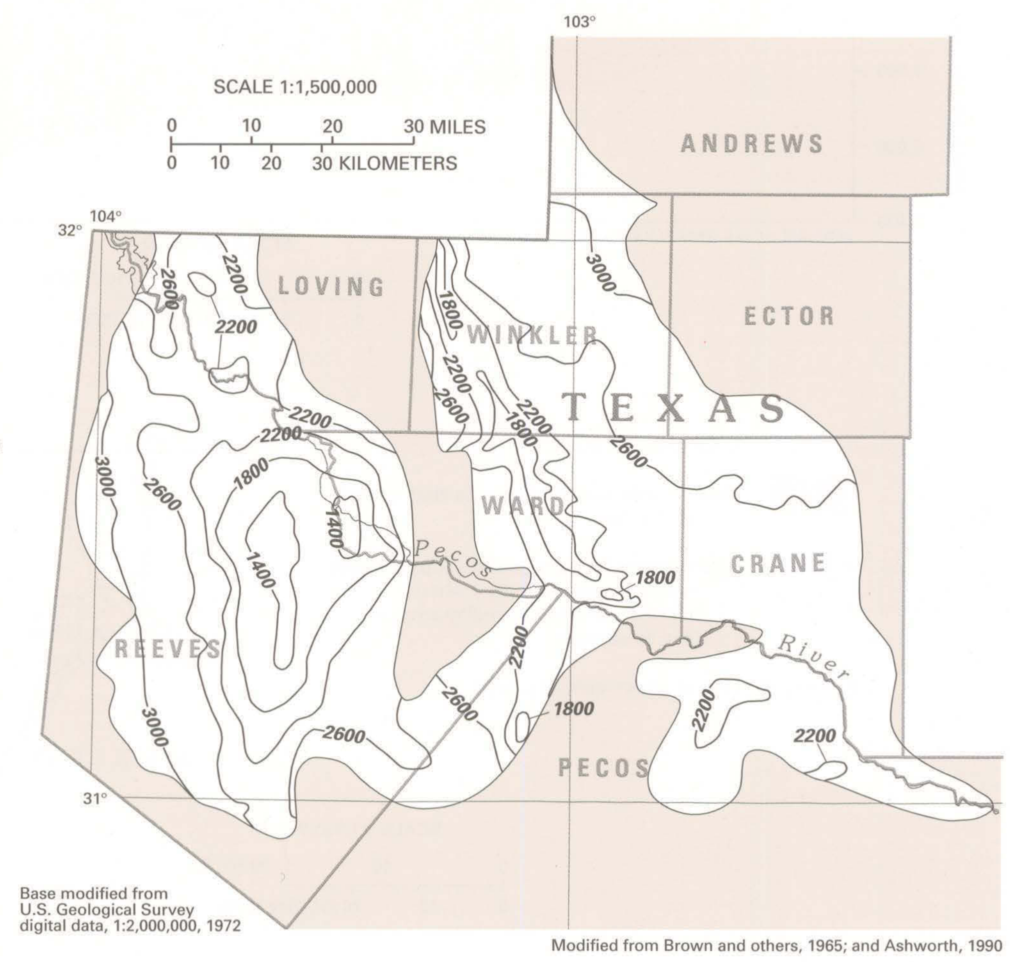


Figure 29. The altitude of the potentiometric surface for the main part of the Pecos River Basin alluvial aquifer in 1989 ranged from about 2,300 to 3,300 feet above sea level. Water moves regionally toward the Pecos River, and locally toward centers of intense pumpage in central Reeves and northern Pecos Counties.

EXPLANATION

—2500— **Potentiometric contour**—Shows approximate altitude at which water levels would have stood in tightly cased wells. Hachures indicate depression. Contour interval 100 feet. Datum is sea level

← **Direction of ground-water movement**

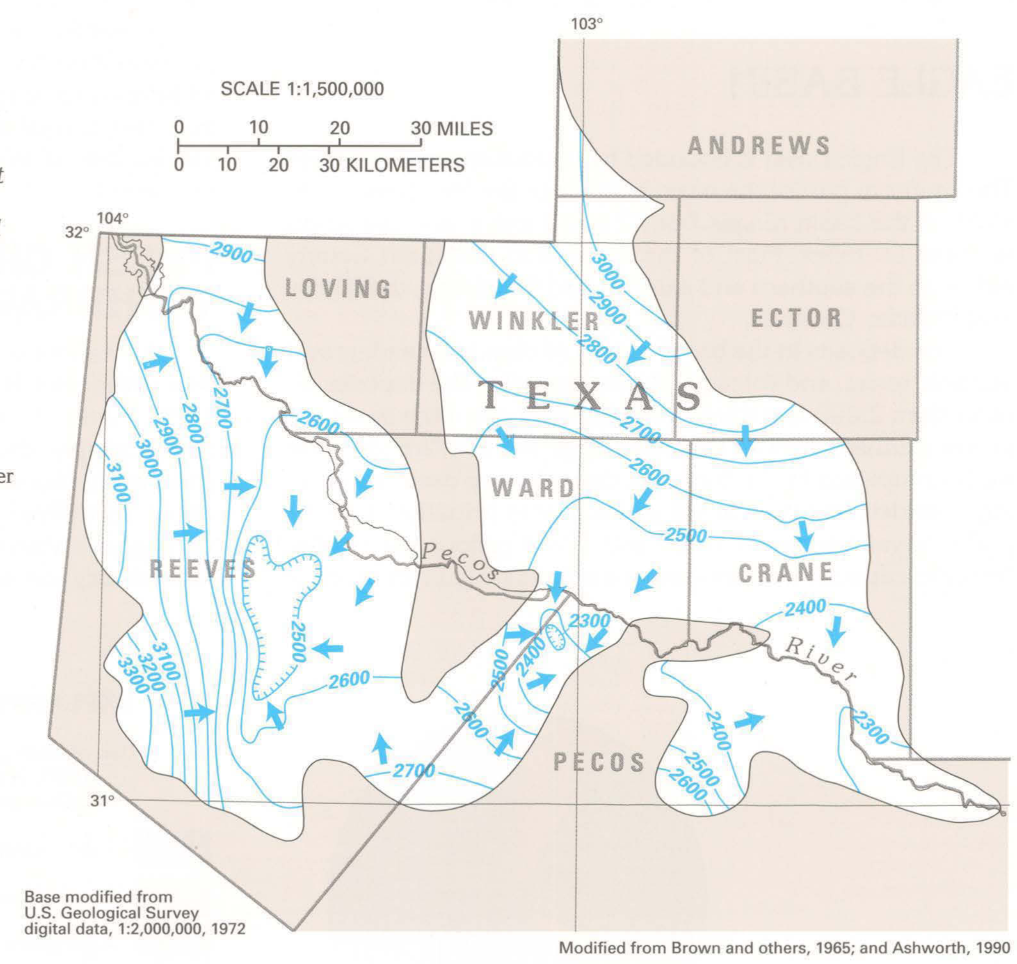


Figure 30. The saturated thickness of the main part of the Pecos River Basin alluvial aquifer in 1989 generally ranged from 0 to 1,200 feet. The area of greatest saturated thickness coincided with the large depression in the base of the aquifer in east-central Reeves County.

EXPLANATION

Saturated thickness of the Pecos River Basin alluvial aquifer, in feet, 1989

200
400
600
800
1,000

No data

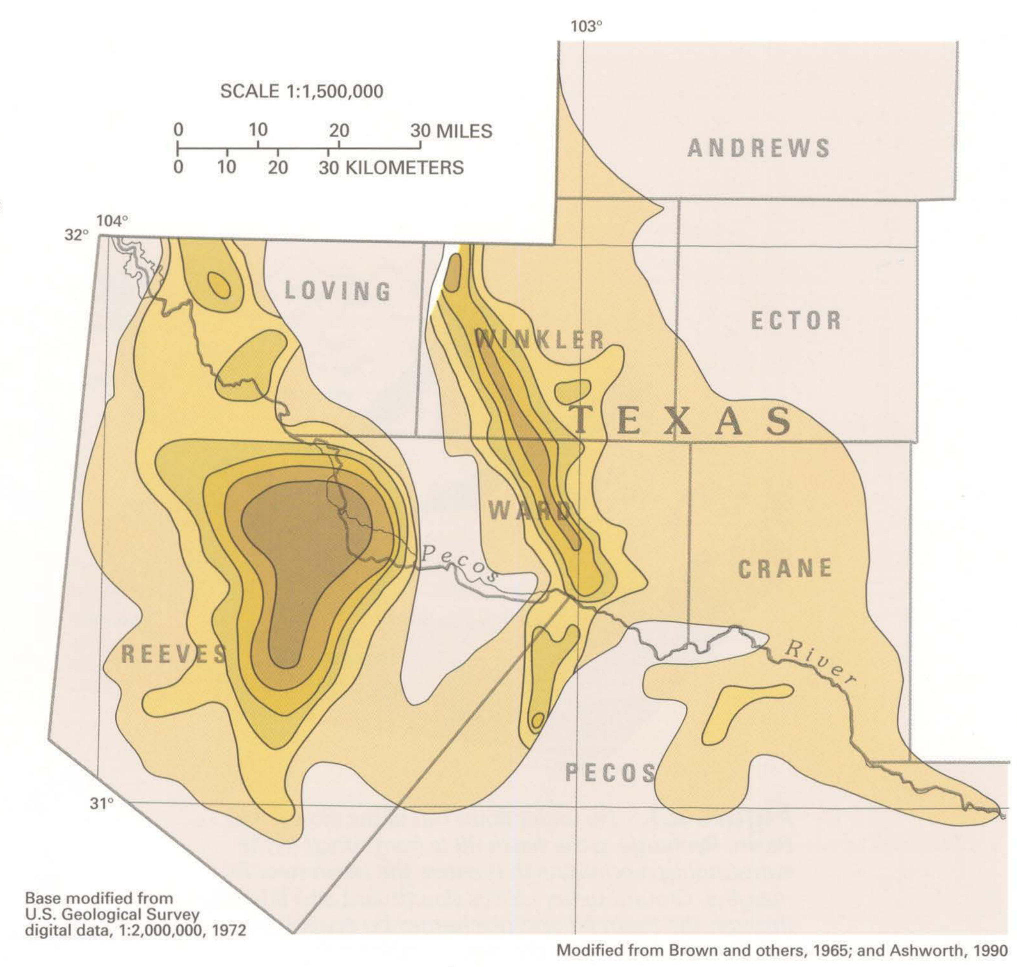
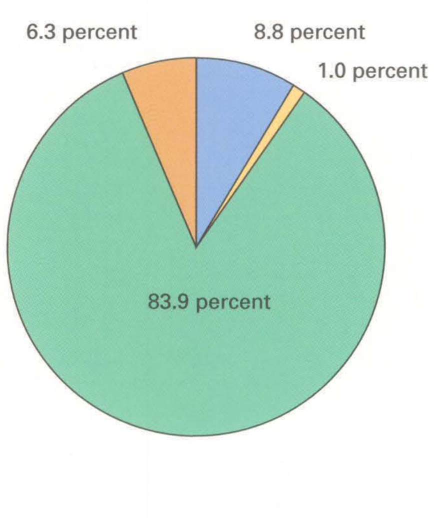


Figure 31. Most of the freshwater withdrawn from the Pecos River Basin alluvial aquifer during 1985 was used for agricultural purposes.



EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total withdrawals 80 million gallons per day

- 8.8 Public supply
- 1.0 Domestic and commercial
- 83.9 Agricultural
- 6.3 Industrial, mining, and thermoelectric power

Data from N.L. Barber and D.L. Lurry, U.S. Geological Survey, written communication, 1989; and William Moltz, Texas Water Development Board, written communication, 1989

FRESH GROUND-WATER WITHDRAWALS

Withdrawals of freshwater from the Pecos River Basin alluvial aquifer totaled about 80 million gallons per day during 1985 (**fig. 31**). About 67 million gallons per day was withdrawn for agricultural purposes, the principal water use. Approximately 7 million gallons per day was withdrawn for public supply. About 5 million gallons per day was withdrawn for industrial, mining, and thermoelectric-power uses, and about 1 million gallons per day was withdrawn for domestic and commercial uses.

INTRODUCTION

The Seymour aquifer consists mainly of the scattered erosional remnants of the Seymour Formation of Pleistocene age. The aquifer has been referred to in the literature as the "north-central Texas alluvial aquifers" because it is in 22 separate areas of alluvium in parts of 20 Texas counties in the upper Red and upper Brazos River Basins (**fig. 32**). The areas are predominantly in the Central Lowland Physiographic Province; only parts of the five westernmost areas are in the Great Plains Province. Average annual precipitation in the area ranges from 19 to 26 inches, and average annual runoff ranges from 0.2 to 1 inch. The aquifer generally has less than 100 feet of saturated thickness, but it is an important source of water for domestic, municipal, and irrigation needs.

HYDROGEOLOGY

During Pleistocene time, the eroded bedrock surface, which was developed mostly on poorly permeable red beds of Permian age, was covered by the Seymour Formation. The Seymour Formation consists of clay, silt, sand, and gravel that were deposited by eastward-flowing streams. Subsequent erosion left scattered remnants of the Seymour Formation mostly in interstream areas, and some of the eroded material was redeposited, thus forming the younger alluvium and alluvial terraces in stream valleys. The younger deposits are similar in composition to the Seymour Formation and compose part of the Seymour aquifer (**fig. 33**).

Areal extents of the individual alluvial areas range from about 20 square miles for an area in Baylor County to about 430 square miles for an area that spans Haskell and Knox Counties. Saturated thickness locally is as much as 100 feet but usually ranges between 20 and 60 feet. Water in the aquifer generally is unconfined; however, it may be confined locally by beds of clay. The alluvium is recharged mainly by direct infiltration of precipitation that falls on the land surface. Ground water moves toward points of discharge along streams or toward pumping wells. Yields of wells completed in the alluvium range from less than 100 to as much as 1,300 gallons per minute and average about 300 gallons per minute. The chemical quality of water in the alluvial aquifer ranges from fresh to slightly saline. In some areas, the water is hard and contains dissolved-solids concentrations in excess of 2,500 milligrams per liter; consequently, its suitability for some uses is restricted.

About 4.5 million acre-feet of fresh to slightly saline water was estimated to be in storage in the Seymour aquifer in 1974. About 75 percent of this water, or about 3.4 million acre-feet, was estimated to be recoverable.

An estimated 120 million gallons per day was withdrawn from the Seymour aquifer during 1959. About 94 percent was used for irrigation, and the remainder, for public and industrial supplies. More than 50 percent of the total withdrawal was for irrigation in the area that spans Haskell and Knox Counties.

SEYMOUR AQUIFER IN HASKELL AND KNOX COUNTIES

The part of the Seymour aquifer that is most intensively developed is in Haskell and Knox Counties, and is the largest continuous part of the aquifer. The Seymour aquifer is the only available source of water for moderate to large irrigation supplies in the local area. The aquifer furnished water to more than 2,000 irrigation wells during 1976; it also is a widely used source for domestic and livestock watering supplies. The areal extent of this part of the aquifer is about 430 square miles. Saturated thickness of the aquifer is generally 20 to 40 feet but is as much as 60 feet in northern Haskell County (**fig. 34**). Buried channels and valleys on the surface of the Permian red beds are areas where the Seymour Formation is thick and consists of coarse grained material. Sand and gravel that form productive aquifers are generally in the lower part of the Seymour Formation.

The hydrogeologic section in **figure 35** is located along the maximum length of the aquifer from western Haskell County to eastern Knox County, and shows that the Seymour Formation overlies the Clear Fork Group of Permian age. The younger alluvium and alluvial terraces along the Brazos River are at lower altitudes and are not in hydraulic connection with the Seymour Formation. The slope of the potentiometric surface of the Seymour aquifer generally conforms to the slope of the land surface and to the surface of the underlying Permian rocks. The altitude of the potentiometric surface in January 1977 (**fig. 36**) indicates that ground water moved generally northward toward the Brazos River from a high area on the potentiometric surface in central Haskell County.

Wells completed in the Seymour aquifer are typically 40 to 60 feet deep. Well yields average about 270 gallons per minute and are as great as 1,300 gallons per minute. Transmissivity of the aquifer ranges from 2,700 to more than 40,000 feet squared per day and averages 13,400 feet squared per day. The chemical quality of the ground water is extremely variable. Concentrations of dissolved solids range from 300 to 3,000 milligrams per liter; most values are between 400 and 1,000 milligrams per liter.

Ground-water contamination is a problem in some areas and is related mainly to pesticides and fertilizers used in agriculture and to human and animal wastes (septic tanks, barnyards, feedlots, and sewage-treatment plants). Contamination from brine disposal and leakage from wells that are or were a part of oilfield activities is expected to remain a localized problem.

FRESH GROUND-WATER WITHDRAWALS

Withdrawals of freshwater from the Seymour aquifer totaled about 121 million gallons per day during 1985 (**fig. 37**). Approximately 110 million gallons per day was withdrawn for agricultural purposes, the principal water use. About 9 million gallons per day was withdrawn for public supply, and about 1 million gallons per day was pumped for domestic and commercial uses. About 1 million gallons per day was withdrawn for industrial, mining, and thermoelectric-power uses.

Seymour aquifer

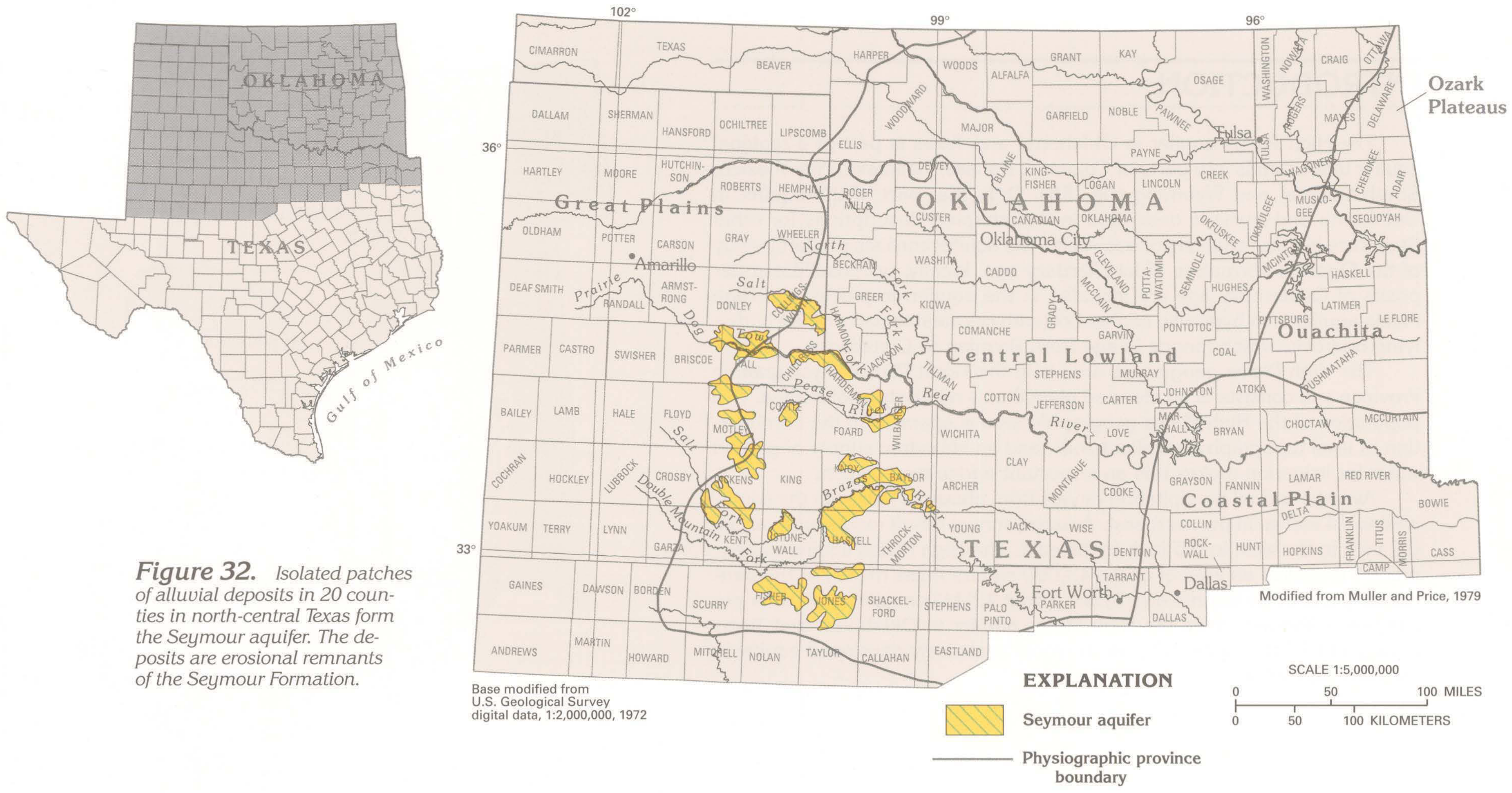


Figure 32. Isolated patches of alluvial deposits in 20 counties in north-central Texas form the Seymour aquifer. The deposits are erosional remnants of the Seymour Formation.

Figure 33. Alluvial deposits that are mostly part of the Seymour Formation are major water-yielding units in the upper parts of the Red and the Brazos River Basins in north-central Texas.

Era	System	Series	Stratigraphic unit	Lithology	Hydrogeologic unit
Cenozoic	Quaternary	Holocene and Pleistocene, undifferentiated	Alluvium (includes river alluvium, terraces, and sand dunes), and Seymour Formation	Clay, silt, sand, and gravel	Seymour aquifer

Modified from Baker and others, 1963

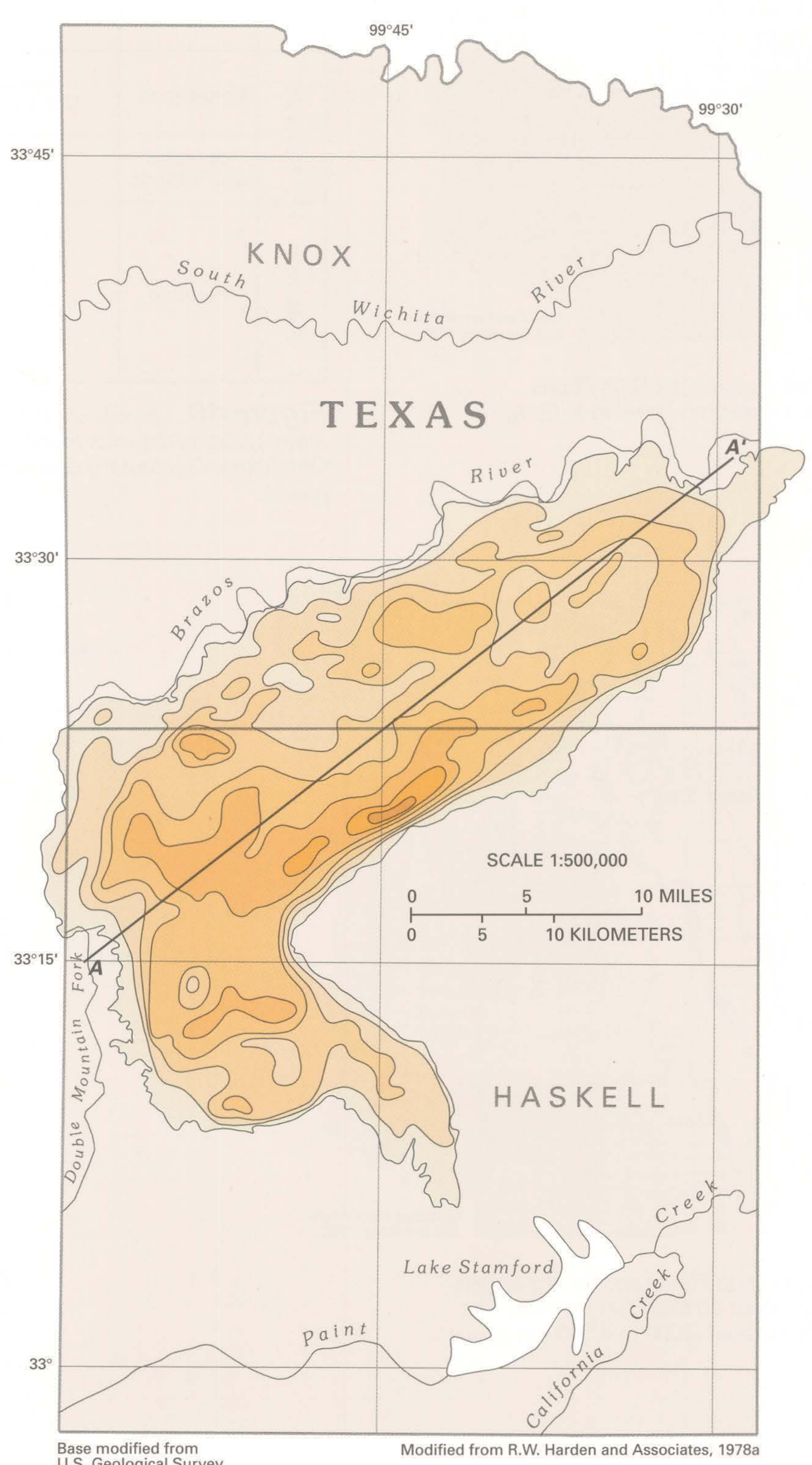


Figure 34. Saturated thickness in the largest of the alluvial areas that compose the Seymour aquifer is as much as 60 feet in northern Haskell County.

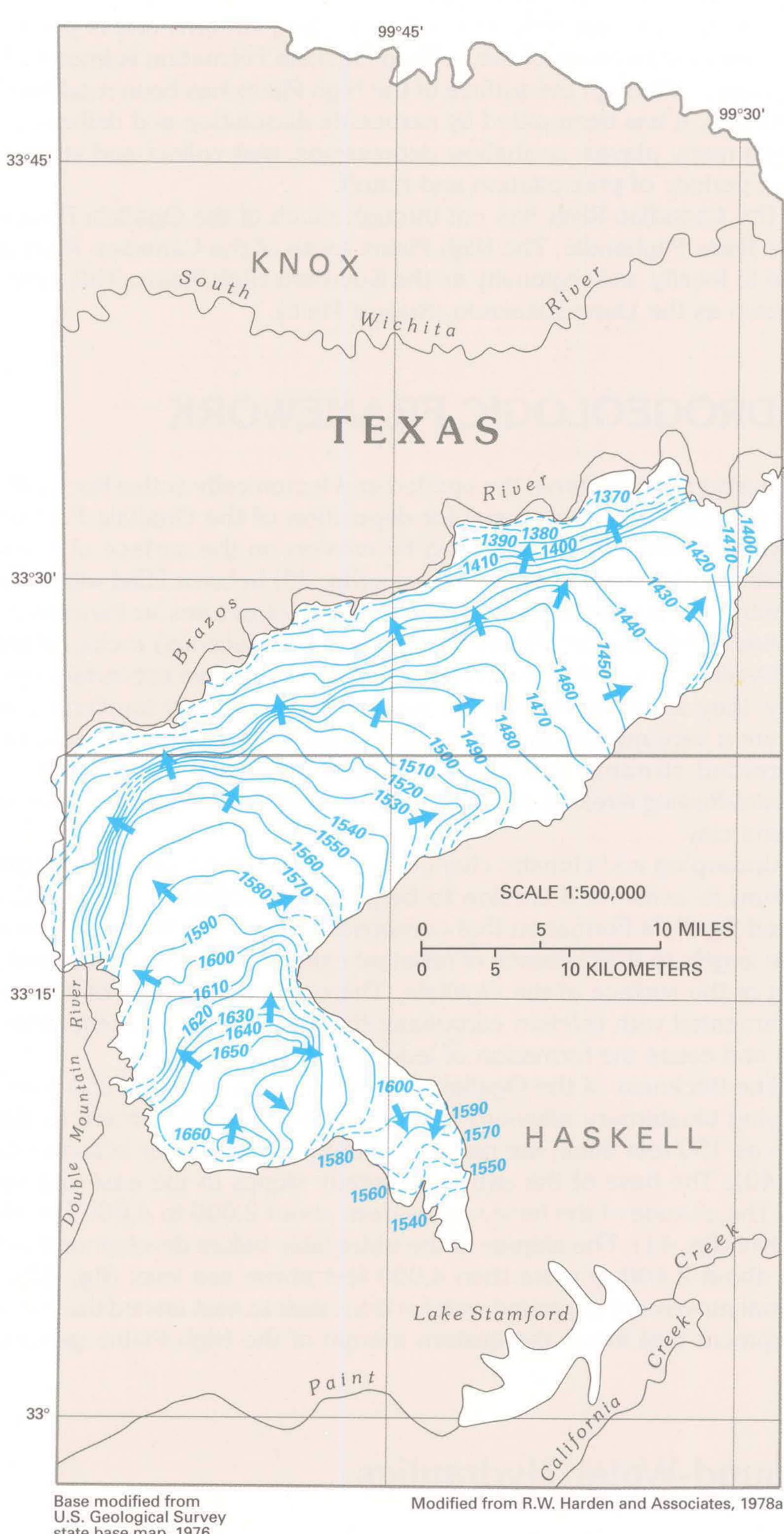


Figure 36. The potentiometric surface in January 1977 for the largest of the alluvial areas of the Seymour aquifer slopes generally northeast and southeast from an altitude of about 1,660 feet above sea level. Ground water generally moves northward toward the Brazos River from the potentiometric high in central Haskell County.

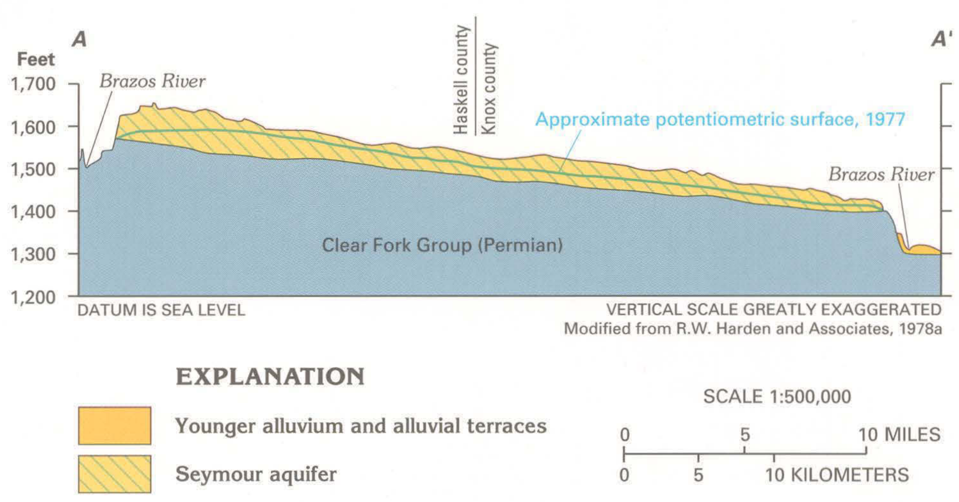


Figure 35. A hydrogeologic section across the largest of the alluvial areas that compose the Seymour aquifer shows that about 20 to 40 feet of saturated alluvium overlies poorly permeable bedrock of Permian age. The line of the hydrogeologic section is shown in figure 34.

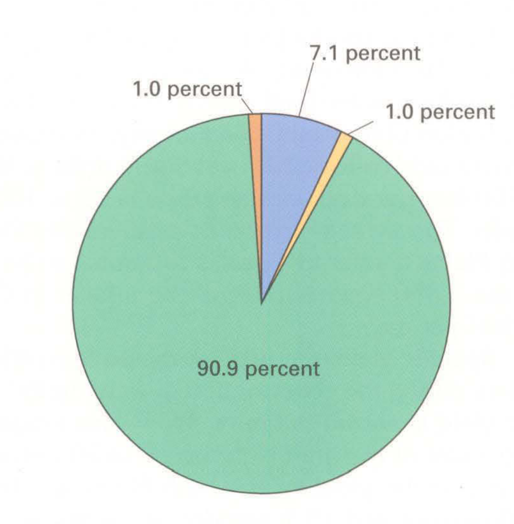


Figure 37. Most of the freshwater withdrawn from the Seymour aquifer during 1985 was used for agricultural purposes.

High Plains aquifer

INTRODUCTION

The High Plains aquifer in Oklahoma and Texas is part of a regional aquifer that extends into parts of Colorado, Kansas, Nebraska, New Mexico, South Dakota, and Wyoming (**fig. 38**). Only that part of the aquifer in Oklahoma and Texas is described in this chapter; descriptions for other States are in other chapters of this Atlas. The aquifer consists predominantly of the Ogallala Formation of late Tertiary age; locally, unconsolidated deposits of Quaternary age are included in the aquifer. In places, the High Plains aquifer is in hydraulic connection with permeable parts of the underlying bedrock, which ranges in age from Permian to Cretaceous.

The High Plains geographic area is in the Great Plains Physiographic Province and consists of an elevated plain that is relatively undissected. The population of the High Plains geographic area is sparse, but the combination of level topography, excellent soils, and an abundant supply of ground water for irrigation makes this an important agricultural region.

Average annual precipitation ranges from about 12 inches in the southwest to 24 inches in the northeast. Average annual runoff ranges from about 0.2 inch in the west to 0.5 inch in the east. The High Plains aquifer in Segment 4 underlies an area of about 43,000 square miles mostly in the panhandle parts of Oklahoma and Texas. About 4.5 billion gallons of water per day was withdrawn from the High Plains aquifer in Oklahoma and Texas during 1985. The aquifer is by far the most intensively developed aquifer in the two-State area.

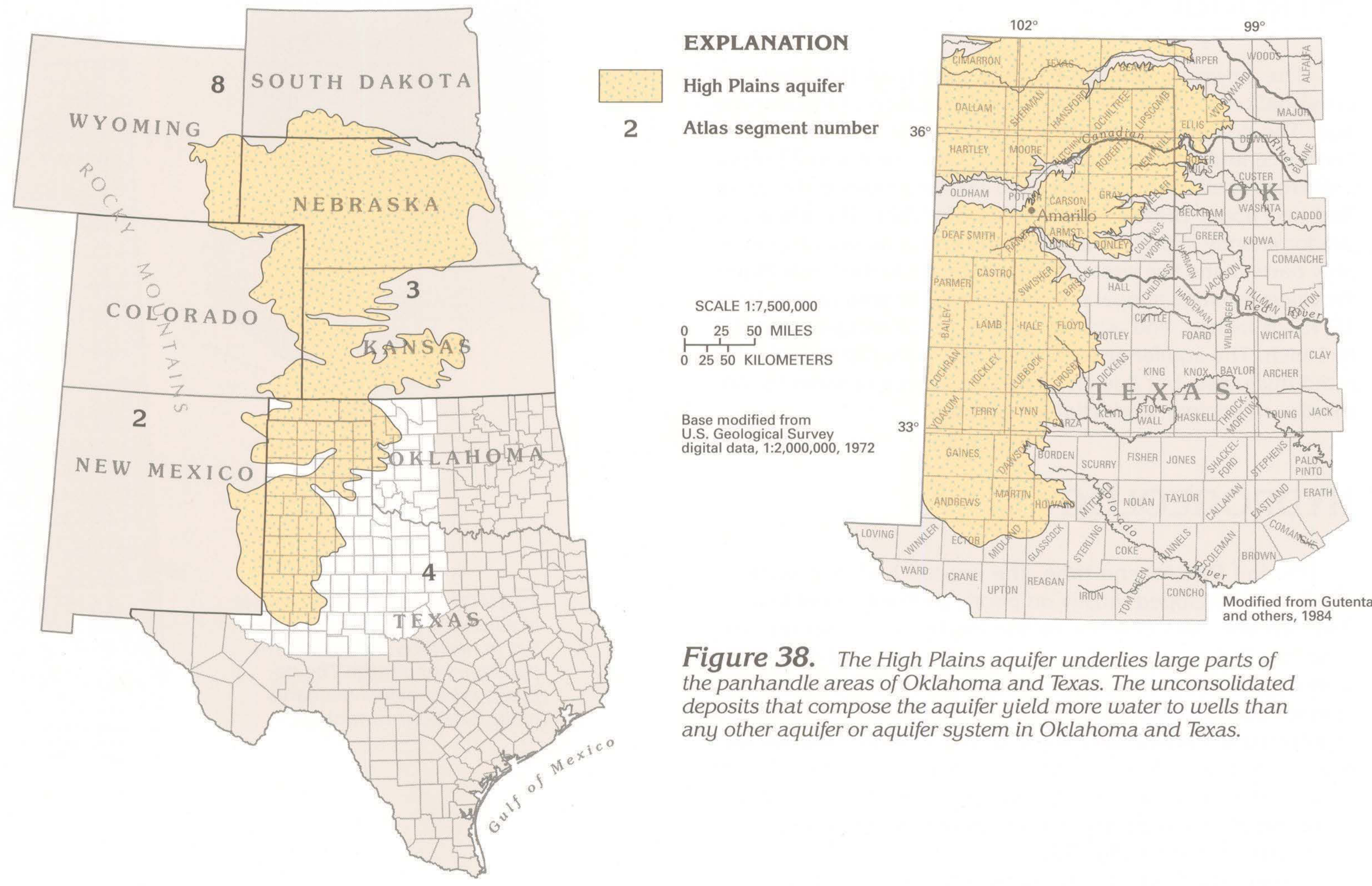


Figure 38. The High Plains aquifer underlies large parts of the panhandle areas of Oklahoma and Texas. The unconsolidated deposits that compose the aquifer yield more water to wells than any other aquifer or aquifer system in Oklahoma and Texas.

HYDROGEOLOGY

The High Plains aquifer described in this chapter has been called the Ogallala aquifer in many published reports. The age of the Ogallala Formation is considered to be Miocene in this chapter, but is listed as Pliocene or Pliocene and Miocene in many published reports.

At the close of deposition of the Ogallala Formation several million years ago, the Great Plains was a vast, gently sloping plain that extended from the edge of the Rocky Mountains eastward for hundreds of miles. Regional uplift and erosion stripped away the plain in many places, but a large central area was little affected by eroding streams and is preserved. This preserved remnant of the uplifted Ogallala Formation is known as the High Plains. Although the surface of the High Plains has been modified little by streams, it has been pitted by carbonate dissolution and deflation, thus forming many playas, or shallow depressions, that collect and store water during periods of precipitation and runoff.

The Canadian River has cut through much of the Ogallala Formation in the Texas Panhandle. The High Plains south of the Canadian River is referred to locally and regionally as the Southern High Plains. This area also is known as the Llano Estacado (Staked Plain).

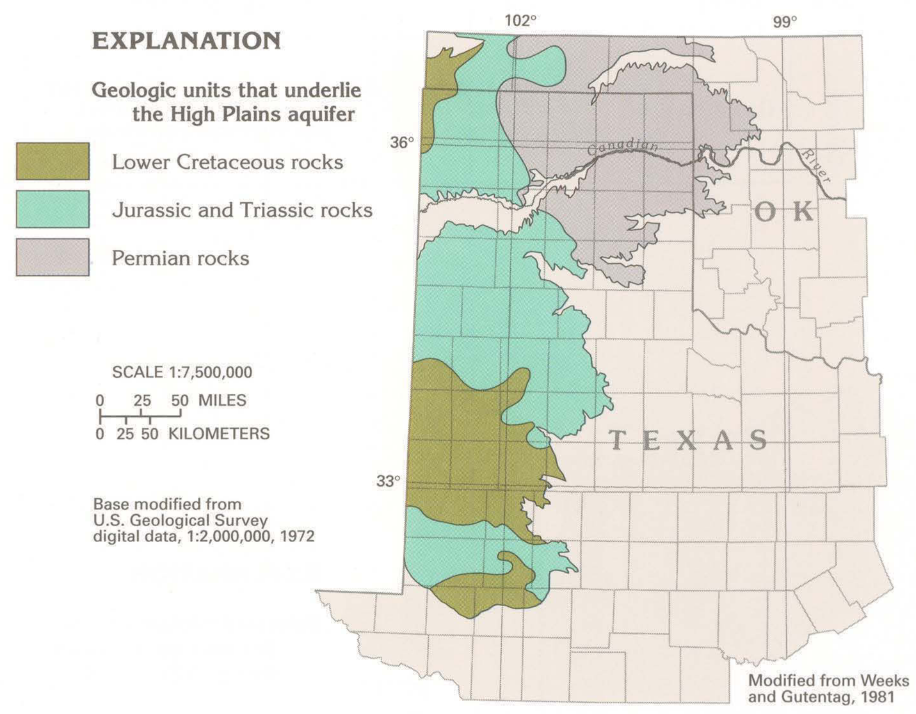


Figure 39. The bedrock units that underlie the High Plains aquifer in Texas and Oklahoma range in age from Permian to Early Cretaceous.

Era	System	Series	Stratigraphic unit	Lithology	Hydrogeologic unit
Cenozoic	Quaternary	Holocene and Pleistocene	Alluvium, eolian, and lacustrine deposits	Windblown sand and silt, fluvial flood plain deposits, and lake deposits of silt and clay	High Plains aquifer
	Tertiary	Miocene	Ogallala Formation	Tan, yellow, and reddish-brown, silty to coarse sand mixed or alternating with yellow to red silty clay and variably sized gravel. Caliche layers common near surface	
Mesozoic	Cretaceous	Lower Cretaceous	Undifferentiated	Fine to medium, thin to thick-bedded sandstone, shale, and limestone	
	Jurassic and Triassic		Undifferentiated	Shale, fine to coarse sandstone, and limestone	
Paleozoic	Permian		Undifferentiated	Interbedded red shale, siltstone, sandstone, gypsum, anhydrite, dolomite, salt, and local limestone	

Modified from Gutentag and others, 1984; and Knowles and others, 1984

Figure 40. Sands of the Ogallala Formation are the major water-yielding deposits in the High Plains aquifer of Texas and Oklahoma. Quaternary deposits are part of the aquifer in some places.

HYDROGEOLOGIC FRAMEWORK

During Miocene time, the uplifted and tectonically active Rocky Mountains provided source material for deposition of the Ogallala Formation. Valleys and basins that developed by erosion on the surface of Permian, Triassic, Jurassic, and Cretaceous rocks (**fig. 39**) became filled with Ogallala sediments. In northern Texas, some collapse structures in Permian rocks are filled with Mesozoic (Triassic, Jurassic, or Cretaceous) rocks, as well as with Ogallala deposits. Where the Mesozoic rocks have secondary permeability, they are considered to be part of the High Plains aquifer; however, they are a very minor component. The Ogallala sediments were deposited by braided streams that spread across a generally level plain. The eastward-flowing streams deposited a heterogeneous mixture of gravel, sand, silt, and clay.

Upwarping and climatic change in Pliocene time caused deposition of alluvium to cease and erosion to begin. Preservation of the remnant of uplifted Ogallala Formation that composes most of the High Plains aquifer is due largely to the presence of resistant caliche cap rock that formed over much of the surface of the Ogallala. The cap rock consists of zones that are cemented with calcium carbonate; these zones are resistant to weathering and cause the formation of ledges and escarpments.

The thickness of the Ogallala Formation is as much as 650 feet. The overlying Quaternary alluvium and windblown sand, which are locally as much as 150 feet thick, are part of the High Plains aquifer in some places (**fig. 40**). The base of the aquifer generally slopes to the east and southeast. The altitude of the base ranges from about 2,000 to 4,000 feet above sea level (**fig. 41**). The altitude of the water table before development ranged from about 2,400 to more than 4,000 feet above sea level (**fig. 42**). The regional movement of ground water is from west to east toward the cap-rock escarpment that forms the eastern margin of the High Plains geographic area.

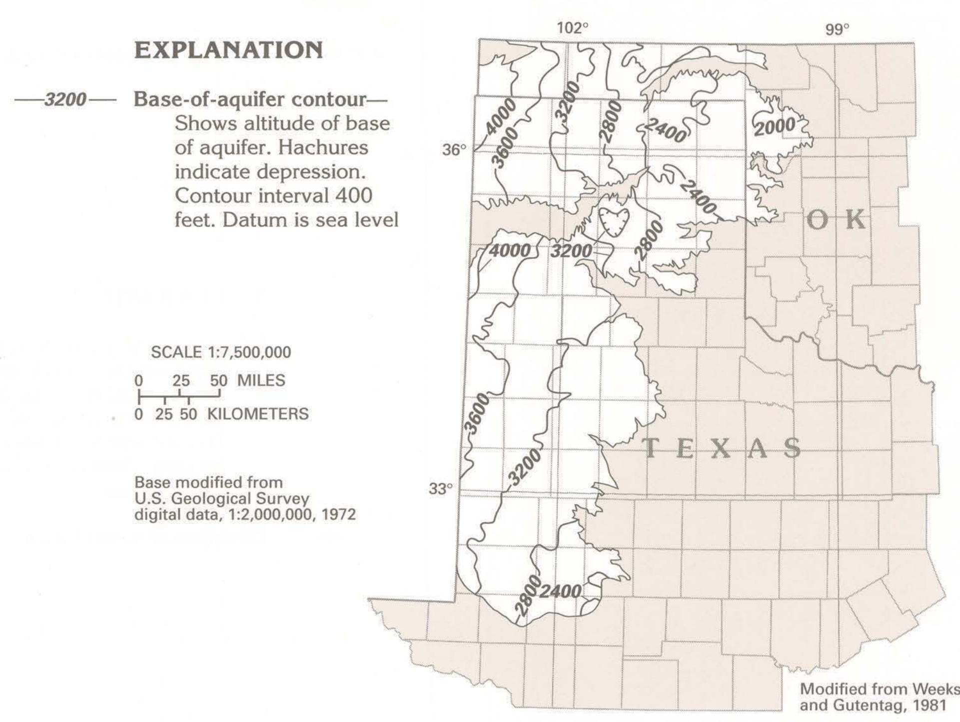


Figure 41. The base of the High Plains aquifer slopes generally to the east-southeast at about 10 to 20 feet per mile. The altitude of the base ranges from about 2,000 to 4,000 feet above sea level.

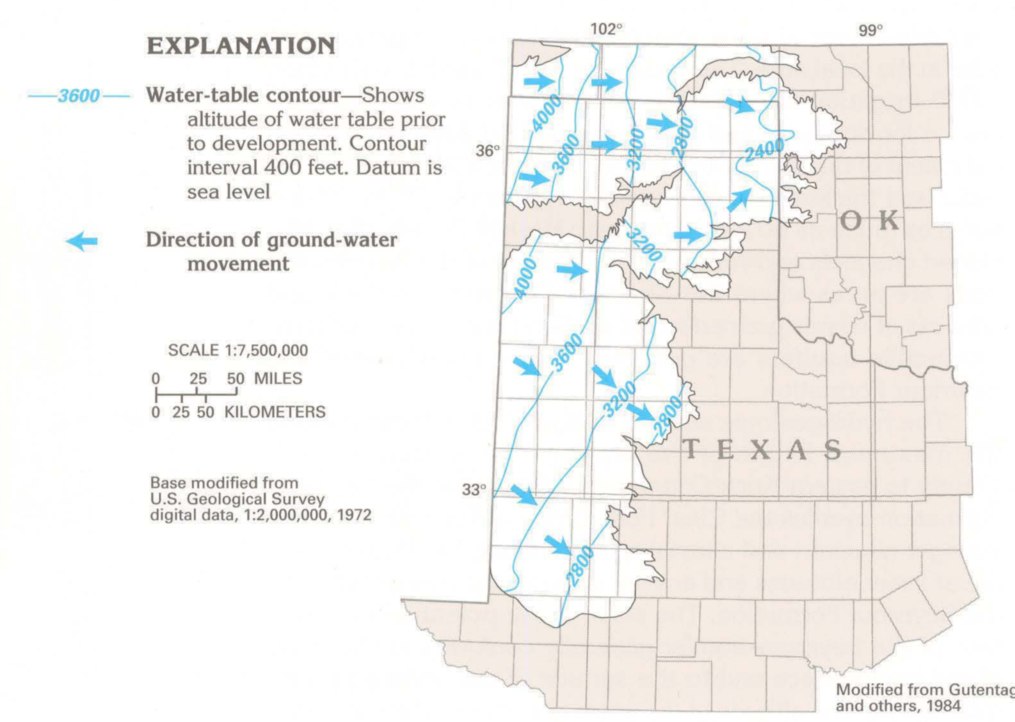


Figure 42. The altitude of the predevelopment water table in the High Plains aquifer ranged from about 2,400 to 4,000 feet above sea level. Ground water moves generally from west to east toward the cap-rock escarpment that forms the eastern margin of the aquifer.

Ground-Water Hydraulics

The High Plains aquifer is recharged by the infiltration of precipitation that falls directly on the aquifer. This recharge is estimated to range from 0.024 inch per year in the Southern High Plains of Texas to 2.2 inches per year in Texas County, Okla. and is about 0.1 percent and 12 percent of average annual precipitation, respectively. Additional recharge may occur when a part of the water that is pumped for irrigation infiltrates the soil and returns to the water table. As much as 54 percent of irrigation pumpage might be reentering the aquifer in Castro and Parmer Counties, Tex., whereas only 20 percent of irrigation water applied in the Oklahoma Panhandle might be returned to the High Plains aquifer.

Ground water discharges naturally through seeps and springs, primarily along the eastern escarpment and the Canadian River. Most ground water is discharged artificially through wells.

Hydraulic conductivity and specific yield of the sediments that compose the High Plains aquifer are important properties that control well yields and resulting water-level depths and rates of water-level declines. The areal distribution of hydraulic conductivity, as shown in **figure 43**, was estimated from records collected by water well drillers. Values range from less than 1 to 200 feet per day, and the range is 25 to 100 feet per day for most of the aquifer. The average hydraulic conductivity for the 35,450 square miles of High Plains aquifer in Texas is estimated to be 65 feet per day; the average for the 7,350 square miles of the aquifer in Oklahoma is estimated to be 61 feet per day.

Specific yield also was estimated from lithologic descriptions made by drillers during the construction of water wells. The areal distribution of specific yield is shown in **figure 44**. Values range from less than 1 to 30 percent; most of the area is in the 10 to 20 percent range. The estimated average specific yield for the High Plains aquifer in Texas and Oklahoma is 15.6 percent and 18.5 percent, respectively.

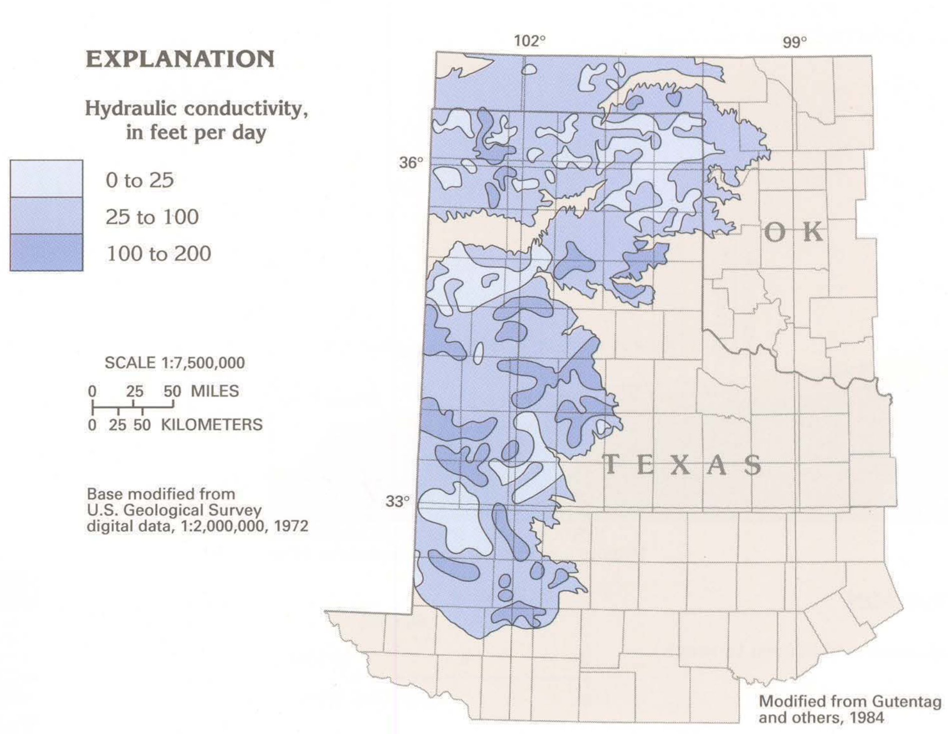


Figure 43. The areal distribution of hydraulic conductivity in the High Plains aquifer is random and ranges from less than 1 to 200 feet per day; values in most places range from 25 to 100 feet per day.

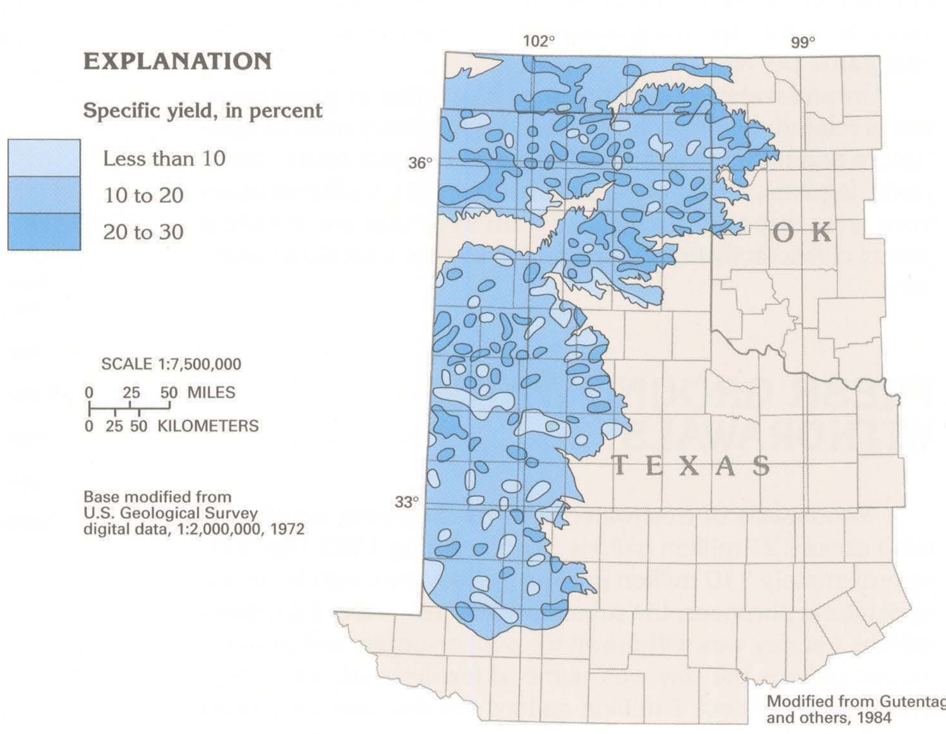


Figure 44. The specific yield of the High Plains aquifer is generally in the 10- to 20-percent range. The specific yield, saturated thickness, and area determine the approximate volume of drainable water in storage in the aquifer.

GROUND-WATER QUALITY

Small concentrations of dissolved solids in ground water in the High Plains aquifer indicate that the water either has had a short residence time in the aquifer or has been in contact with relatively insoluble minerals, or both. Larger concentrations indicate longer residence time, contact with soluble minerals such as gypsum, anhydrite, and halite, or mixing with more mineralized water from bedrock.

Water from the High Plains aquifer is used mostly for crop irrigation. If leaching or drainage is adequate, then concentrations of dissolved solids between 500 and 1,500 milligrams per liter in irrigation water are not likely to be harmful to crops. Concentrations of individual chemical constituents, such as sodium, also are important in determining the suitability of the water for most uses. Excessive sodium concentrations, for example, can cause chemical imbalances and can interfere with normal plant growth.

Most of the water in the High Plains aquifer has a dissolved-solids concentration of less than 500 milligrams per liter (**fig. 45**). Concentrations exceed 500 milligrams per liter in water from a large part of the Southern High Plains in Texas. In water from the southernmost part of the aquifer in Texas, concentrations of dissolved solids exceed 1,000 milligrams per liter but are generally less than 3,000 milligrams per liter. In this area, highly mineralized water in underlying Mesozoic rocks of marine origin probably moves into the High Plains aquifer in response to hydraulic-head differences. Locally, the more mineralized water seems to be associated with several alkali lake basins in areas underlain by Cretaceous rocks in Lamb, Hockley, Terry, Lynn, eastern Gaines, and Martin Counties. Sodium and increased dissolved-solids concentrations may increase locally because of industrial activities and irrigation practices.

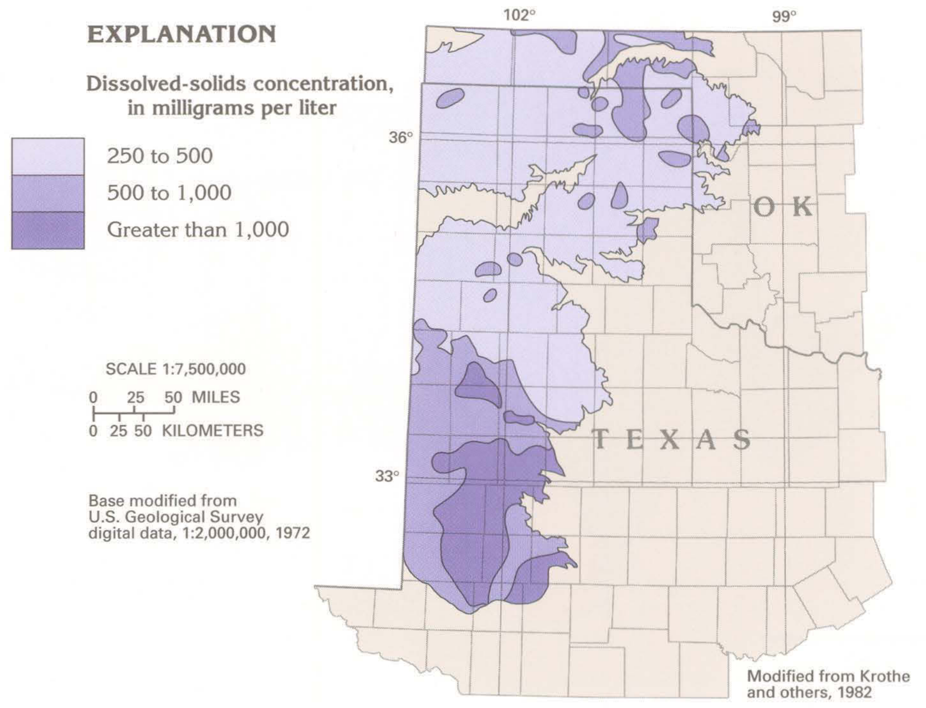


Figure 45. Dissolved-solids concentrations in water from the High Plains aquifer range from 250 to more than 1,000 milligrams per liter. Concentrations generally increase from north to south.

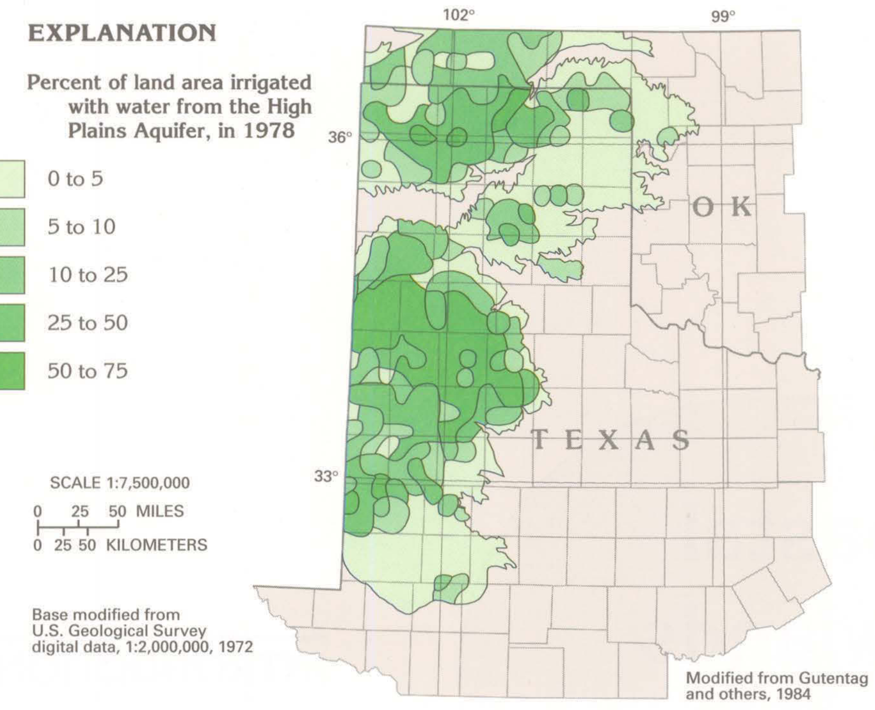


Figure 46. The density of acreage that was irrigated by ground water in 1978 was greatest in the northern one-half of the Southern High Plains of Texas.

GROUND-WATER DEVELOPMENT

Pumpage of ground water for irrigation on the High Plains began in the early 1900's and increased slowly until the mid-1940's. In Texas, the acreage irrigated by ground water increased rapidly between the mid-1940's and 1959 but increased little between 1959 and 1980. The irrigated acreage in 1980 on the High Plains of Texas was 3.9 million acres, which was about the 1959 level. This leveling off after 1959 is primarily the result of declining water availability in the Southern High Plains. Acreage irrigated by ground water in the Oklahoma part of the High Plains in 1980 was about 389,000 acres. During the 1980 growing season, an estimated 5,169,000 acre-feet of water was pumped from the High Plains aquifer for irrigation in Texas, and an estimated 540,000 acre-feet was pumped in Oklahoma.

The density of acreage that was irrigated by ground water from the High Plains aquifer during 1978 is shown in **figure 46**. Most of the irrigated acreage was in the northern one-half of the Southern High Plains of Texas. In Texas alone, the High Plains aquifer supplied water to about 75,000 irrigation wells.

Because pumpage to satisfy the large demand for crop irrigation has been considerably in excess of recharge, water levels in the High Plains aquifer have declined substantially. The altitude of the water table in the High Plains aquifer in 1980 is shown in **figure 47**. When compared with the predevelopment water table (**fig. 42**), the general westward shift of the contours indicates water-level declines.

The change between the predevelopment and the 1980 water tables is shown in **figure 48**. Water-level declines of 50 to more than 100 feet have been measured in a large area in the northern part of the Southern High Plains of Texas where the irrigated acreage is most dense. Water levels in most areas declined between 10 and 50 feet but rose in some areas. Water-level rises in Texas probably resulted from the clearing of native vegetation for cultivation, which increased the rate of recharge from precipitation by reducing transpiration. Water-level rises in Oklahoma probably represent a recovery from abnormally low water levels during the drought of 1933–40. These low water levels were among the earliest data available in Oklahoma and were used to construct the predevelopment water-table map.

The general decline of the water table has resulted in a considerable loss of water from storage and a decreased saturated thickness of the High Plains aquifer. The total volume of drainable water in storage is a product of specific yield, saturated thickness, and area. In 1980, the estimated total volume of drainable water in storage in the High Plains aquifer was 390 million acre-feet in Texas and 114 million acre-feet in Oklahoma. The saturated thickness of the aquifer ranged from 0 to 600 feet in 1980 (**fig. 49**). The saturated deposits generally thicken from south to north. Most of the aquifer south of the Canadian River had a saturated thickness of less than 100 feet.

Changes in saturated thickness and in well yields are directly related. The saturated thickness of the High Plains aquifer in Texas reportedly decreased by more than 50 percent in large parts of Castro, Crosby, Floyd, Hale, Lubbock, Parmer, and Swisher Counties, south of the Canadian River. From 1958 to 1980, irrigated land in the seven counties decreased from 2.5 million to 1.9 million acres, while the number of irrigation wells increased from about 21,000 to 30,000. The average number of acres irrigated per well decreased from 118 in 1958 to 62 in 1980. Decreased well yields are one result of water-level declines.

Another result of water-level declines and decreased saturated thickness is an increase in the depth to water. The generalized depth to water in the High Plains aquifer in 1980 is shown in **figure 50**. Depths ranged from 0 to 400 feet and exceeded 100 feet for most of the area. Greatest depths to water are in the vicinity of the Canadian River. Increased depths to water equate to increased pumping lifts which, together with decreased well yields, add substantially to the cost of withdrawing water from the High Plains aquifer.

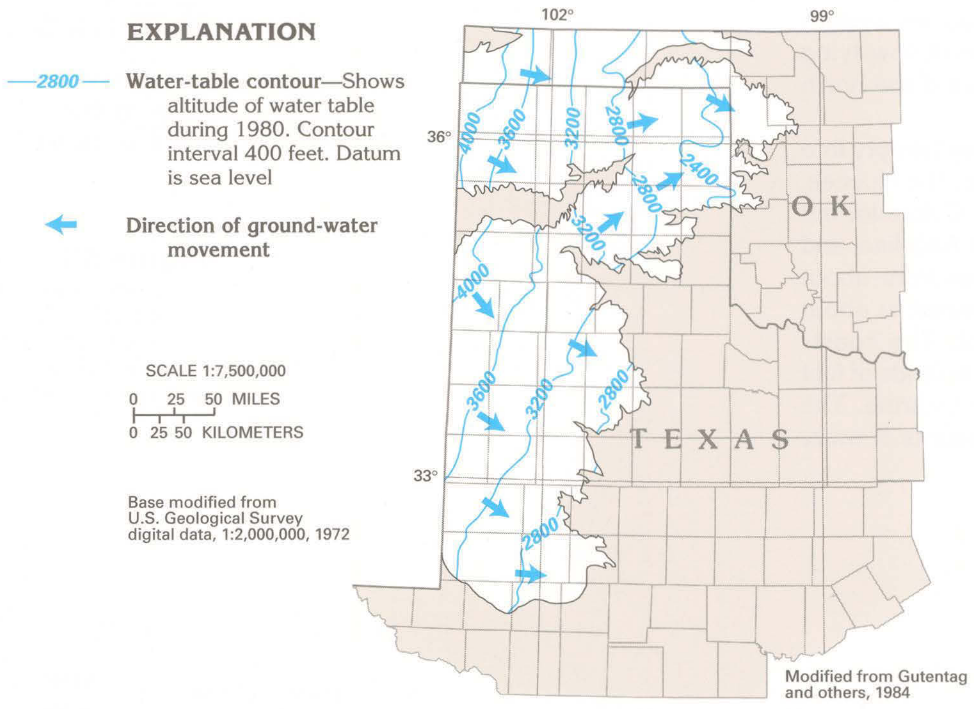


Figure 47. Water-table contours for 1980 have generally shifted westward as withdrawals resulted in water-level declines. The regional configuration of the water table and direction of ground-water flow are similar to those of predevelopment conditions.

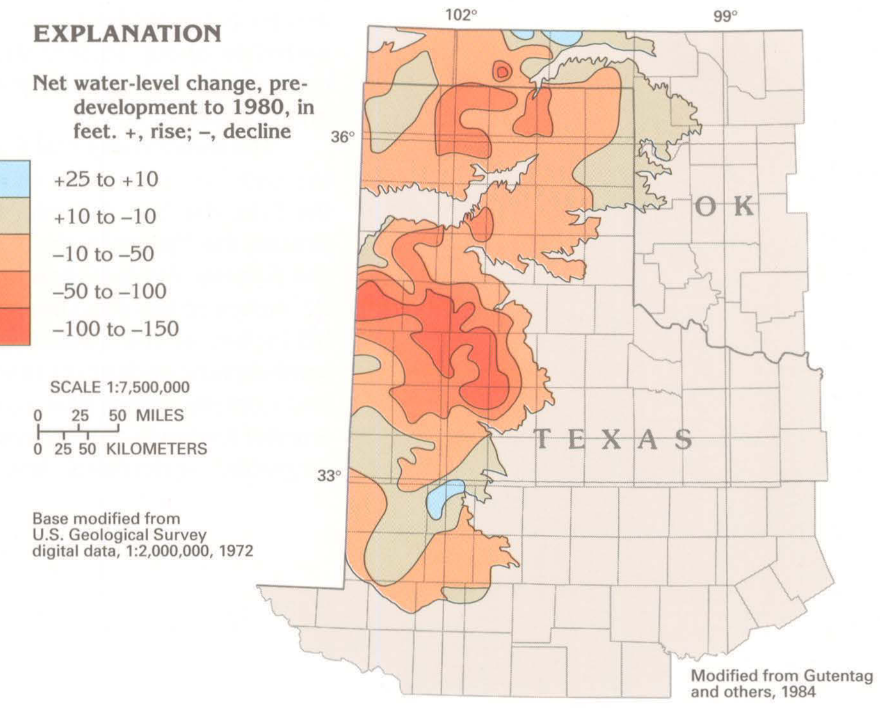


Figure 48. Water levels in the High Plains aquifer declined in places by more than 100 feet from predevelopment to 1980. The area of greatest decline is in the northern one-half of the Southern High Plains of Texas where pumpage for irrigation is most intense.

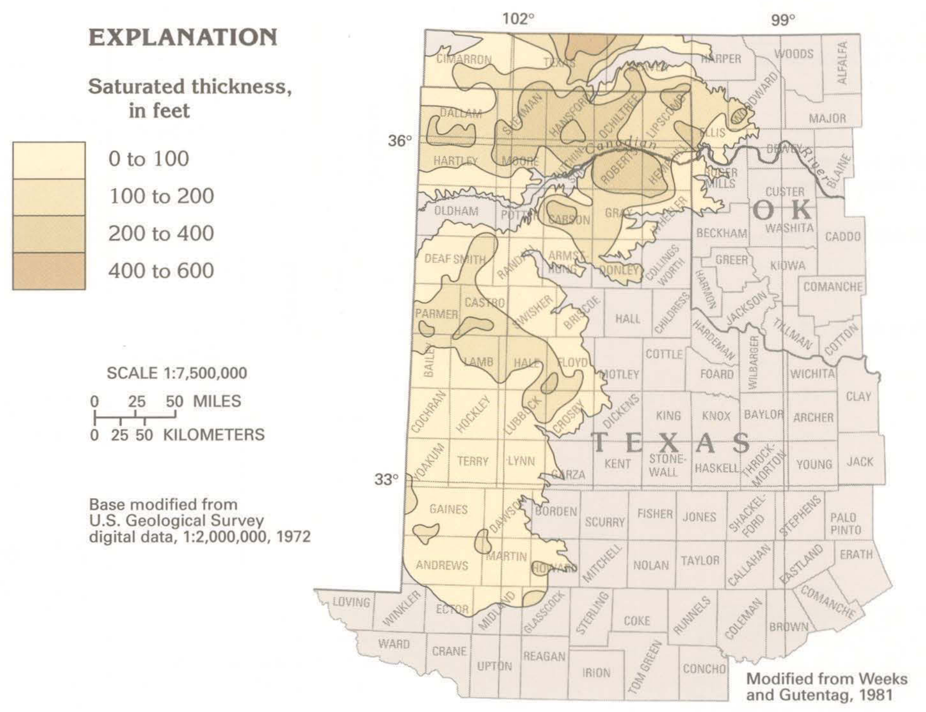


Figure 49. The saturated thickness of the High Plains aquifer ranged from 0 to 600 feet in 1980. Saturated thickness generally increases from south to north.

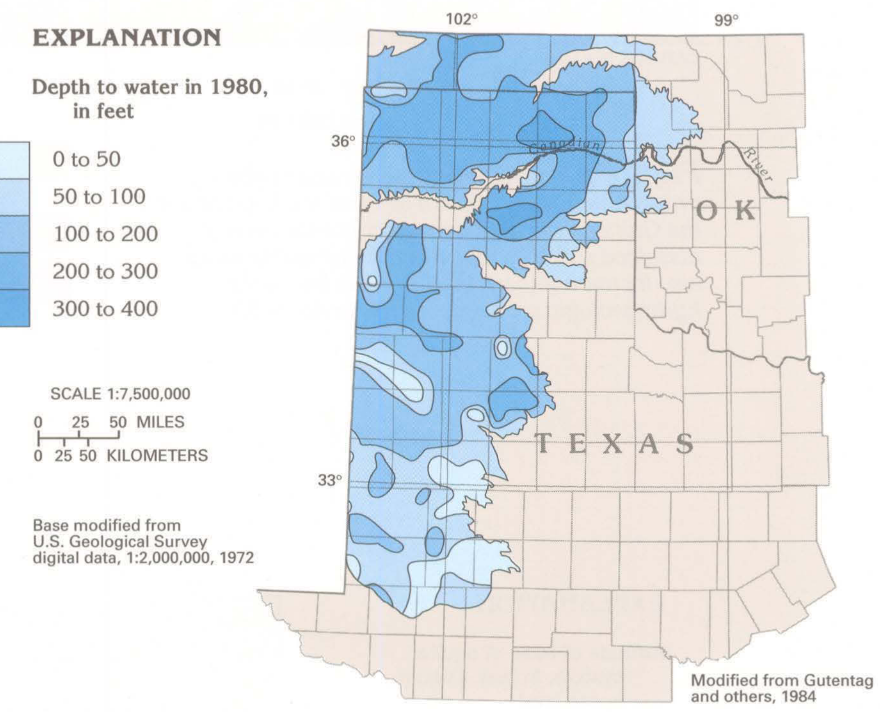
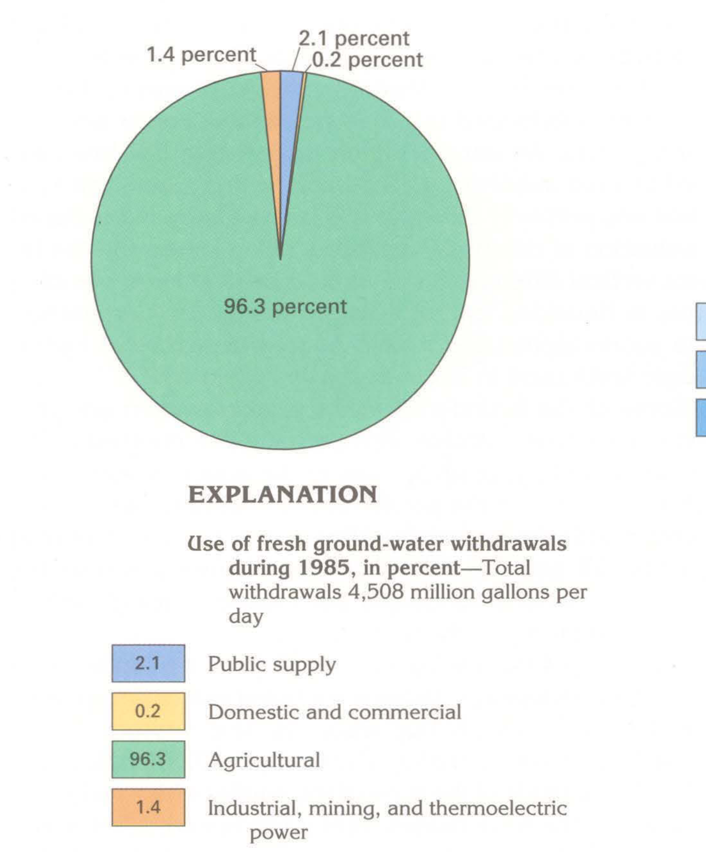


Figure 50. The generalized depth to water in the High Plains aquifer ranged from 0 to 400 feet in 1980. For most of the area, depth to water exceeded 100 feet.



Data from N.L. Barber and D.L. Lurry, U.S. Geological Survey, written communication, 1989; U.S. Geological Survey, Tulsa Oklahoma, written communication, 1989; and William Moltz, Texas Water Development Board, written communication, 1989

Figure 51. Most of the freshwater withdrawn from the High Plains aquifer during 1985 was used for agricultural purposes.

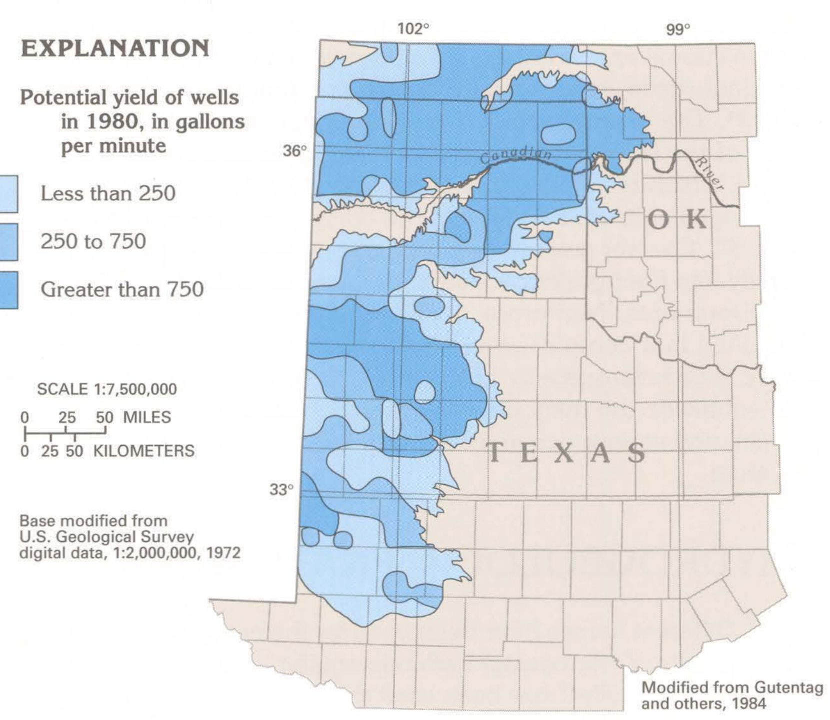


Figure 52. Potential yields of wells completed in the High Plains aquifer, particularly north of the Canadian River, commonly exceeded 750 gallons per minute in 1980.

FRESH GROUND-WATER WITHDRAWALS

Withdrawals of freshwater from the High Plains aquifer in Texas and Oklahoma totaled 4,508 million gallons per day during 1985 (**fig. 51**). Agricultural purposes, the principal water use, required about 4,343 million gallons per day. About 93 million gallons per day was withdrawn for public supply and about 9 million gallons per day was pumped for domestic and commercial uses. Withdrawals for industrial, mining, and thermoelectric-power uses were 63 million gallons per day.

POTENTIAL FOR DEVELOPMENT

The map of potential yields of wells completed in the High Plains aquifer shown in **figure 52** is based on hydraulic conductivity and the 1980 saturated thickness. In a large part of the area, especially north of the Canadian River, well yields in excess of 750 gallons per minute can be expected. One well capable of yielding 750 gallons per minute can irrigate 160 acres and effectively operate a quarter-section (0.25 square-mile) center-pivot irrigation system. Irrigation development is less favorable in areas, such as a large part of the Southern High Plains of Texas, where well yields are less than 250 gallons per minute. Areas with further declines in water level (therefore declining well yields) may experience a decline in irrigated acreage, as noted in the "Ground-Water Development" section above for the seven-county area in Texas. In some areas, particularly the southernmost area, irrigation development may be limited because of large sodium or dissolved-solids concentrations (**fig. 45**).

Because the High Plains aquifer is being pumped far in excess of recharge, the ground water is a limited resource. Questions of major concern are: How long will the ground-water resource last?; and How can the remaining water be managed and used most efficiently? Among the factors that influence further development of the High Plains aquifer are crop prices, energy and other farm costs, droughts and surplus precipitation, conservation practices, regulatory policies, and water-use technology improvements.

The Texas Department of Water Resources projects an increasing shortage of water from the High Plains aquifer for future irrigation needs. Unless an effective conservation program is implemented, it is estimated that the irrigated acreage on the High Plains of Texas will be decreased by slightly more than one-half of the present acreage by 2030. Water conservation methods and secondary recovery of capillary water are among some of the alternatives that are being explored to solve the water-supply problems in the High Plains of Texas. To assist in that exploration, digital computer simulations have been used to predict the possible effects of future ground-water pumpage on the High Plains aquifer under various pumpage estimates and management strategies.

Coastal lowlands aquifer system

EXPLANATION

Coastal lowlands aquifer system

A——A' Line of hydrogeologic section

5 Atlas segment number

INTRODUCTION

The coastal lowlands aquifer system consists of mostly Miocene and younger unconsolidated deposits that lie above and coastward of the Vicksburg–Jackson confining unit; the deposits extend to land surface (**figs. 53 and 54**). The aquifer system is in the Coastal Plain Physiographic Province and is in all or parts of 51 counties in Texas. It extends eastward into parts of the Coastal Plain of Louisiana and Mississippi and is further discussed in Chapter F of this Atlas. A small part of the system extends into southern Alabama and the western part of Panhandle Florida where it is called the sand and gravel aquifer (Chapter G of this Atlas). In Texas, the aquifer system underlies about 35,000 square miles of the level, low-lying coastal plain whose surface rises gradually toward the north and northwest.

The major rivers that flow through the area and empty into the Gulf are, from west to east, the Rio Grande, the Nueces, the Frio, the San Antonio, the Guadalupe, the Colorado, the Brazos, the Navasota, the Trinity, the Neches, the Angelina, and the Sabine. Average annual precipitation ranges from about 22 inches in the Rio Grande Valley in the southwest to about 56 inches at the Louisiana border in the east. The coastward-dipping sediments reach thicknesses of thousands of feet and contain waters that range from freshwater to brine. The coastal lowlands aquifer system yields large amounts of water for public, agricultural, and industrial needs.

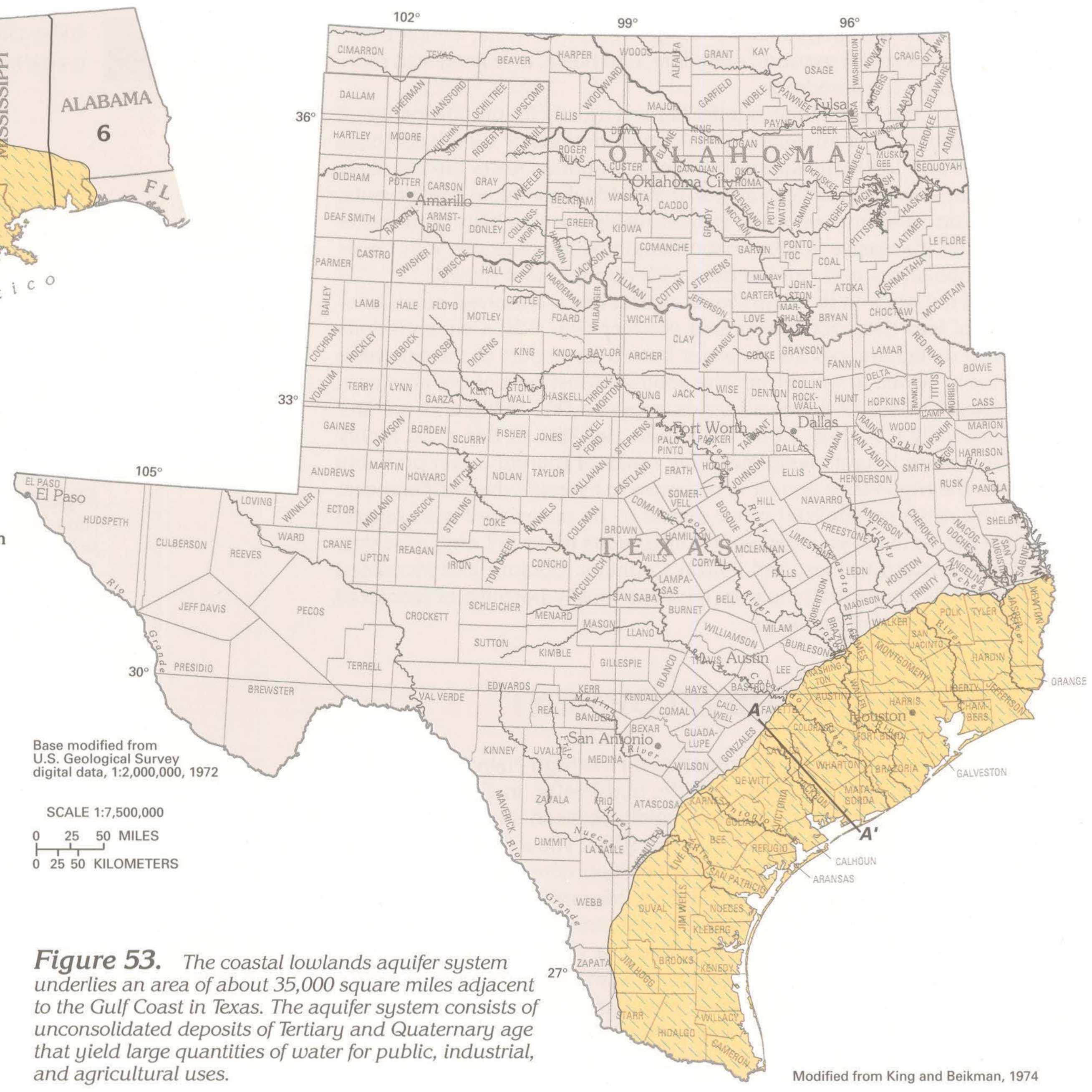


Figure 53. The coastal lowlands aquifer system underlies an area of about 35,000 square miles adjacent to the Gulf Coast in Texas. The aquifer system consists of unconsolidated deposits of Tertiary and Quaternary age that yield large quantities of water for public, industrial, and agricultural uses.

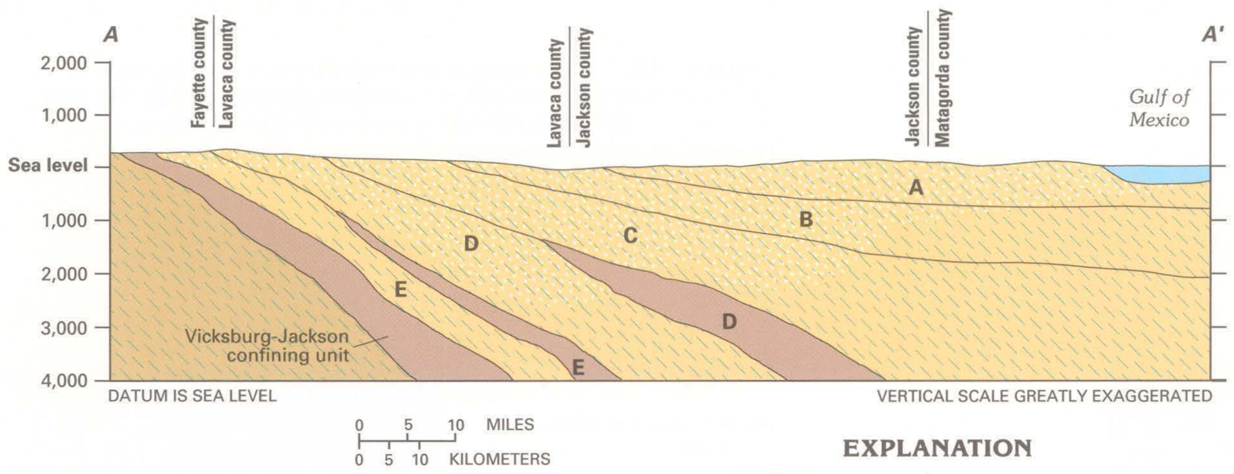


Figure 54. Permeable zones and confining units of the aquifer system dip and thicken toward the Gulf of Mexico. Estimated concentrations of dissolved solids in water in the permeable zones also increase toward the Gulf. The line of the hydrogeologic section is shown in figure 53.

EXPLANATION

Coastal lowlands aquifer system—Dot patterned area indicates freshwater

Texas coastal uplands aquifer system

Confining unit

D Hydrogeologic unit—See figure 55

Era	System	Series	Stratigraphic unit (Modified from Baker, 1979)	Lithology	Hydrogeologic unit commonly used in Texas (Modified from Baker, 1979)	Hydrogeologic nomenclature used in this report (Modified from Weiss, 1992)
Cenozoic	Quaternary	Holocene	Alluvium	Sand, silt, and clay	Chicot aquifer	Permeable zone A
		Pleistocene	Beaumont Formation Montgomery Formation Bentley Formation			
			Willis Sand	Sand, silt, and clay		Permeable zone B
	Tertiary	Pliocene	Goliad Sand	Sand, silt, and clay	Evangeline aquifer	Permeable zone C
		Miocene	Fleming Formation	Clay, silt and sand	Burkeville confining unit	Zone D confining unit[1]
			Oakville Sandstone			
			Catahoula Sandstone or Tuff[2]	Sand, silt, and clay	Jasper aquifer	Permeable zone D
			Anahuac Formation[1]	Clay, silt and sand	Catahoula confining unit (restricted)	Zone E confining unit[1]
		Oligocene	Frio Formation[1]	Sand, silt, and clay		Permeable zone E
			Frio Clay[3] / Vicksburg Formation[1]	Clay and silt	Vicksburg-Jackson confining unit	Vicksburg-Jackson confining unit
		Eocene	Jackson Group: Whitsett Formation, Manning Clay, Wellborn Sandstone, Caddell Formation			

Permeable zones A through E and the Zone D and Zone E confining units: Coastal lowlands aquifer system

[1]Present only in the subsurface
[2]Called Catahoula Tuff west of Lavaca County
[3]Not recognized at surface east of Live Oak County

Figure 55. Alternating sands, silts, and clays that overlie the thick, extensive Vicksburg–Jackson confining unit are grouped into permeable zones and confining units on the basis of relative permeabilities and hydraulic heads. These units compose the coastal lowlands aquifer system.

EXPLANATION

Altitude of base of aquifer system, in feet. Datum is sea level

500 to 0

0 to -1,000

-1,000 to -2,000

-2,000 to -4,000

-4,000 to -6,000

Vicksburg-Jackson confining unit

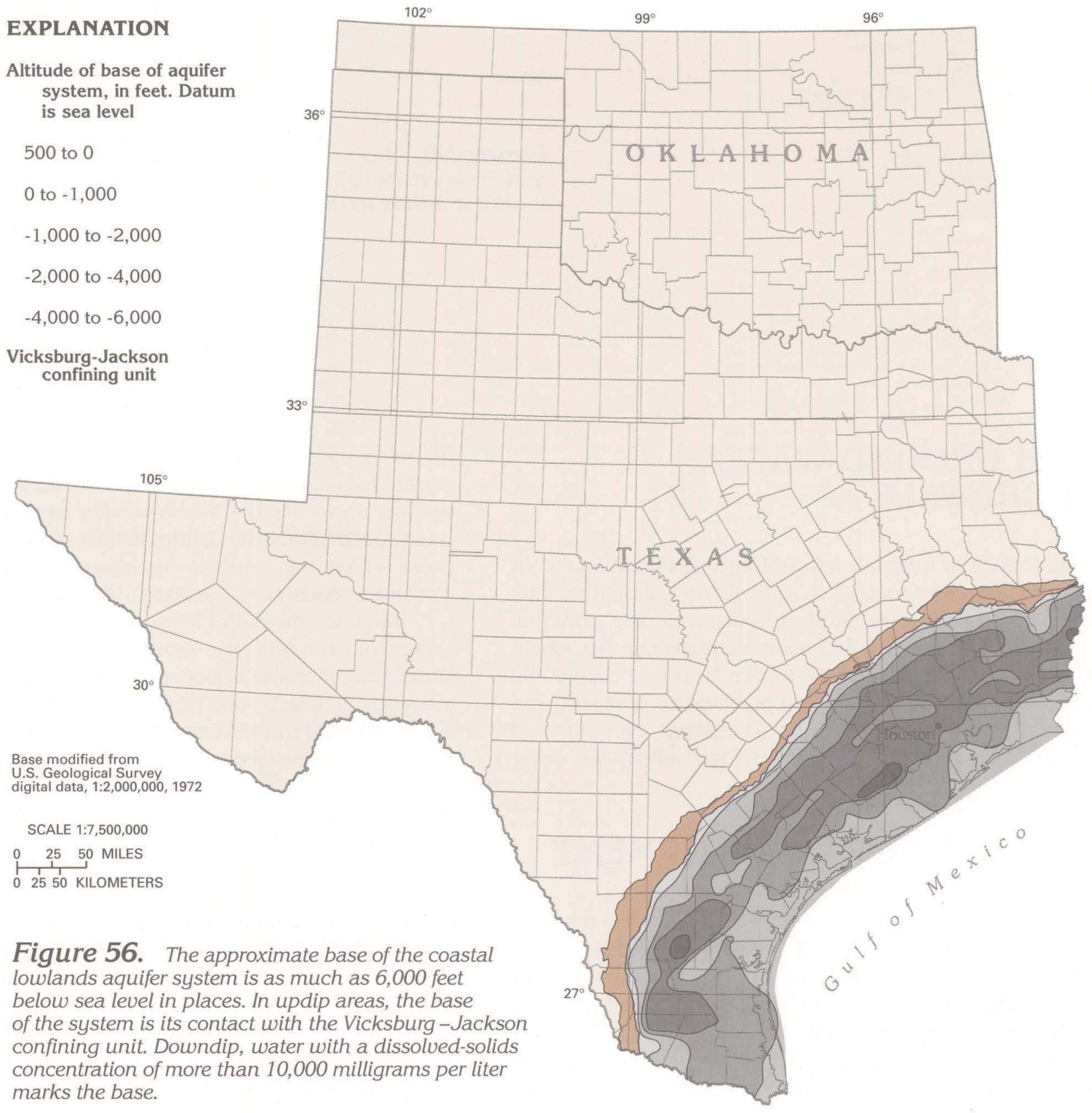


Figure 56. The approximate base of the coastal lowlands aquifer system is as much as 6,000 feet below sea level in places. In updip areas, the base of the system is its contact with the Vicksburg–Jackson confining unit. Downdip, water with a dissolved-solids concentration of more than 10,000 milligrams per liter marks the base.

HYDROGEOLOGY

The deposits that compose the coastal lowlands aquifer system range in age from Oligocene to Holocene (**fig. 55**). The lithology is generally sand, silt, and clay and reflects three depositional environments—continental (alluvial plain), transitional (delta, lagoon, and beach), and marine (continental shelf). The gradual subsidence of the depositional basin and rise of the land surface caused the deposits to thicken Gulfward, which resulted in a wedge-shaped configuration of the hydrogeologic units as seen in the cross section shown in **figure 54**. Coarser grained nonmarine deposits updip grade laterally into finer-grained material that was deposited in marine environments. Numerous oscillations of ancient shorelines resulted in a complex, overlapping mixture of sand, silt, and clay. This heterogeneity has made it difficult for investigators to subdivide the thick deposits into individual hydrogeologic units, and various schemes of subdivision are found in the literature.

HYDROGEOLOGIC FRAMEWORK

Different names have been used for the aquifers and confining units of the coastal lowlands aquifer system. The term "Gulf Coast aquifer" has been used to refer to and describe the composite sands, silts, and clays of the aquifer system. The "Chicot aquifer" and "Evangeline aquifer" are commonly used hydrogeologic-unit designations for subdivisions of the upper, mostly sandy part of the deposits. In a recently completed regional study that was part of the U.S. Geological Survey's Regional Aquifer-System Analysis (RASA) program, the deposits were subdivided into five permeable zones and two confining units. An informal letter designation has been assigned to each subdivision. The basis of this seven-unit subdivision was primarily differences in permeability, but included an evaluation of depths of water-producing zones and the resultant vertical differences in hydraulic head at large pumping centers in Houston, Tex., and Baton Rouge, La. Comparison of the subdivisions used in this Atlas with names of hydrogeologic units used in Texas is shown in **figure 55**.

Some of the boundaries of the aquifer system are geographic and some coincide with permeability contrasts. The landward boundary, or updip limit of the aquifer system, is in outcrop areas where the aquifer system feathers out at point of contact with the underlying Vicksburg–Jackson confining unit (**figs. 53 and 54**). The Gulfward boundary is near the coastline where the ground water becomes increasingly saline; the upper boundary is the land surface.

The base of the aquifer system is either its contact with the top of the Vicksburg–Jackson confining unit or the approximate depth at which the water in the system has a dissolved-solids concentration of more than 10,000 milligrams per liter. The altitude of the base of the aquifer system is shown in **figure 56**. The base ranges from a few hundred feet above sea level near the updip limit, to as much as 6,000 feet below sea level in areas about midway between the updip limit and the coastline.

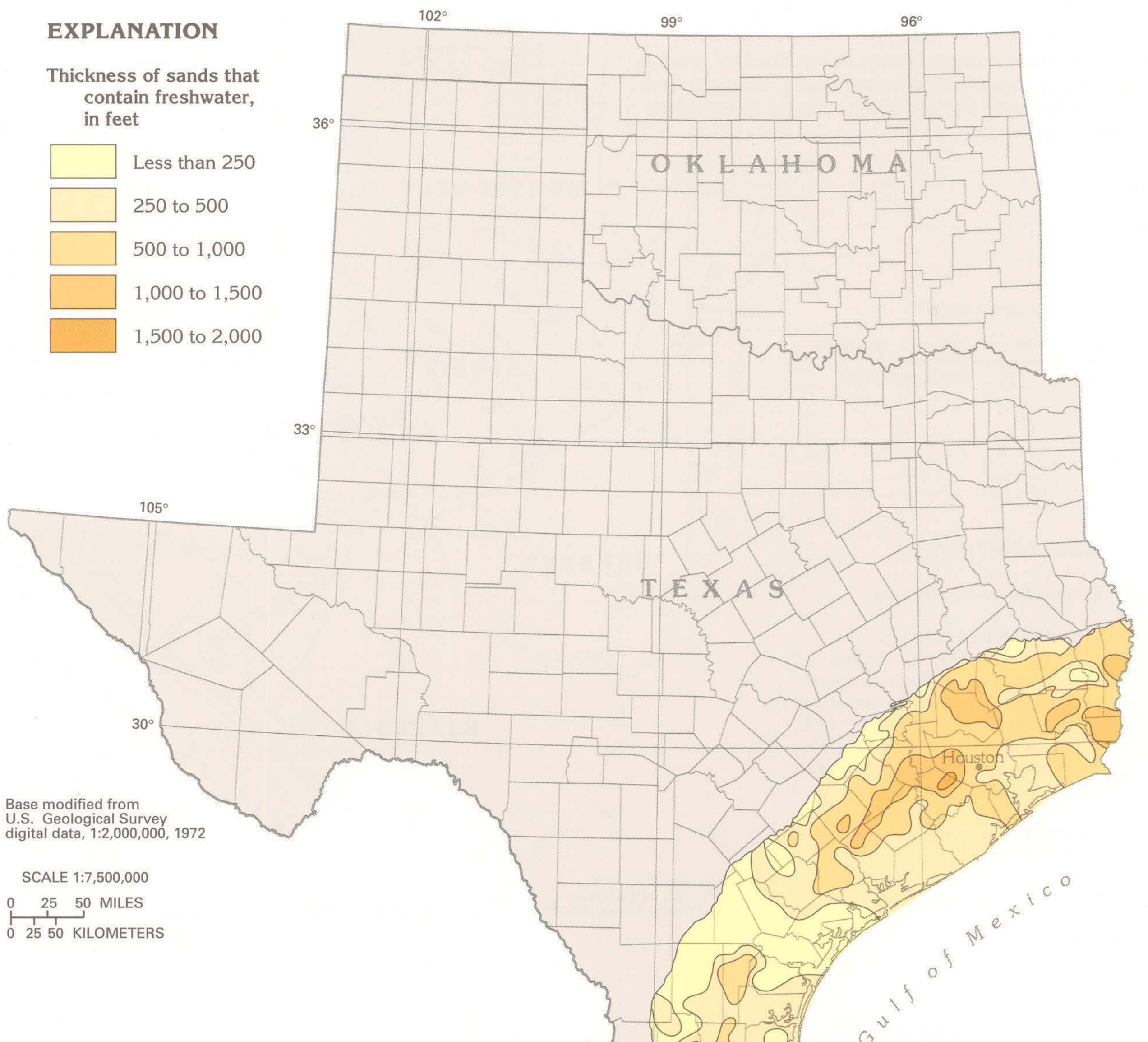


Figure 57. The aggregate thickness of sands that contain water with dissolved-solids concentrations of less than 1,000 milligrams per liter is greater in the east than elsewhere.

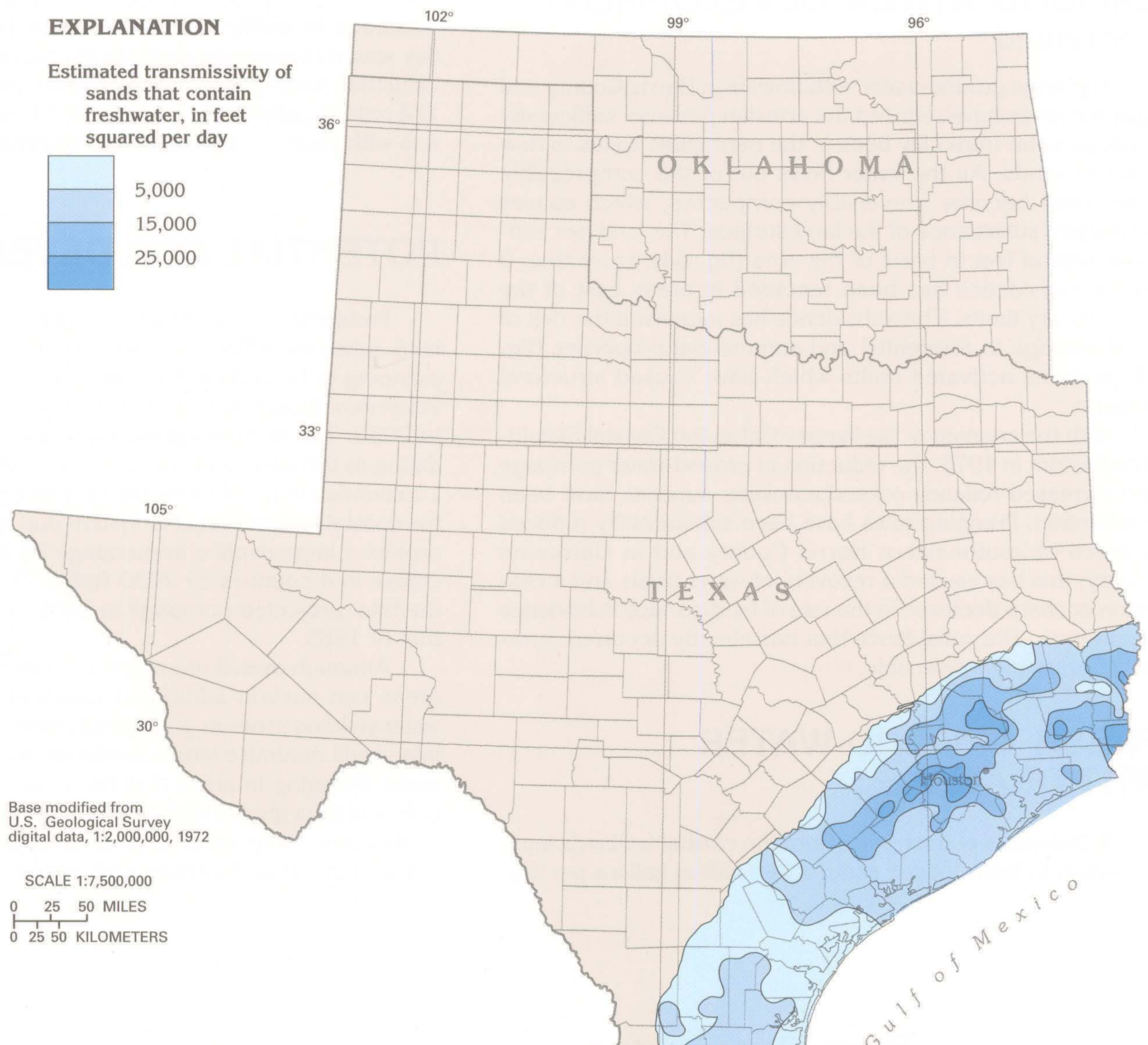


Figure 58. The estimated transmissivity of the sands that contain water with dissolved-solids concentrations of less than 1,000 milligrams per liter is greater in the east and locally is nearly 35,000 feet squared per day.

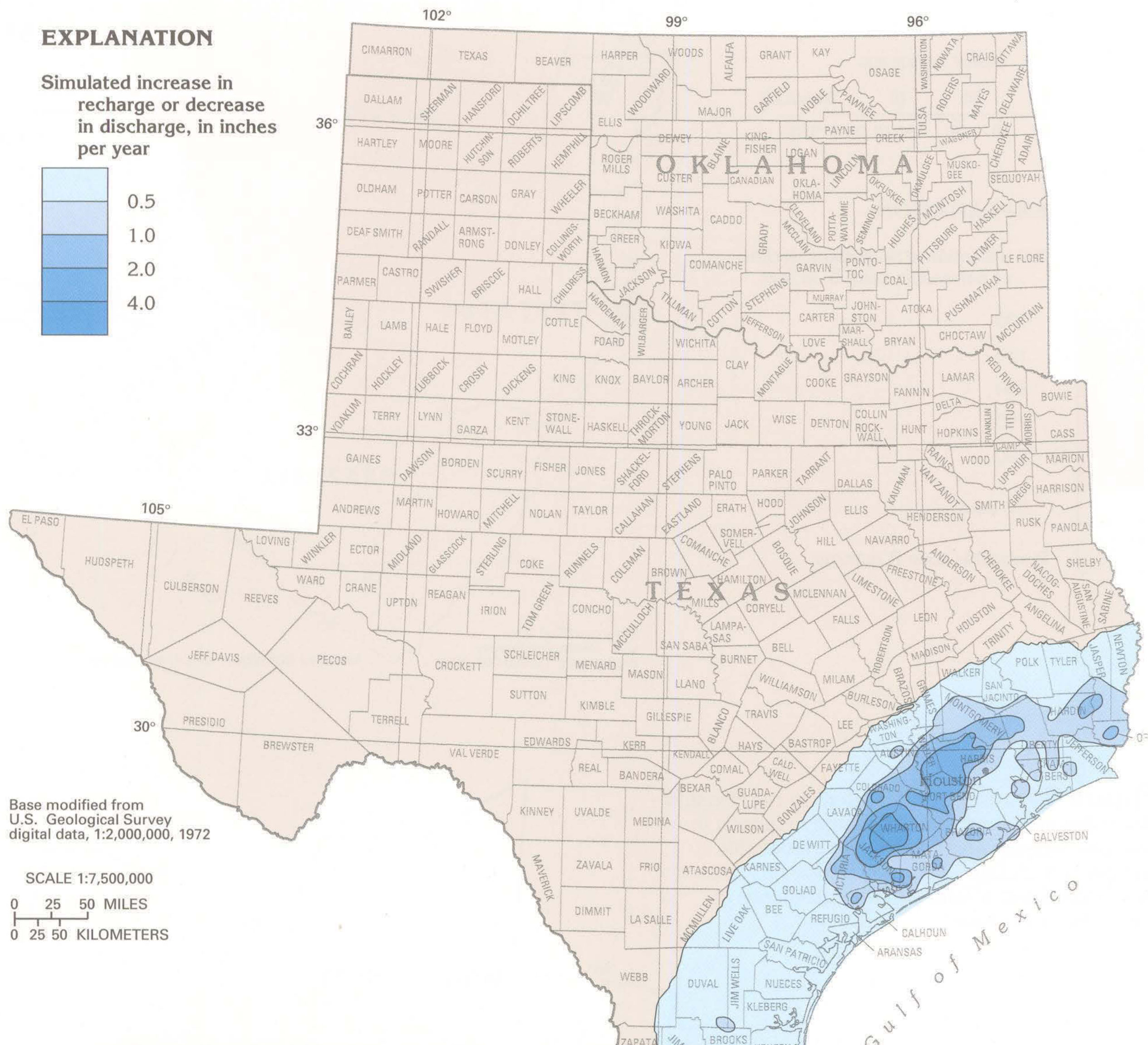


Figure 59. Before development, recharge in the outcrop areas of the coastal lowlands aquifer system was generally less than 1 inch per year. By 1982, pumpage caused predevelopment recharge rates to increase by as much as 6 inches per year.

GROUND-WATER HYDRAULICS

The aquifer system is recharged by the infiltration of precipitation that falls on topographically high aquifer outcrop areas. Natural discharge occurs by evapotranspiration, loss of water to streams as base flow, and upward leakage to shallow aquifers in low-lying coastal areas or in the Gulf of Mexico. Recharge and discharge in areas with little or no pumpage are generally between 0 and 1 inch per year. Additional recharge occurs where water levels are lowered by pumping because the vertical hydraulic head gradient is increased. In places where head gradients might become reversed, water might move from former discharge areas along streams into the aquifers.

With the exception of shallow zones in the outcrop, the water in the coastal lowlands aquifer system is under confined conditions. In the shallow zones, the specific yield for sandy deposits ranges generally between 10 and 30 percent; for confined aquifers, the storage coefficient is estimated to range between 1×10^{-4} and 1×10^{-3}. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield. The storage coefficient is an important factor that determines the size and rate of development of cones of depression that result from ground-water withdrawals.

The productivity of the aquifer system is directly related to the total thickness of the sands in the aquifer system that contain freshwater. This aggregate sand thickness is shown in **figure 57**. Values range from zero at the updip limit of the aquifer system to as much as 2,000 feet in the east. The transmissivity of the sands is a measure of the ease with which water will move through them. Transmissivity can be calculated by multiplying the average hydraulic conductivity of the sands times the thickness of the sands that contain freshwater. Transmissivity, storage coefficient, and recharge rate control the rate of well yields and the size and shape of the cones of depression that result on an aquifer's potentiometric surface because of pumping.

The average hydraulic conductivity of the sands was estimated from a digital computer model. East of the San Antonio River, the average hydraulic conductivity is about 21 feet per day; west of the river, it is about 17 feet per day. By using these values and the freshwater sand thickness as shown in **figure 57**, an estimate of the transmissivity can be computed and mapped, as shown in **figure 58**. Values of transmissivity range from less than 5,000 to nearly 35,000 feet squared per day.

GROUND-WATER DEVELOPMENT

For the coastal lowlands aquifer system in general, ground-water pumpage was relatively small and constant from the early 1900's until the late 1930's. Pumping rates increased sharply during the 1940's and 1950's until about 1960, when about 800 million gallons per day was withdrawn. Withdrawal rates increased relatively slowly thereafter, and, during 1985, 1,090 million gallons per day was withdrawn.

Withdrawals during 1985 were largely from the east-central area; the largest pumpage was in the Houston area of Harris County. Harris County accounted for 35 percent of the total withdrawals, and the combined withdrawals from Harris and Wharton Counties were 50 percent of the total (**table1**). Ten counties in the east-central area accounted for 82 percent

Table 1. Combined withdrawals from the coastal lowlands aquifer system during 1985 in Harris and Wharton Counties were 50 percent of the total freshwater withdrawn from the aquifer system

[Data from William Moltz, Texas Water Development Board, written commun., 1990]

County	Fresh ground-water withdrawals, in million gallons per day				
	Public supply	Domestic and commercial	Agricultural	Industrial, mining, and thermoelectric power	Total
Harris	318	7	21	39	385
Wharton	5	1	156	1	163
Jackson	2	0	63	1	66
Fort Bend	24	3	29	4	60
Jasper	4	1	0	41	46
Colorado	3	0	34	1	38
Brazoria	20	2	13	3	38
Waller	3	0	29	2	34
Matagorda	4	1	23	3	31
Victoria	10	1	11	7	29
Total for counties	393	16	379	102	890
Total for aquifer system	476	53	447	114	1,090

of total withdrawals; the largest usage was divided about equally between public supply and agriculture (**table 1**).

During 1982, some of the greatest pumpage from the aquifer system was in the coastal area of rice irrigation centered in Jackson and Wharton Counties and including parts of Colorado, Lavaca, Victoria, and Matagorda Counties. About 322 million gallons per day was withdrawn from permeable zone A, the uppermost permeable zone of the aquifer system in this area. Because the permeable zone crops out near this area, recharge in the outcrop area provided a source to quickly balance the large withdrawals. Thus, drawdowns were not large (generally less than 50 feet), but the increase in recharge rates over predevelopment rates was large. Recharge rates were increased by as much as 4 to 6 inches per year in the rice irrigation area, as indicated by the model simulation results shown in **figure 59**.

Another area that was pumped intensively during 1982 is centered in the city of Houston and includes Harris and all or parts of Chambers, Galveston, Brazoria, Fort Bend, Waller, Montgomery, and Liberty Counties. Withdrawals from permeable zones A, B, and C, the three uppermost water-yielding zones in the aquifer system, were mostly for public and industrial supplies and were about 260, 260, and 165 million gallons per day, respectively. As a result of the intense pumping, the potentiometric surface was lowered in all three zones. The lowering was least severe in zone A, the shallowest zone, where water levels declined to a maximum of 150 feet below sea level. The effect on the potentiometric surface was more severe in the deeper zones because their outcrop recharge areas were far updip from the pumping centers and a substantial amount of water was removed from aquifer storage. In Houston, the 1982 potentiometric surface declined to more than 250 feet below sea level in zone B (**fig. 60**) and more than 350 feet below sea level in zone C (**fig. 61**). Maps of the distribution of the change in the predevelopment to 1982 potentiometric surfaces show a decline of more than 300 feet in zone B (**fig. 62**), and more than 400 feet in zone C (**fig. 63**).

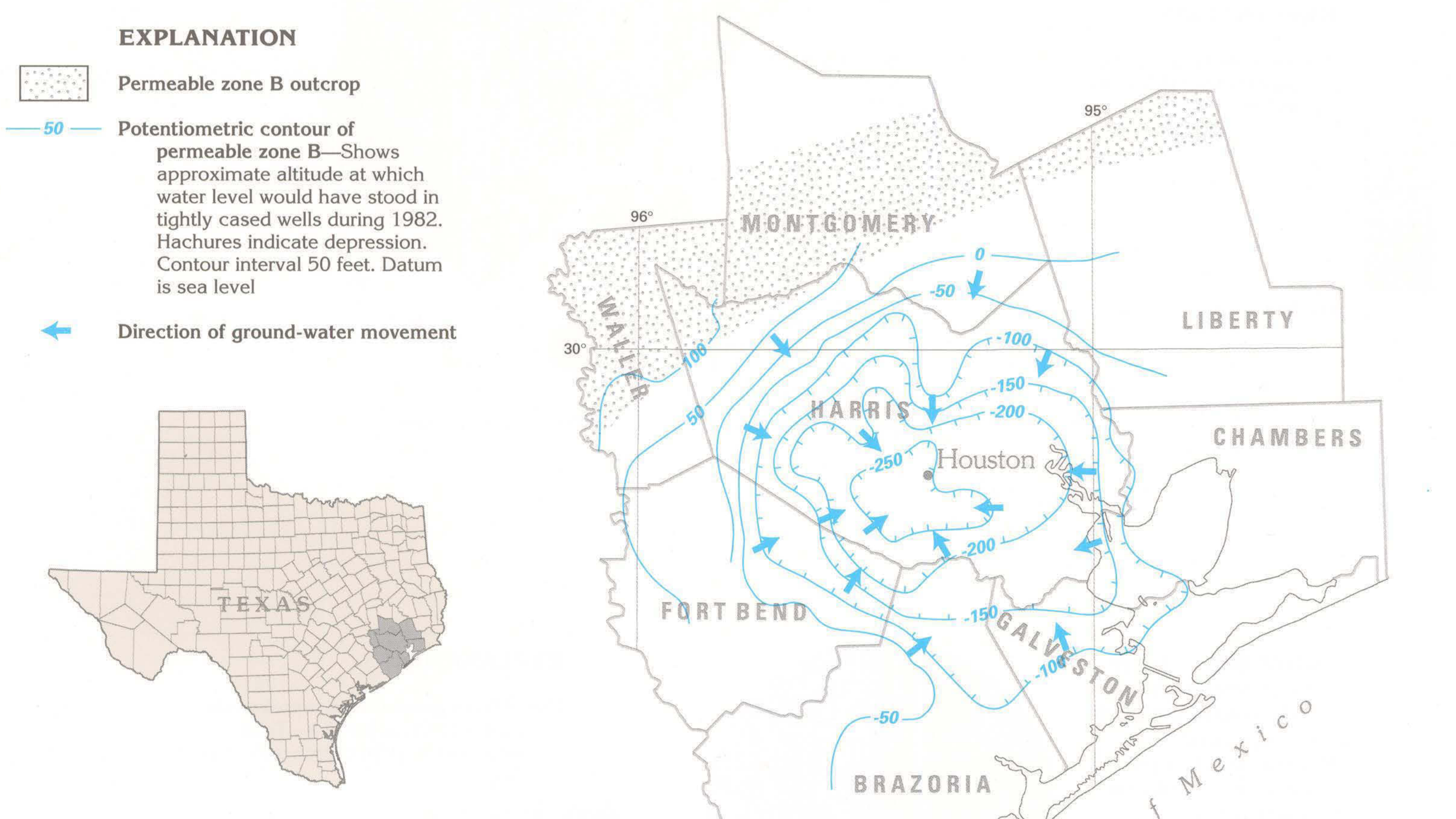


Figure 60. Major withdrawals have created a large cone of depression on the potentiometric surface of permeable zone B. In 1982, the center of the cone was in Houston where the potentiometric surface of the zone was more than 250 feet below sea level.

GROUND-WATER DEVELOPMENT—Continued

The large ground-water withdrawals in Harris County and adjacent areas have reduced the artesian pressure sufficiently to cause water from clay beds in the permeable zones to flow into the sands. As the water flows out of the compressible clays, they become irreversibly compacted, which causes permanent subsidence of the land surface. The land has subsided several feet in parts of the area (**fig. 64**); more than 9 feet of subsidence has been recorded in areas east of the Houston city limits. The subsidence has increased the risk of flood damage to residential and commercial properties (**fig. 65**) and has activated faults which have caused structural damage.

With the creation of the Harris–Galveston Coastal Subsidence District in 1975, the reduction of ground-water pumpage and increased reliance on surface-water supplies have been emphasized. Pumping rates have been substantially reduced in much of southeastern Harris County and in Galveston County; this has caused a recovery of water levels and a cessation or sharp decrease in the rate of land-surface subsidence in that area. The subsidence that has already occurred, however, is virtually irreversible.

FRESH GROUND-WATER WITHDRAWALS

Withdrawals of freshwater from the coastal lowlands aquifer system in Texas totaled about 1,090 million gallons per day during 1985 (**fig. 66**). About 476 million gallons per day was withdrawn for public supply, and about 447 million gallons per day was withdrawn for agricultural purposes. Withdrawals for industrial, mining, and thermoelectric-power uses were about 114 million gallons per day. About 53 million gallons per day was withdrawn for domestic and commercial uses.

POTENTIAL FOR DEVELOPMENT

Problems associated with ground-water pumpage, such as land subsidence and saltwater encroachment, have caused pumping to be curtailed in some areas. The Texas Water Development Board has made projections of ground-water use to 2030. The tentative projections undergo revision and updating as technical and socioeconomic factors change. For the 10 counties that withdrew the largest amounts of water from the coastal lowlands aquifer system during 1985, State officials project a large decline in pumpage for 6 counties and an increase in 4 counties by 2030 (**table 2**). For the 10 counties, the total projected pumpage in 2030 is 39 percent less than that of 1985.

Although overall use of ground water might decline, some areas can sustain additional development. Pumping from water-yielding zones in geologically older rocks that are farther inland will minimize land subsidence and saltwater encroachment. Pumping in areas that have more abundant precipitation, and thus greater recharge potential, is less likely to cause continuous, steep water-level declines and such problems as stream base-flow depletion and greater pumping lifts.

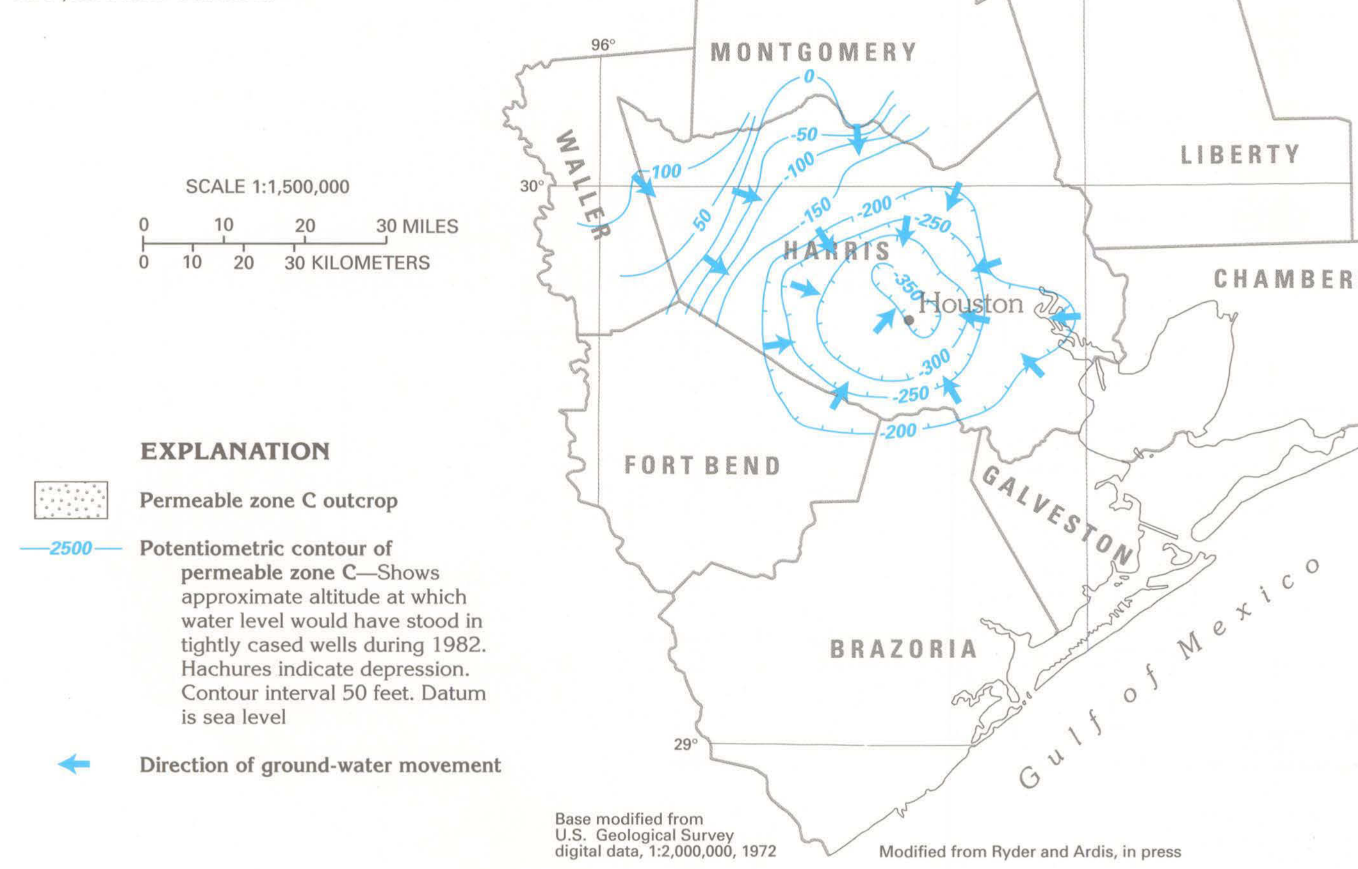


Figure 61. The center of major withdrawals from permeable zone C is farther away from the outcrop area than that of the other pumped zones in the Houston area. A very steep cone of depression is centered in Houston where the 1982 potentiometric surface of the zone was more than 350 feet below sea level.

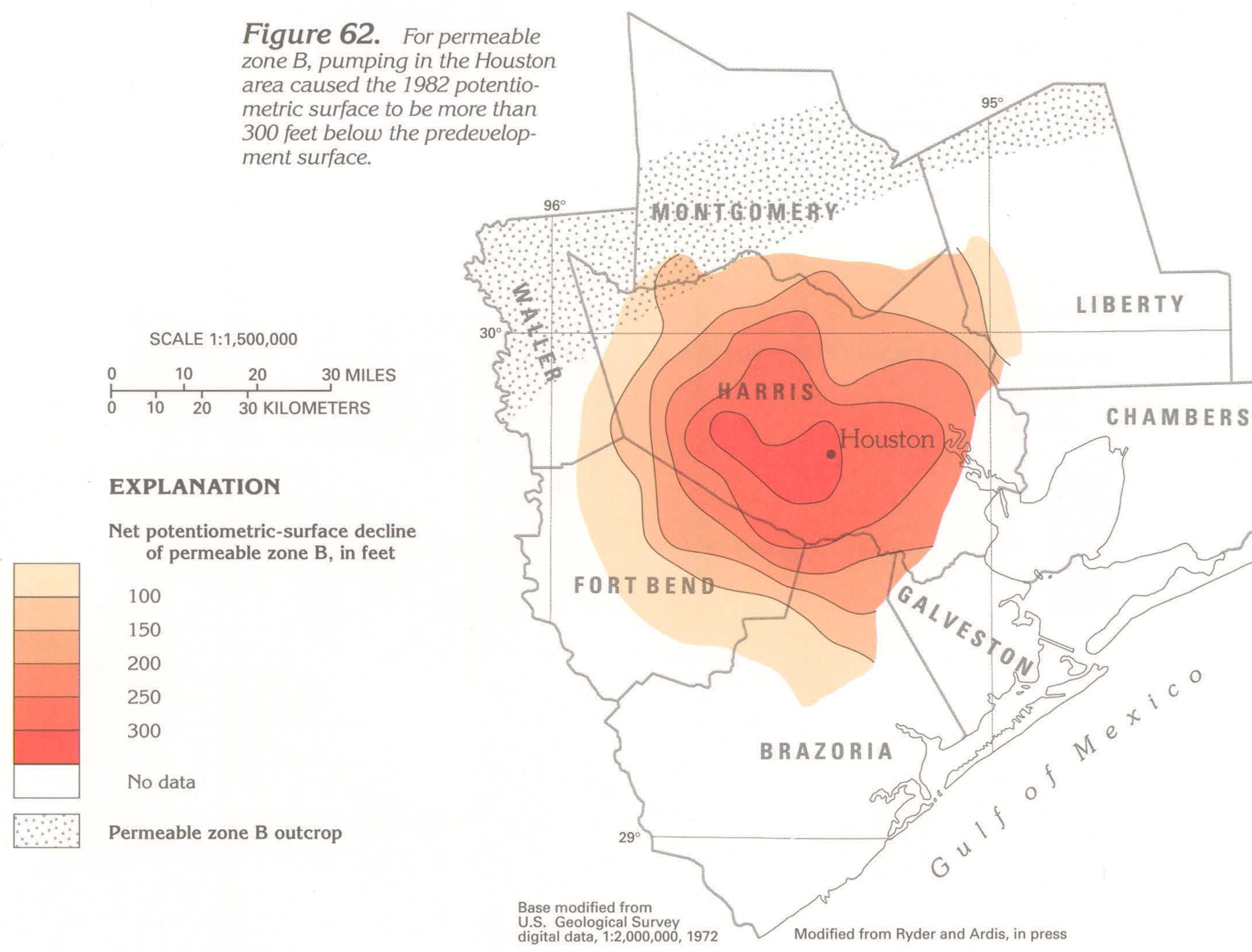


Figure 62. For permeable zone B, pumping in the Houston area caused the 1982 potentiometric surface to be more than 300 feet below the predevelopment surface.

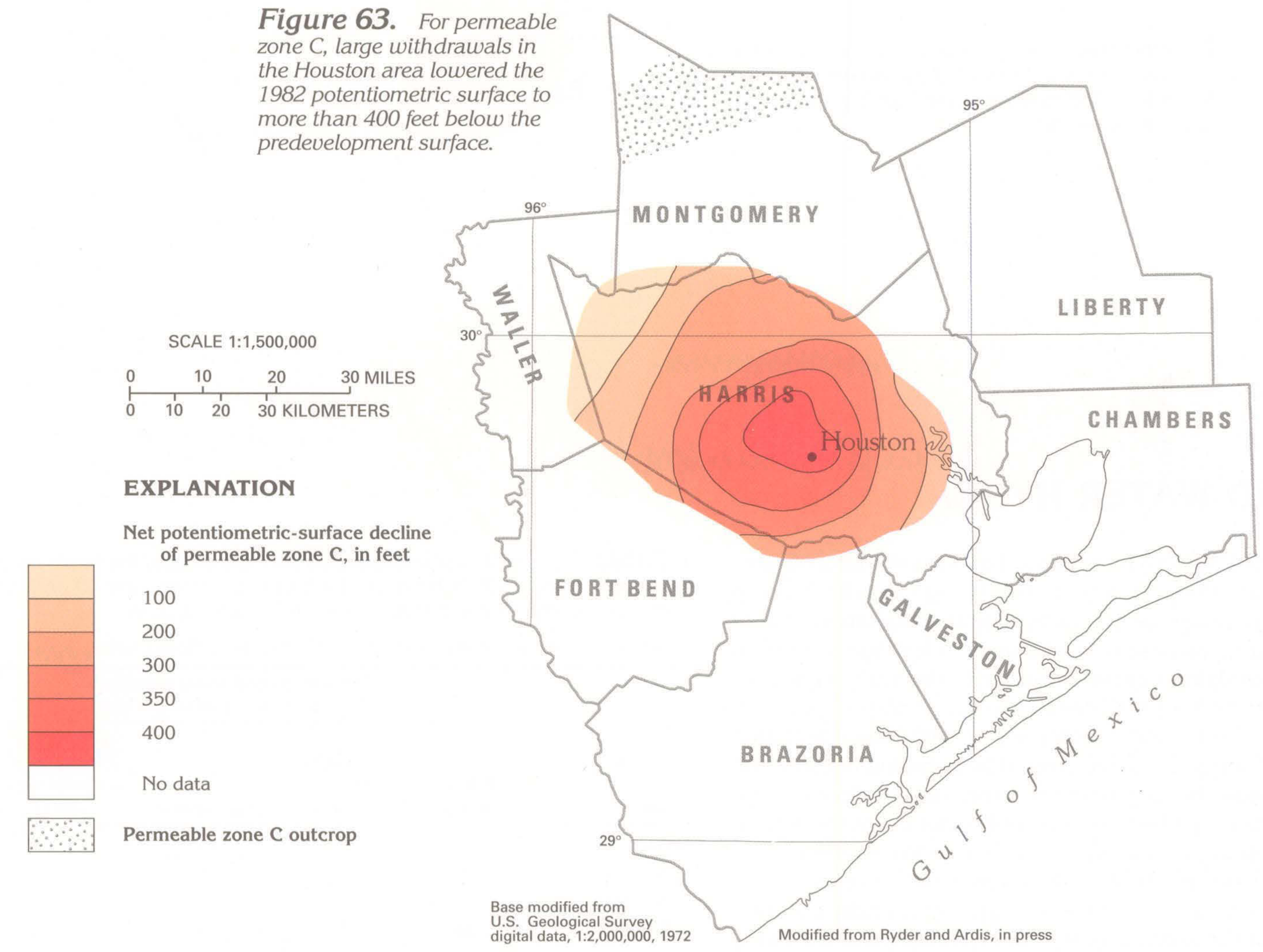


Figure 63. For permeable zone C, large withdrawals in the Houston area lowered the 1982 potentiometric surface to more than 400 feet below the predevelopment surface.

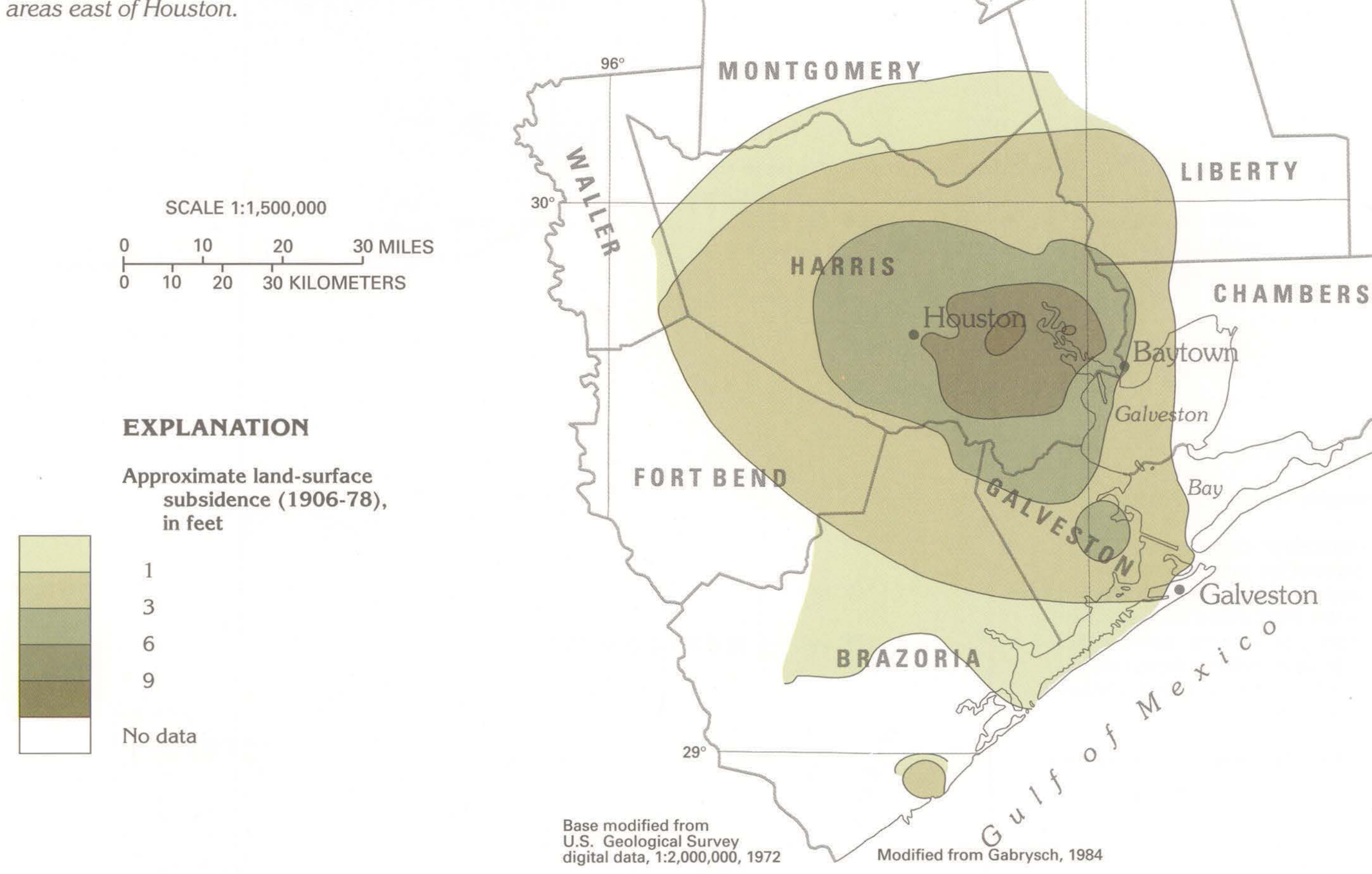


Figure 64. Large withdrawals in the Houston–Galveston area have caused a large reduction in artesian pressure and consequent irreversible compaction of clays. This compaction has caused more than 9 feet of land-surface subsidence in areas east of Houston.

Figure 65. The land surface has subsided more than 9 feet in Baytown, Tex., and has caused some residential areas to be permanently flooded by the encroachment of water from Galveston Bay.

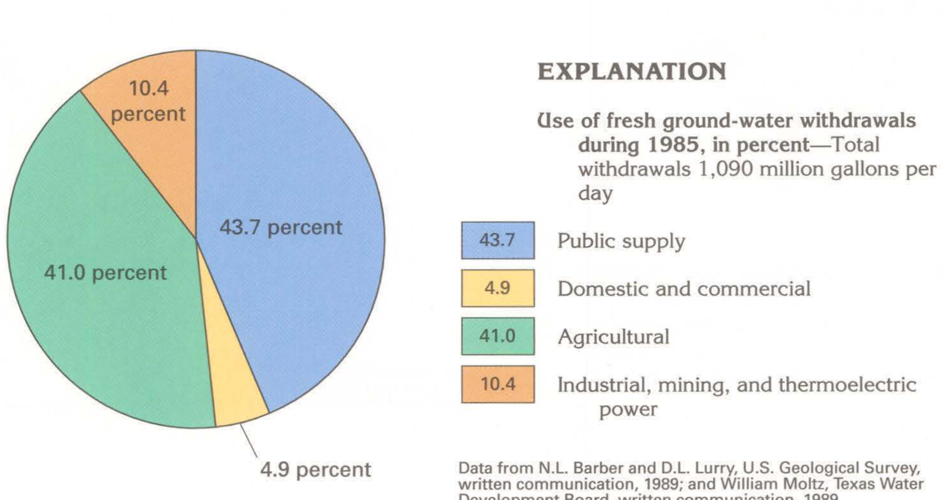


Figure 66. Most of the freshwater withdrawn from the coastal lowlands aquifer system during 1985 was used for public supply and agricultural purposes.

Table 2. Some of the 10 counties with the most intensive pupmage from the coastal lowlands aquifer system during 1985 are projected to have an increase in pumpage by 2030, but most have a projected decrease

[Data from Texas Water Development Board, written commun., 1988]

	Fresh ground-water withdrawals, in million gallons per day			
County	1985	2030 (projected)	Net change	Percentage net change
Harris	385	237	-148	-38
Wharton	163	34	-129	-79
Jackson	66	25	-41	-62
Fort Bend	60	61	+1	+2
Jasper	46	20	-26	-56
Colorado	38	28	-10	-26
Brazoria	38	44	+6	+16
Waller	34	50	+16	+47
Matagorda	31	16	-15	-48
Victoria	29	30	+1	+3
Total	890	545	-345	-39

Texas coastal uplands aquifer system

INTRODUCTION

The Texas coastal uplands aquifer system consists of Eocene deposits of the Claiborne Group and Eocene and Paleocene deposits of the Wilcox Group. Both groups are below the Vicksburg–Jackson confining unit and above the Midway confining unit (**figs. 67 and 68**). East of the Texas–Arkansas and Texas–Louisiana State lines, stratigraphically equivalent beds are called the Mississippi Embayment aquifer system. The sediments that compose the Texas coastal uplands aquifer system dip coastward beneath the coastal lowlands aquifer system. The Texas coastal uplands aquifer system underlies an area of about 48,000 square miles in the Coastal Plain Physiographic Province and is in all or parts of 70 counties in Texas. The topography of the coastal uplands is more dissected and rolling than that of the coastal lowlands. Average annual precipitation in the uplands ranges from about 21 inches in the Rio Grande Valley to about 50 inches at the Louisiana border.

The Texas coastal uplands aquifer system furnishes large quantities of water for agricultural, public, and industrial needs. Water withdrawn for public supply generally contains dissolved-solids concentrations of less than 1,000 milligrams per liter. Slightly saline water with dissolved-solids concentrations that range from 1,000 to 3,000 milligrams per liter can be used for many agricultural and industrial purposes. Nearly one-half of all freshwater withdrawn from the Texas coastal uplands aquifer system during 1985 was pumped for agricultural use from Zavala, Frio, Atascosa, and Dimmit Counties in the west.

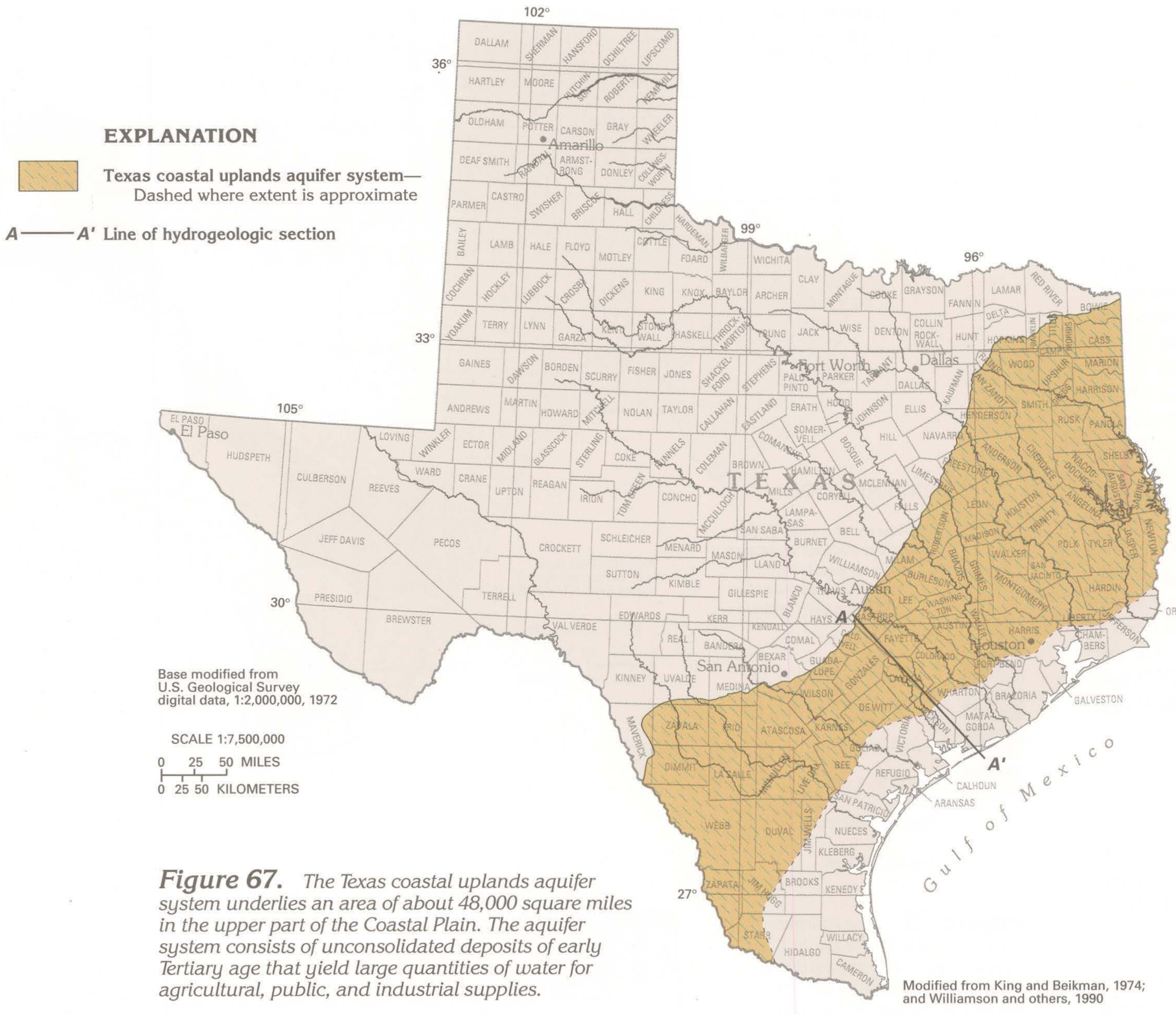


Figure 67. *The Texas coastal uplands aquifer system underlies an area of about 48,000 square miles in the upper part of the Coastal Plain. The aquifer system consists of unconsolidated deposits of early Tertiary age that yield large quantities of water for agricultural, public, and industrial supplies.*

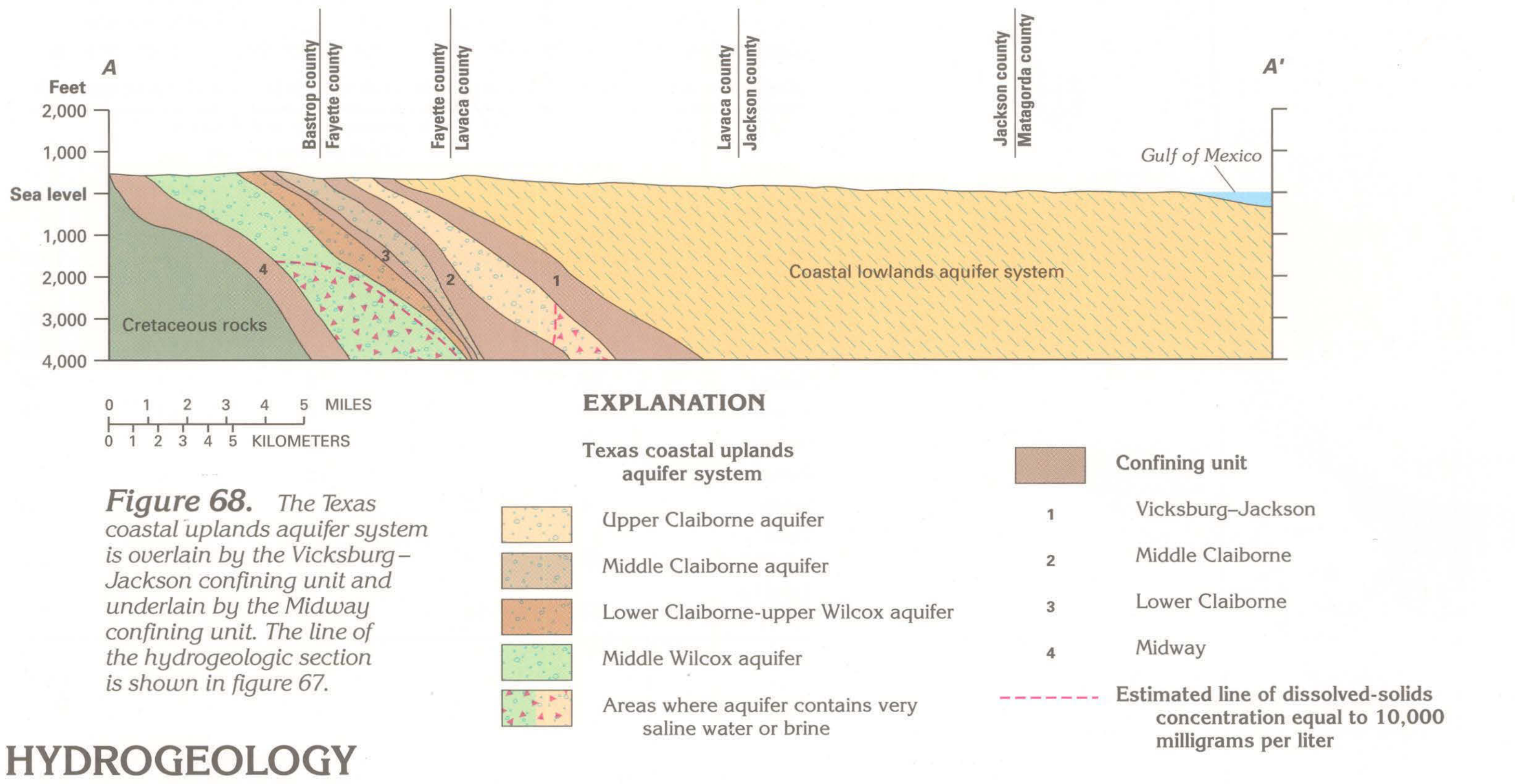


Figure 68. *The Texas coastal uplands aquifer system is overlain by the Vicksburg–Jackson confining unit and underlain by the Midway confining unit. The line of the hydrogeologic section is shown in figure 67.*

HYDROGEOLOGY

Deposits of the early Tertiary Claiborne and Wilcox Groups compose the Texas coastal uplands aquifer system (**fig. 69**). The sediments, in order of dominance, consist mostly of sand, silt, and clay and are distributed as relatively uniform sequences of predominantly fine- or coarse-grained material.

The Texas coastal uplands aquifer system is subdivided into four aquifers and two confining units. These are, from shallowest to deepest, the upper Claiborne aquifer; the middle Claiborne confining unit; the middle Claiborne aquifer; the lower Claiborne confining unit; the lower Claiborne–upper Wilcox aquifer; and the middle Wilcox aquifer. The widespread, intensively pumped lower Claiborne–upper Wilcox aquifer has been chosen to illustrate the aquifer system. Other aquifers in the system, though of lesser importance, show similar geometry, hydraulic characteristics, and water-quality trends.

The landward boundary of the aquifer system is at the updip limit of the outcrop of the Wilcox Group. The Gulfward boundary is generally the farthest downdip extent of water in the aquifer system that has a dissolved-solids concentration of less than 10,000 milligrams per liter (**fig. 68**). The top of the aquifer system is either land surface or the base of the Vicksburg–Jackson confining unit. The base of the aquifer system is either its contact with the top of the Midway confining unit or the approximate depth at which the water in the system has a dissolved-solids concentration that exceeds 10,000 milligrams per liter. The altitude of the base of the aquifer system is shown in **figure 70**. The base ranges from less than 1,000 feet above sea level to nearly 8,000 feet below sea level. The thickness of the freshwater sands of the aquifer system ranges from 0 to nearly 3,000 feet (**fig. 71**).

Era	System	Series	Group	Stratigraphic unit (Modified from Hosman and Weiss, 1991): Southern Texas	Stratigraphic unit: Southeastern and northeastern Texas	Lithology	Hydrogeologic unit commonly used in Texas (Modified from Muller and Price, 1979)	Hydrogeologic nomenclature used in this report	
Cenozoic	Tertiary	Oligocene		Frio Clay		Clay and silt		Vicksburg–Jackson confining unit	
		Eocene	Jackson Group	Whitsett Formation	Whitsett Formation				
				Manning Clay	Manning Clay				
				Wellborn Sandstone	Wellborn Sandstone				
				Caddell Formation	Caddell Formation				
			Claiborne Group	Yegua Formation	Yegua Formation	Sand, silt, and clay		Upper Claiborne aquifer	Texas coastal uplands aquifer system
				Laredo Formation	Cook Mountain Formation	Clay, silt and sand		Middle Claiborne confining unit	
					Sparta Sand	Sand, silt, and clay	Sparta aquifer[1]	Middle Claiborne aquifer	
				El Pico Clay	Weches Formation	Clay, silt and sand		Lower Claiborne confining unit	
					Queen City Sand		Queen City aquifer		
				Bigford Formation	Reklaw Formation				
				Carrizo Sand	Carrizo Sand	Sand, silt, and clay	Carrizo–Wilcox aquifer	Lower Claiborne–upper Wilcox aquifer	
		Paleocene	Wilcox Group	Undifferentiated deposits	Undifferentiated deposits	Sand, silt, and clay		Middle Wilcox aquifer	
			Midway Group	Wills Point Formation	Wills Point Formation	Clay and silt		Midway confining unit	
				Kincaid Formation	Kincaid Formation				

[1]Not recognized west of Frio County

Figure 69. *Predominantly permeable sand units separated by extensive fine-grained formations compose the aquifers and confining units of the Texas coastal uplands aquifer system.*

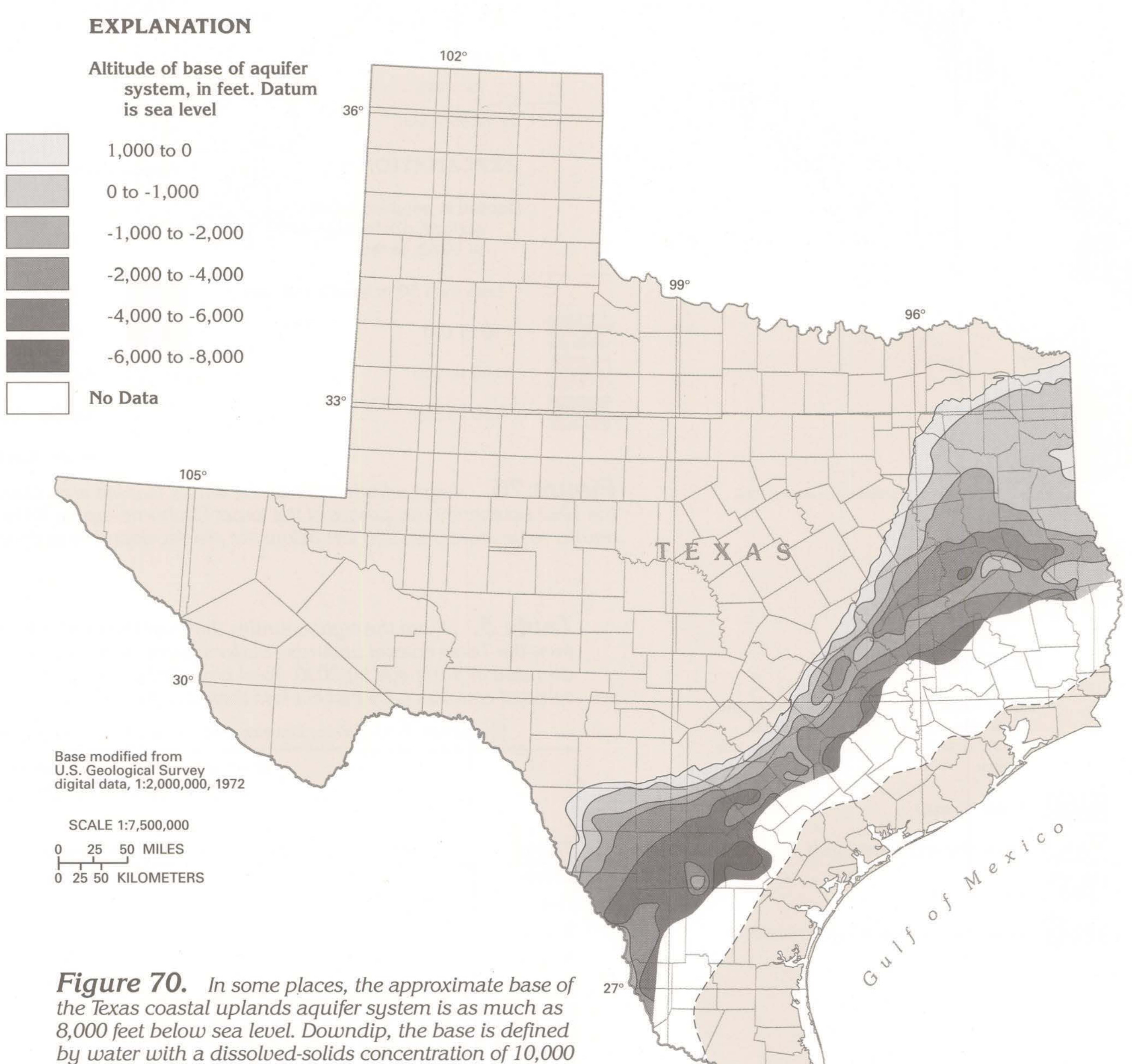


Figure 70. *In some places, the approximate base of the Texas coastal uplands aquifer system is as much as 8,000 feet below sea level. Downdip, the base is defined by water with a dissolved-solids concentration of 10,000 milligrams per liter. The base of the system in updip areas is its contact with the Midway confining unit.*

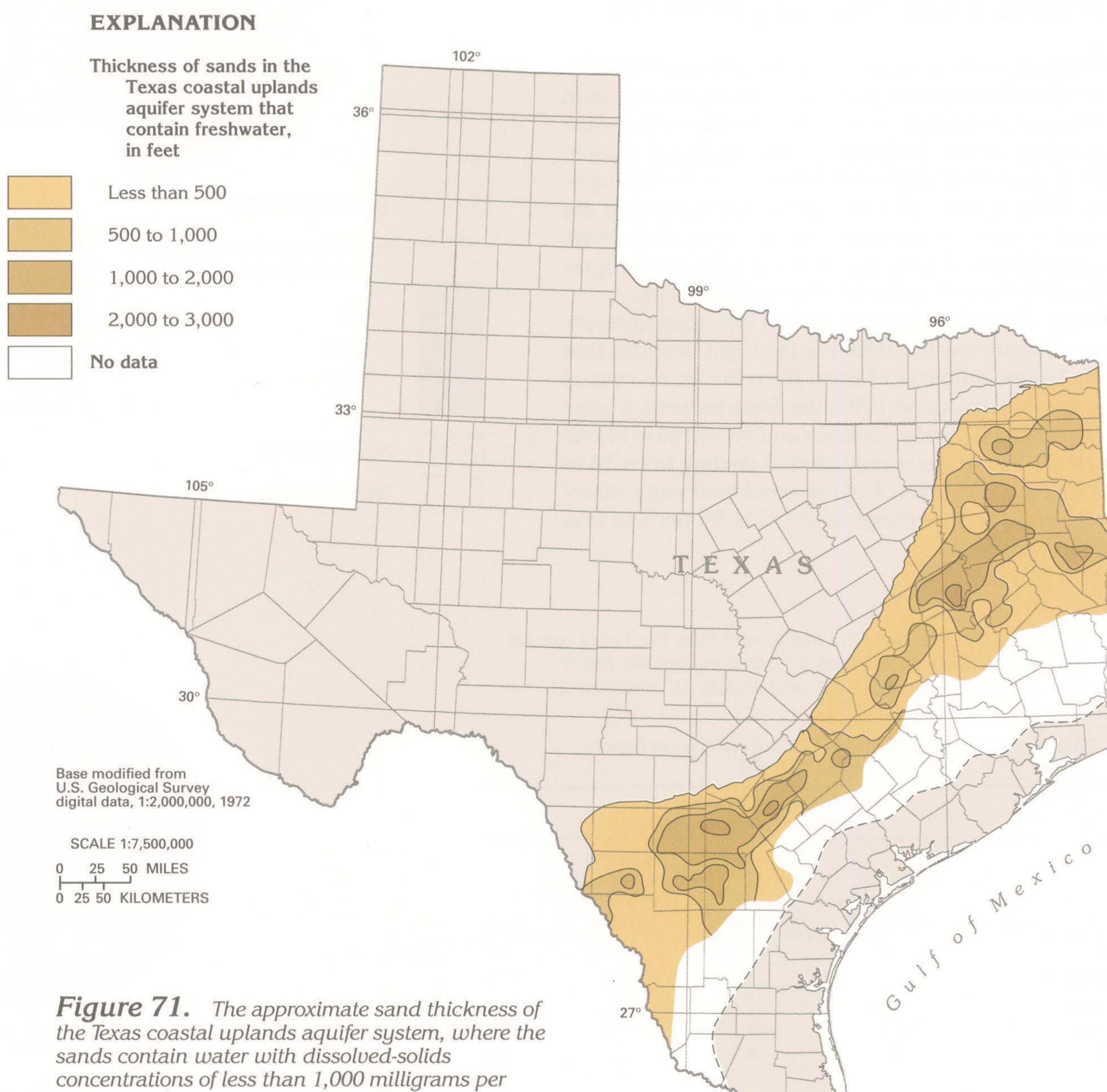


Figure 71. *The approximate sand thickness of the Texas coastal uplands aquifer system, where the sands contain water with dissolved-solids concentrations of less than 1,000 milligrams per liter, ranges from 0 to nearly 3,000 feet.*

LOWER CLAIBORNE–UPPER WILCOX AQUIFER

Ground-Water Hydraulics

Highly permeable sands that contain large volumes of freshwater over an extensive area make the lower Claiborne–upper Wilcox aquifer the most important aquifer in the Texas coastal uplands aquifer system. The lower Claiborne–upper Wilcox aquifer is recharged by the infiltration of precipitation that falls on topographically high aquifer outcrop areas. Natural discharge occurs as evapotranspiration, loss of water to streams in outcrop areas, and as upward leakage in downdip areas. Recharge and discharge are generally less than 1 inch per year in areas that have little or no pumpage. Water in the aquifer is generally unconfined in aquifer outcrop areas where the specific yield for the sandy deposits might range between 10 and 30 percent. Water is confined in downdip areas by the overlying lower Claiborne confining unit. In these areas, the storage coefficient of the aquifer is estimated to range between 1.0×10^{-4} and 1.5×10^{-3}.

The thickness of the sands of the lower Claiborne–upper Wilcox aquifer that contain freshwater is shown in **figure 72**. Maximum sand thickness is nearly 1,000 feet in some western areas. Transmissivity for the aquifer, as estimated from a digital ground-water flow model, is shown in **figure 73**. Although the transmissivity is generally less than 5,000 feet squared per day, maximum values are nearly 15,000 feet squared per day in the west.

Ground-Water Quality

In extensive areas, the concentration of dissolved solids in water from the lower Claiborne–upper Wilcox aquifer is less than 500 milligrams per liter (**fig. 74**). The water is fresh (dissolved-solids concentrations less than 1,000 milligrams per liter) in nearly the entire eastern one-half of the aquifer and in most of the western one-half. Concentrations exceed 1,000 milligrams per liter in the central and western downdip areas.

Ground-Water Development

Withdrawals from the lower Claiborne–upper Wilcox aquifer during 1985 totaled 296 million gallons per day (**table 3**). This was nearly three-fourths of the total water withdrawn from the Texas coastal uplands aquifer system. Much of the water pumped from the lower Claiborne–upper Wilcox aquifer is used for irrigation in the agricultural Winter Garden area (**fig. 75**). This area is defined as all or major parts of Atascosa, Dimmit, Frio, La Salle, and Zavala Counties, and minor parts of Bexar, McMullen, and Wilson Counties. Combined withdrawals from Atascosa, Frio, Dimmit, and Zavala Counties accounted for nearly one-half of the water withdrawn from the Texas coastal uplands aquifer system during 1985 (**table 4**). The combination of infrequent killing frosts and fertile soils make the Winter Garden area ideal for growing garden vegetables and other food crops. Intense pumpage for irrigation in the Winter Garden area has created a large cone of depression on the potentiometric surface of the lower Claiborne–upper Wilcox aquifer (**fig. 75**). The lowering of the potentiometric surface from predevelopment conditions to 1982 was more than 250 feet in parts of Zavala, Dimmit, and Frio Counties (**fig. 76**). To sustain the large pumpage, recharge rates in parts of the outcrop are estimated to have increased by about 1 to 3 inches per year, and large amounts of water have been obtained from aquifer storage.

FRESH GROUND-WATER WITHDRAWALS

Withdrawals of freshwater, including some slightly saline water used predominantly for irrigation, from the Texas coastal uplands aquifer system totaled 397 million gallons per day during 1985 (**fig. 77**). Approximately 210 million gallons per day was withdrawn for agricultural purposes, the principal water use. About 127 million gallons per day was withdrawn for public supply and about 14 million gallons per day was withdrawn for domestic and commercial uses. About 46 million gallons per day was withdrawn for industrial, mining, and thermoelectric-power uses.

POTENTIAL FOR DEVELOPMENT

For the aquifers of the Texas coastal uplands aquifer system, the potential for development is greater in the east than the west, because precipitation and, thus, recharge potential is higher, and the extent of freshwater in the aquifers is greater. In some areas, particularly the Winter Garden area, the aquifers already are overdeveloped. In this area, the aquifers are being pumped in excess of recharge, and declining water levels are creating problems of excessive pumping lifts and migration of highly mineralized water into the pumped wells.

The Texas Water Development Board has made projections of ground-water use to 2030. For the eight counties that withdrew the largest amounts of water from the Texas coastal uplands aquifer system during 1985, the State projects a large decline in pumpage for seven counties and an increase in one county (**table 5**). Pumpage is predicted to decline from 36 to 83 percent below 1985 rates. For the combined eight counties, the total projected pumpage in 2030 is 59 percent less than the 1985 pumpage.

Figure 72. The thickness of sands of the lower Claiborne–upper Wilcox aquifer that contain freshwater is greater in the west where it is nearly 1,000 feet.

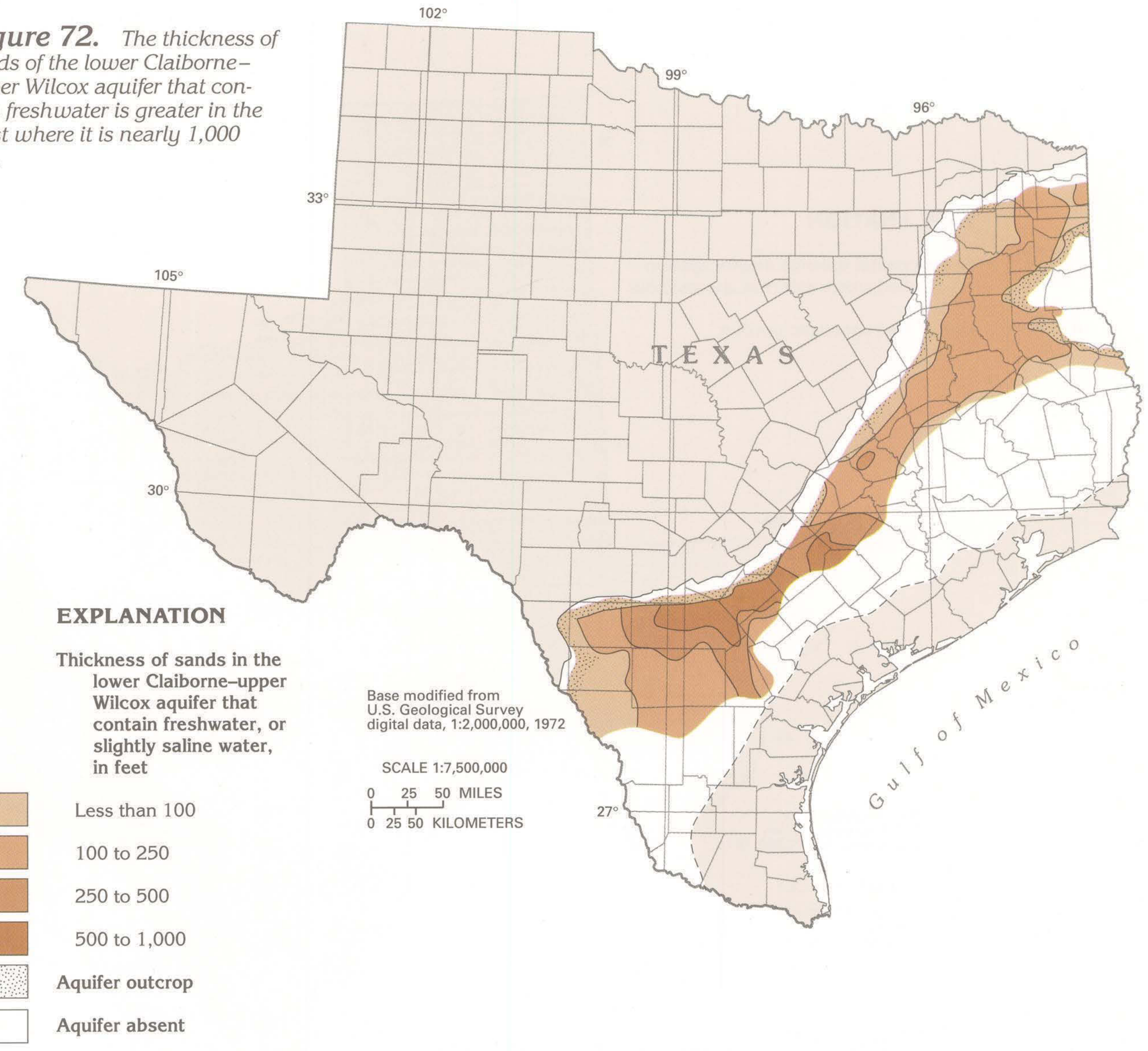


Figure 73. The estimated transmissivity of the lower Claiborne–upper Wilcox aquifer is higher in the west where the aquifer is thicker. Values range from nearly 0 at the updip margin to about 15,000 feet squared per day south of San Antonio.

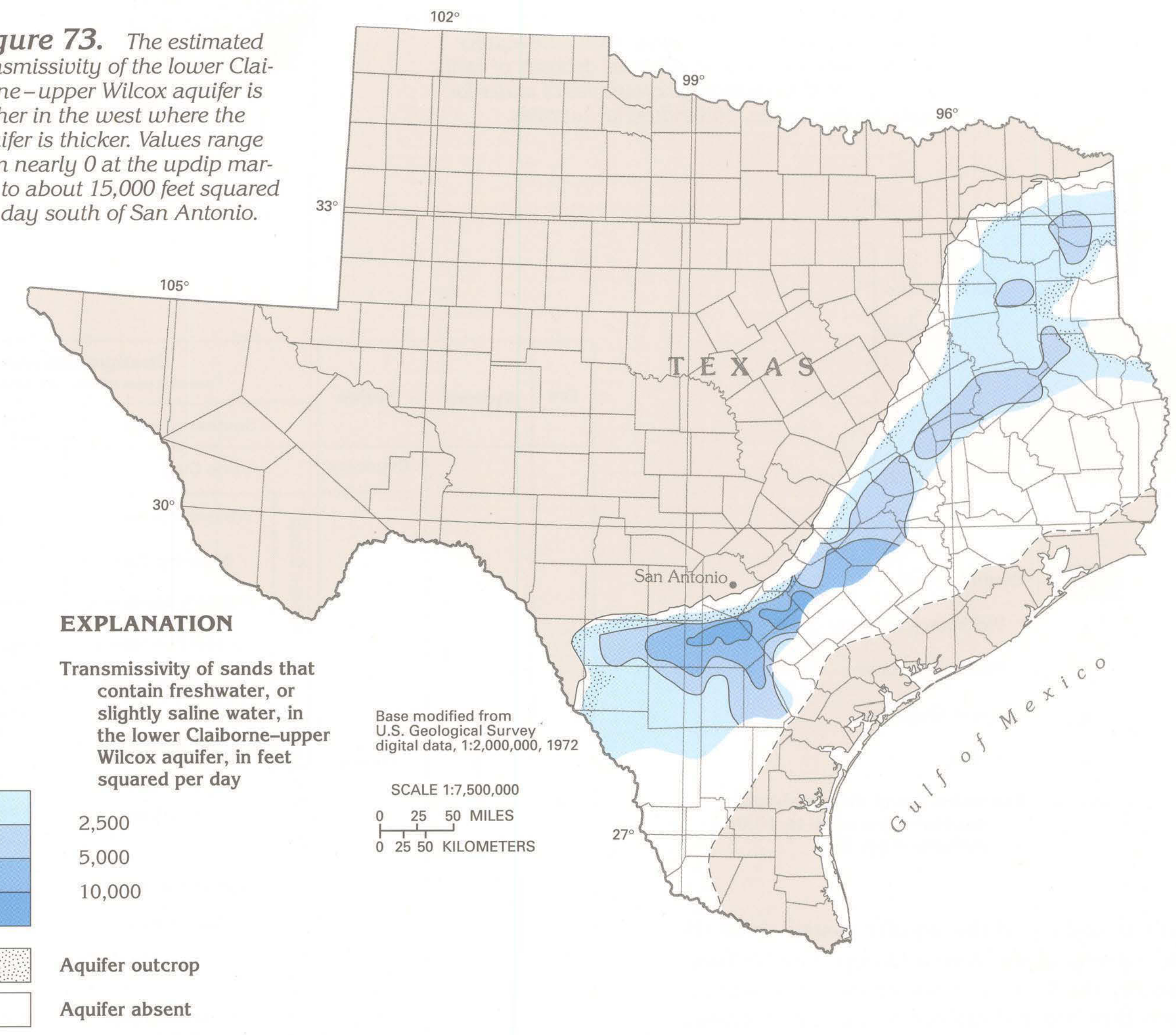
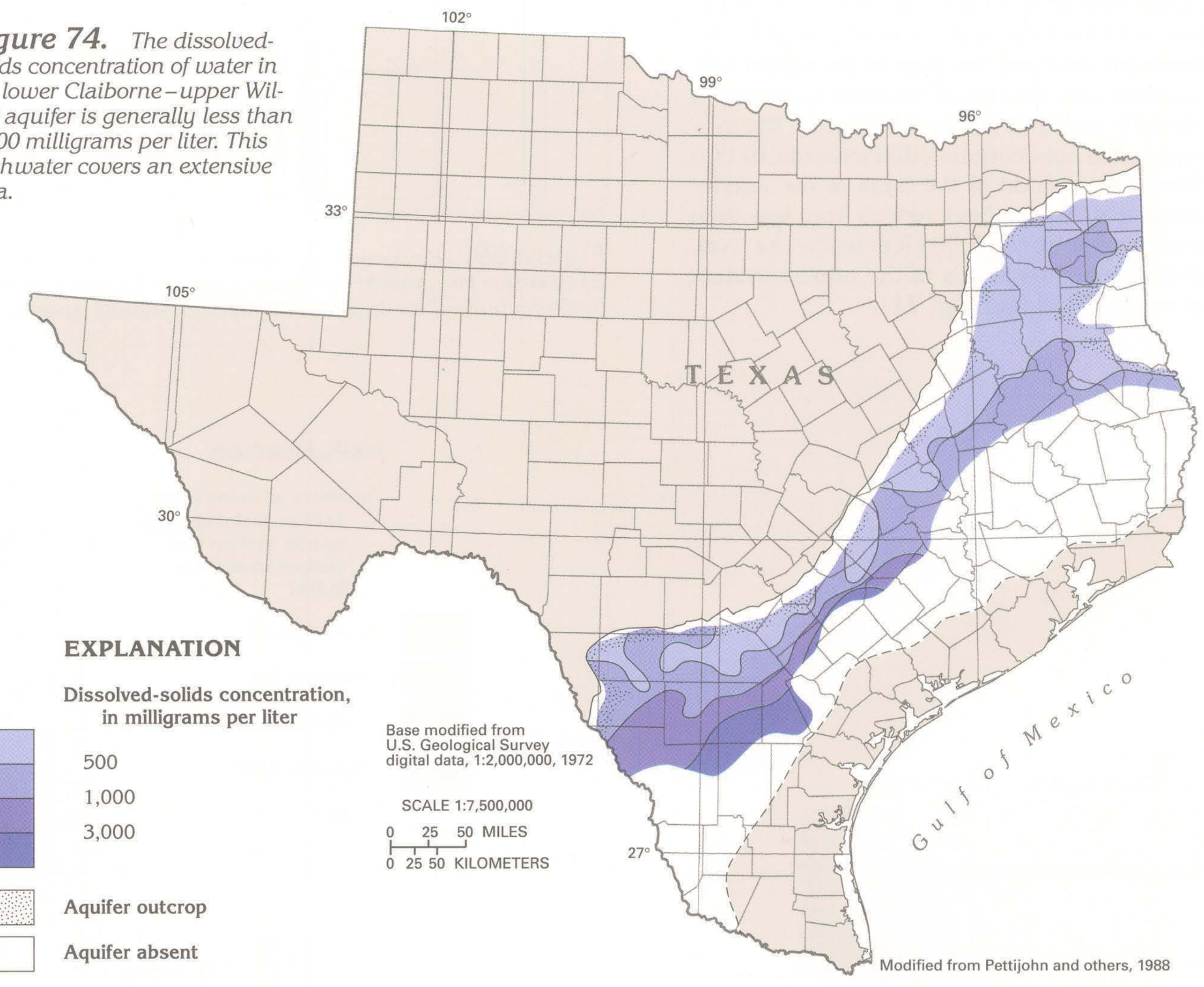


Figure 74. The dissolved-solids concentration of water in the lower Claiborne–upper Wilcox aquifer is generally less than 1,000 milligrams per liter. This freshwater covers an extensive area.



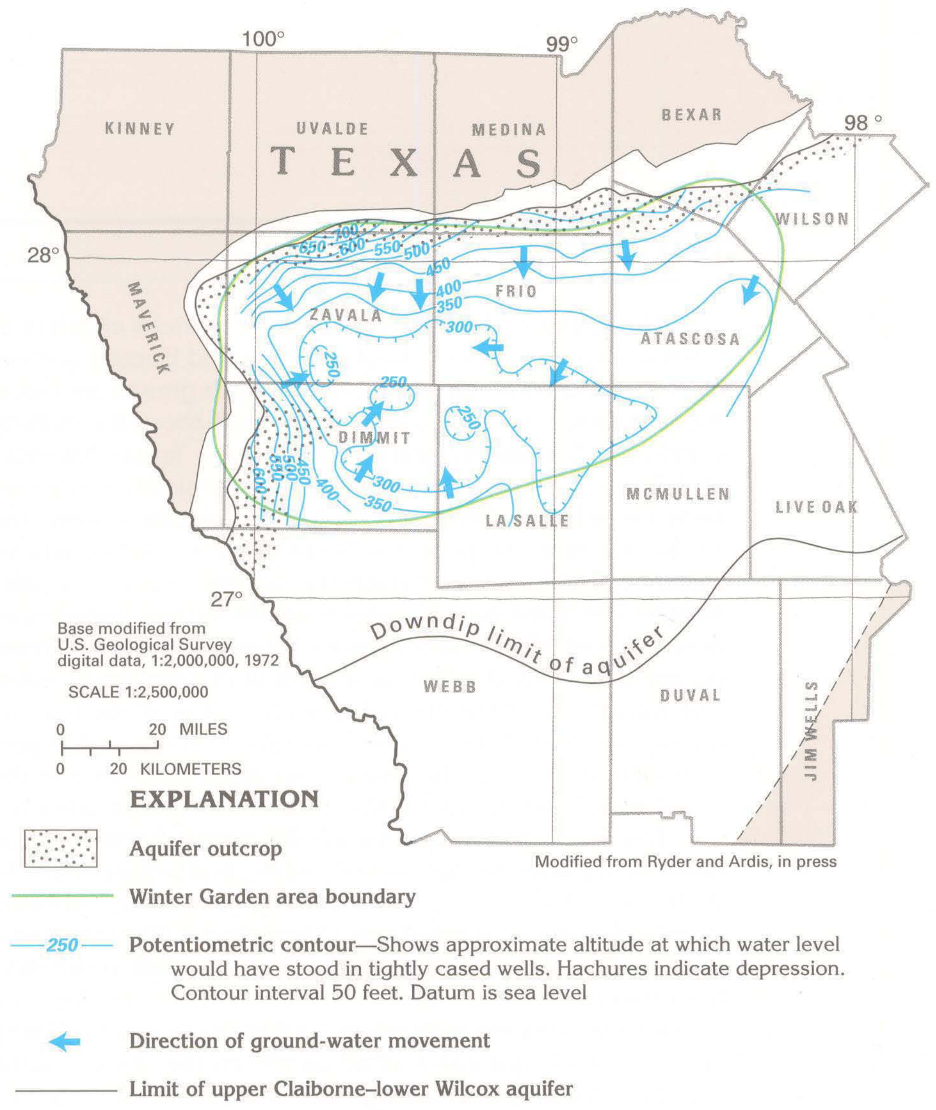


Figure 75. Intensive agricultural pumping has created a large cone of depression on the potentiometric surface of the lower Claiborne–upper Wilcox aquifer in the Winter Garden area. In 1982, the cone was centered in Zavala, Dimmit, and La Salle Counties.

Table 4. Combined withdrawals from eight counties accounted for 72 percent of the total freshwater withdrawn from the Texas coastal uplands aquifer system during 1985. Combined withdrawals from four counties (Zavala, Frio, Atascosa, and Dimmit) accounted for 49 percent of the total

[Data from William Moltz, Texas Water Development Board, written commun., 1990]

County	Fresh ground-water withdrawals, in million gallons per day				
	Public supply	Domestic and commercial	Agricultural	Industrial, mining, and thermoelectric power	Total
Zavala	2	0	84	1	87
Frio	2	0	43	1	46
Atascosa	5	1	28	5	39
Brazos	19	2	6	1	28
Angelina	9	1	0	18	28
Dimmit	2	0	19	1	22
Robertson	2	1	15	0	18
Smith	14	2	0	2	18
Total for counties	55	7	195	29	286
Total for aquifer system	127	14	210	26	397

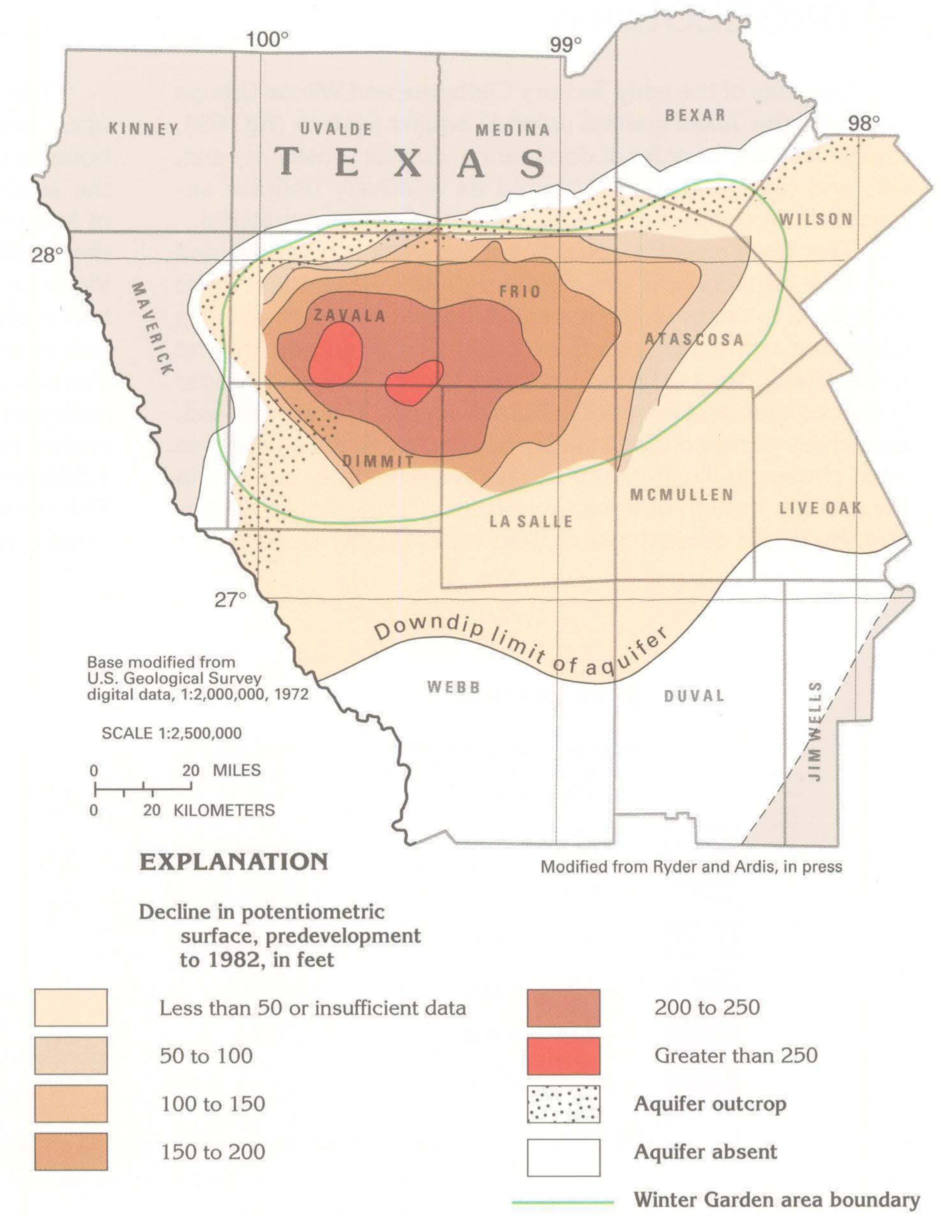


Figure 76. Large withdrawals in the Winter Garden area caused the 1982 potentiometric surface of the lower Claiborne–upper Wilcox aquifer to be more than 250 feet below the pre-development surface.

Table 3. Nearly three-fourths of the freshwater from the Texas coastal uplands aquifer system during 1985 was withdrawn from the lower Claiborne–upper Wilcox aquifer and was used mostly for agricultural purposes

[Data from William Moltz, Texas Water Development Board, written commun., 1989]

Aquifer	Fresh ground-water withdrawals, in million gallons per day				
	Public supply	Domestic and commercial	Agricultural	Industrial, mining, and thermoelectric power	Total
Upper Claiborne	6	2	1	1	10
Middle Claiborne	10	7	4	1	22
Lower Claiborne–upper Wilcox	90	163	33	10	296
Middle Wilcox	21	38	8	2	69
Total for aquifer system	127	210	46	14	397

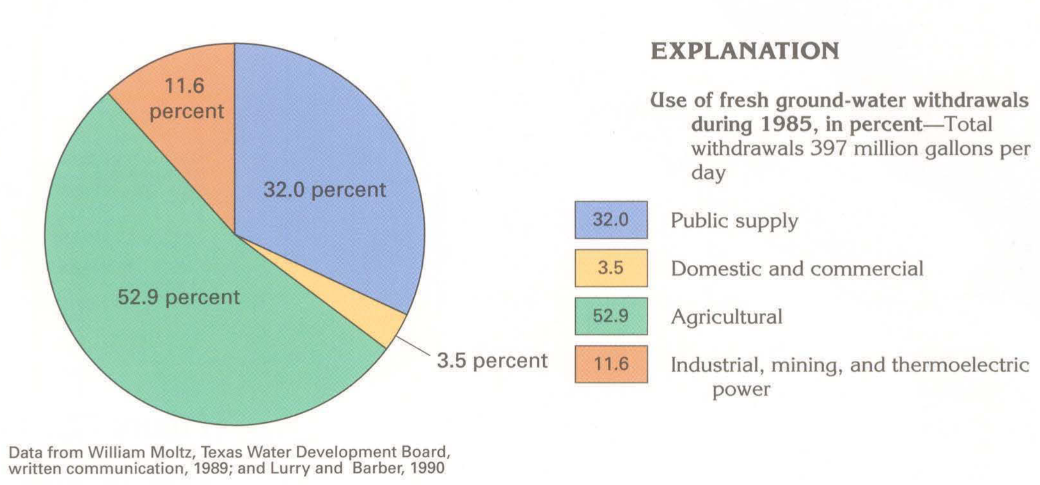


Figure 77. Most of the freshwater withdrawn from the Texas coastal uplands aquifer system during 1985 was used for agricultural purposes and public supply.

Table 5. From the eight counties that had the most intensive pumpage from the Texas coastal uplands aquifer system, seven are projected to have a decrease in pumpage by 2030. Total projected pumpage in 2030 for the eight selected counties is 59 percent less than that for 1985

[Data from Texas Water Development Board, written commun., 1988]

County	Fresh ground-water withdrawals, in million gallons per day			
	1985	2030 (projected)	Net change	Percentage net change
Zavala	87	17	-70	-80
Frio	46	8	-38	-83
Atascosa	39	23	-16	-41
Brazos	28	18	-10	-36
Angelina	28	10	-18	-64
Dimmit	22	11	-11	-50
Robertson	18	20	+2	+11
Smith	18	10	-8	-44
Total	286	117	-169	-59

Edwards–Trinity aquifer system

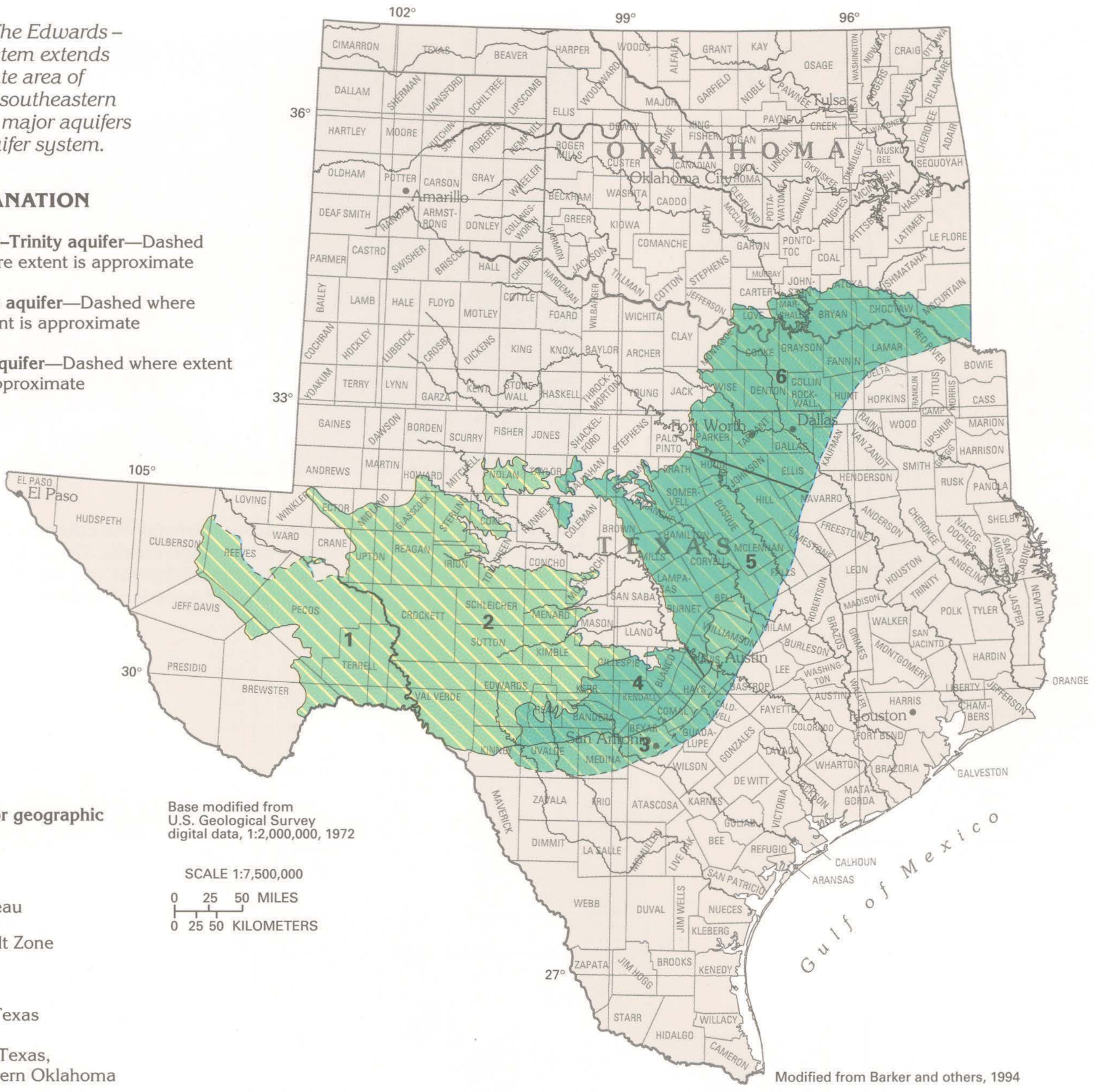


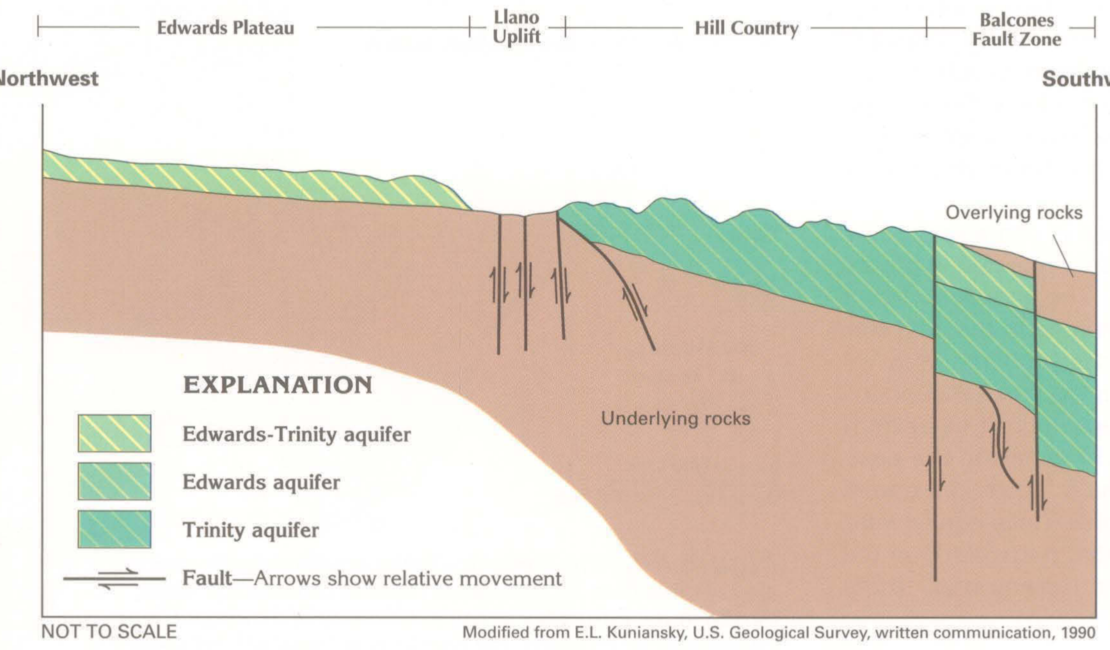
Figure 78. The Edwards–Trinity aquifer system extends over a wide arcuate area of central Texas and southeastern Oklahoma. Three major aquifers constitute the aquifer system.

EXPLANATION

- Edwards–Trinity aquifer—Dashed where extent is approximate
- Edwards aquifer—Dashed where extent is approximate
- Trinity aquifer—Dashed where extent is approximate

Physiographic or geographic regions

1. Trans-Pecos
2. Edwards Plateau
3. Balcones Fault Zone
4. Hill Country
5. East-central Texas
6. Northeastern Texas, southeastern Oklahoma



EXPLANATION

- Edwards-Trinity aquifer
- Edwards aquifer
- Trinity aquifer
- Fault—Arrows show relative movement

Figure 79. A diagrammatic section through the Edwards–Trinity aquifer system shows how the three aquifers relate to each other and to contiguous rocks.

Era	System	Series or Stage	Trans-Pecos (1)	Edwards Plateau (2) Western	Edwards Plateau (2) Eastern	Hill Country (4)	Balcones Fault Zone (3)	East-central Texas (5)	Northeastern Texas, southeastern Oklahoma (6)
Mesozoic	Cretaceous	Washita Stage	Buda Limestone Del Rio Clay Boracho Formation	Buda Limestone Del Rio Clay Fort Lancaster Formation	Buda Limestone Del Rio Clay Edwards Group: Segovia Formation	—	Buda Limestone Del Rio Clay Georgetown Formation	Buda Limestone Del Rio Clay Georgetown Formation	Grayson Marl and Mainstreet Limestone Pawpaw Formation Weno Limestone Denton Clay Fort Worth and Duck Creek Limestone
		Fredericksburg Stage	Finlay Formation	Fort Terrett Formation	Edwards Group: Fort Terrett Formation	—	Edwards Group: Person Formation Kainer Formation	Kiamicni Formation Edwards Limestone Commanche Peak Limestone Walnut Formation	Kiamicni Formation Edwards Limestone Commanche Peak Limestone Walnut Formation Goodland Limestone
		Trinity Stage	Basal Cretaceous sand	Basal Cretaceous sand	Glen Rose Limestone Hansel Sand Member Cow Creek Limestone Mbr Hammett Shale Mbr Basal Cretaceous sand	Glen Rose Limestone Travis Peak Formation: Hansel Sand Member Cow Creek Limestone Mbr Hammett Shale Mbr	Glen Rose Limestone Pearsall Formation: Bexar Shale Member Cow Creek Limestone Member Pine Island Shale Member	Paluxy Formation Glen Rose Fm Travis Peak Formation	Paluxy Formation Glen Rose Formation Twin Mountains Formation
		Coahuilan Series	—	—	—	Sligo Fm Hosston Formation	Sligo Formation Hosston Formation	Sligo Fm Hosston Fm	—
	Jurassic		—	—	—	—	—	Undifferentiated	Undifferentiated
	Triassic		Dockum Group	Dockum Group	—	—	—	—	—
Paleozoic	Permian–Cambrian		Undifferentiated	Undifferentiated	Undifferentiated	Undifferentiated	Undifferentiated	Undifferentiated	Undifferentiated (may include small area of Precambrian rocks in Oklahoma)

Modified from Brand and Deford, 1958; Lozo and Smith, 1964; Stricklin and others, 1971; Rose, 1972; Loucks, 1977; Klemt and others, 1975; Smith and Brown, 1983; and Nordstrom, 1982

Figure 80. Many different geologic formations of Cretaceous age compose the Edwards–Trinity aquifer system. Carbonate rocks, sandstones, and sands are the predominant lithology of the water-yielding rocks of the system. The gray area represents missing rocks. Number refers to map above.

EXPLANATION

- Edwards–Trinity aquifer
- Edwards aquifer
- Trinity aquifer
- 2 Physiographic or geographic regions shown in figure 78

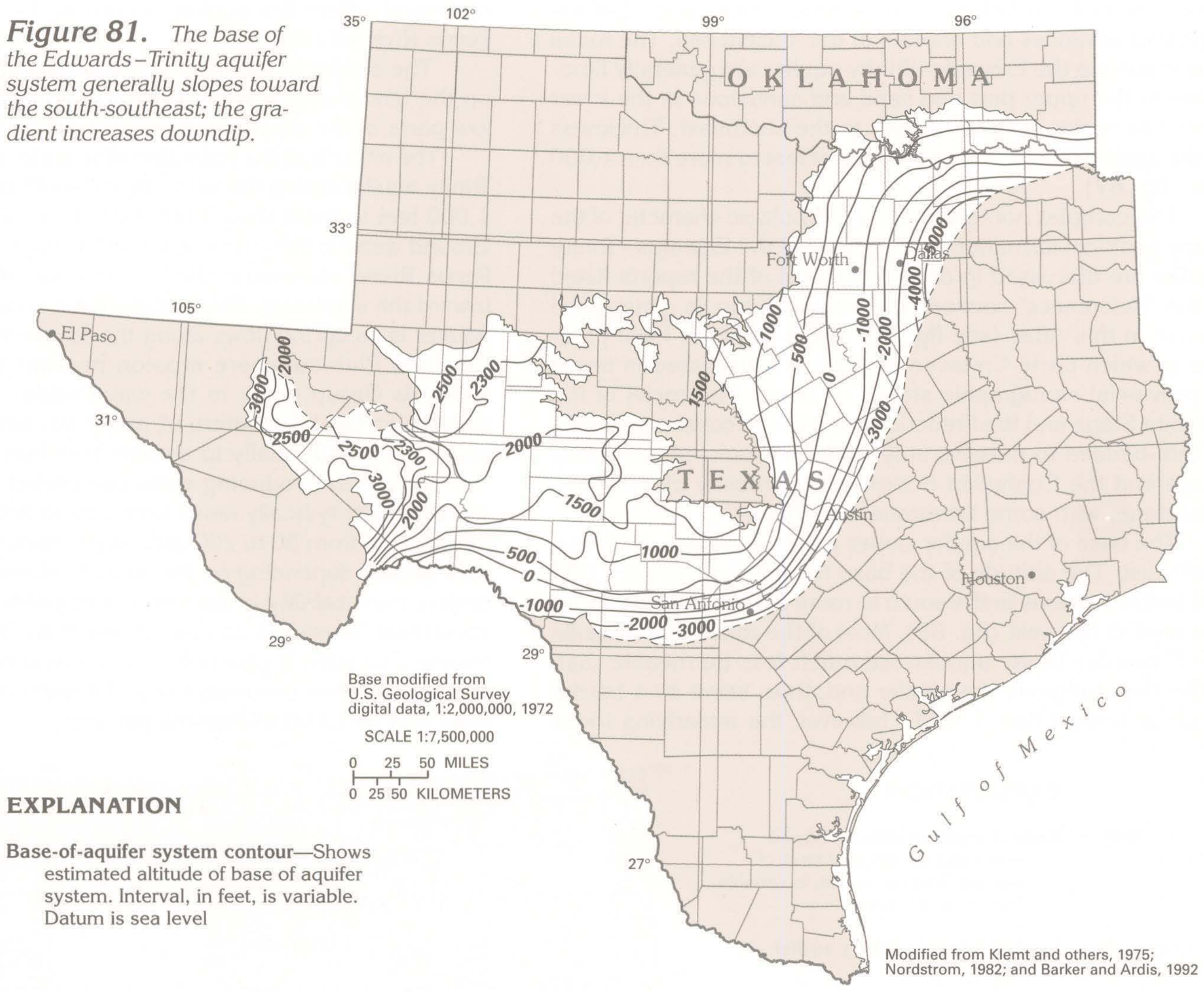


Figure 81. The base of the Edwards–Trinity aquifer system generally slopes toward the south-southeast; the gradient increases downdip.

EXPLANATION

—1500— Base-of-aquifer system contour—Shows estimated altitude of base of aquifer system. Interval, in feet, is variable. Datum is sea level

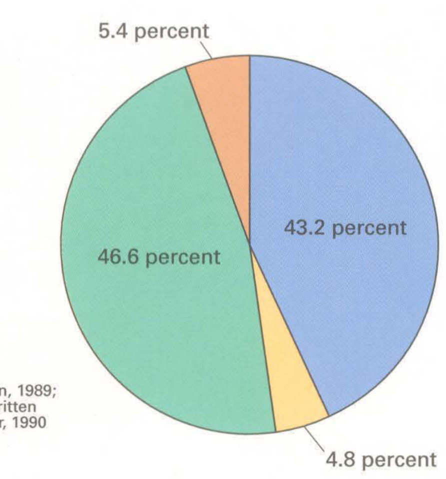


Figure 82. Most of the freshwater withdrawn from the Edwards–Trinity aquifer system during 1985 was used for public supply and agricultural purposes.

Data from and William Moltz, Texas Water Development Board, written communication, 1989; U.S. Geological Survey, Tulsa Oklahoma, written communication 1989; and Lurry and Barber, 1990

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total withdrawals 794 million gallons per day

- 43.2 Public supply
- 4.8 Domestic and commercial
- 46.6 Agricultural
- 5.4 Industrial, mining, and thermoelectric power

INTRODUCTION

The Edwards–Trinity aquifer system is in carbonate and clastic rocks of Cretaceous age in a 77,000-square-mile area that extends from southeastern Oklahoma to western Texas (**fig. 78**). The aquifer system consists of three complexly interrelated aquifers—the Edwards–Trinity, the Edwards, and the Trinity aquifers (**figs. 78 and 79**). The Edwards–Trinity and the Trinity aquifers are stratigraphically equivalent in part and are hydraulically connected in some places. The Edwards aquifer overlies the Trinity aquifer (**fig. 79**) and the two aquifers are hydraulically connected where no confining unit separates them. The ground-water flow systems and permeability of the three aquifers are sufficiently different, however, to allow them to be separately mapped and described.

In the Trans-Pecos area (the area west of the Pecos River) and Edwards Plateau area of western and west-central Texas, the Edwards–Trinity aquifer consists of rocks of the Washita, the Fredericksburg, and the Trinity Stages, and the Coahuilan Series (**fig. 80**). In the Balcones Fault Zone area of south-central Texas, the rocks of the Washita and the Fredericksburg Stages are far more permeable than those of the overlying confining unit or the underlying Trinity aquifer and constitute the nearly separate flow system of the Edwards aquifer. Rocks of the Trinity Stage and the Coahuilan Series constitute the Trinity aquifer, which crops out on its updip edge from the Hill Country of south-central Texas into southeastern Oklahoma. In east-central Texas and into Oklahoma, rocks of the Washita and the Fredericksburg Stages that overlie the Trinity aquifer constitute a confining unit.

The rocks that compose the Edwards–Trinity aquifer are relatively flat-lying and are generally exposed at the land surface in the Trans-Pecos and the Edwards Plateau areas (**fig. 78**). The geologic formations that compose the Trinity and the Edwards aquifers generally are exposed in updip areas, but they dip eastward and southward beneath younger units and lie deep in the subsurface. The downdip boundary of each aquifer approximately coincides with the farthest updip extent of water that contains 10,000 milligrams per liter dissolved solids.

The base of the Edwards–Trinity aquifer system, which is an erosional unconformity developed on the surface of pre-Cretaceous rocks, is shown in **figure 81**. Generally, the base slopes toward the south-southeast; the gradient steepens in a downdip direction. The altitude of the base ranges from more than 5,000 feet below sea level in the northeast to more than 3,000 feet above sea level in the west.

Withdrawals of freshwater from the Edwards–Trinity aquifer system totaled about 794 million gallons per day during 1985 (**fig. 82**). About 370 million gallons per day was withdrawn for agricultural purposes, slightly more than the 343 million gallons per day withdrawn for public supply. About 43 million gallons per day was pumped for industrial, mining, and thermoelectric-power uses, and the remaining 38 million gallons per day was withdrawn for domestic and commercial uses.

Areas with the largest rates of withdrawal are shown in **figure 83**. Withdrawals for municipal and industrial uses during 1980 exceeded 10 million gallons per day in the seven Metropolitan Statistical Areas shown in the figure, as defined by the Texas Department of Water Resources. These areas are Austin, Dallas, Fort Worth–Arlington, Odessa, San Antonio, Sherman–Denison, and Waco. Pumpage of 225 million gallons per day in the San Antonio area was far greater than that of the other Metropolitan Statistical Areas. Withdrawals for irrigation during 1985 exceeded 10 million gallons per day in 10 counties; pumpage was more than 100 million gallons per day in Uvalde County (**fig. 83**).

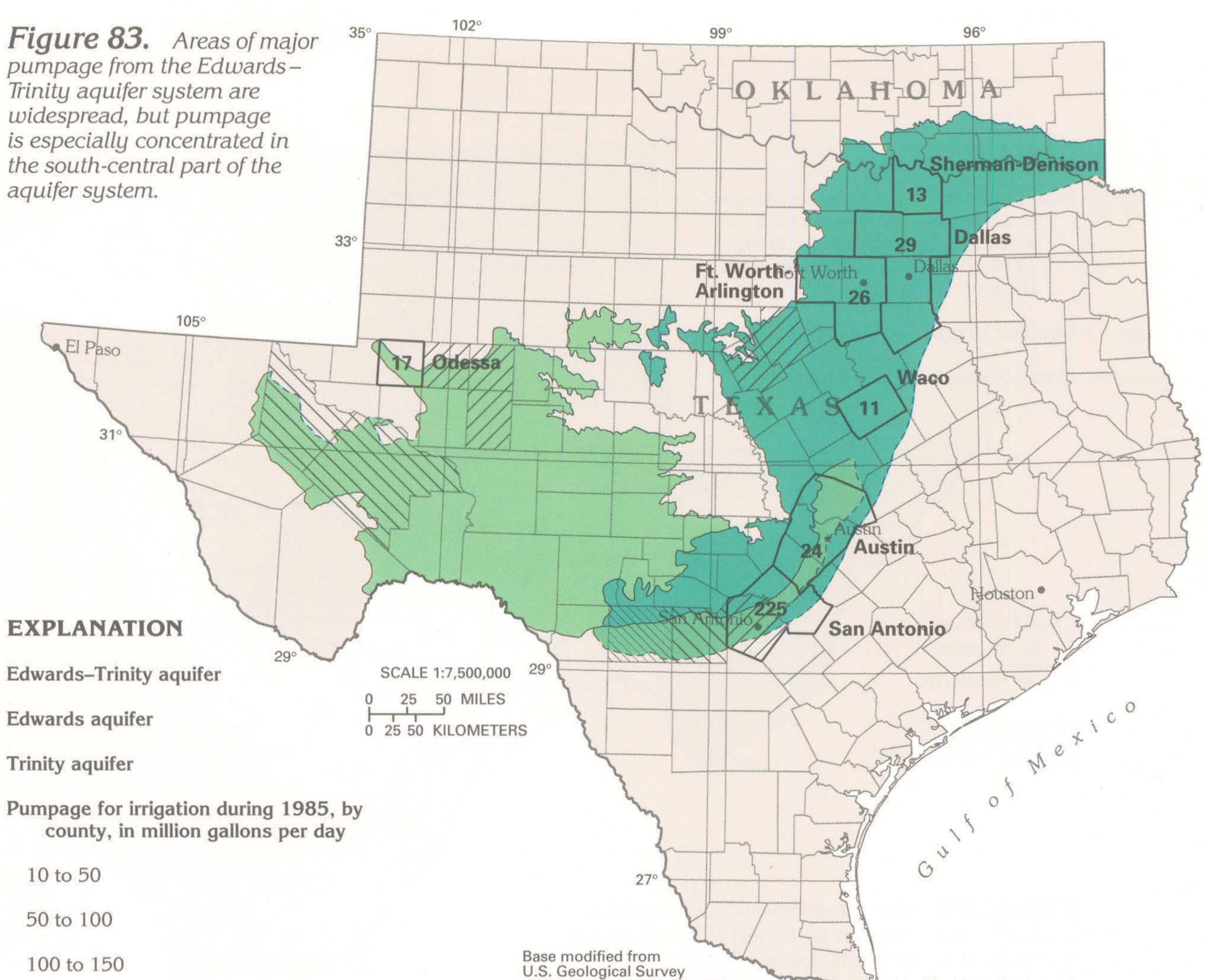


Figure 83. Areas of major pumpage from the Edwards–Trinity aquifer system are widespread, but pumpage is especially concentrated in the south-central part of the aquifer system.

EXPLANATION

- Edwards–Trinity aquifer
- Edwards aquifer
- Trinity aquifer

Pumpage for irrigation during 1985, by county, in million gallons per day

- 10 to 50
- 50 to 100
- 100 to 150

225 Metropolitan Statistical Area where pumpage for municipal and industrial uses during 1980, was greater than 10 million gallons per day—Number is pumpage, in millions of gallons per day

EDWARDS–TRINITY AQUIFER

The Edwards–Trinity aquifer consists of rocks of Cretaceous age that are present in an area of about 35,500 square miles in west-central Texas (**fig. 84**). The aquifer is referred to in much of the literature as the "Edwards–Trinity (Plateau) aquifer." The area underlain by the aquifer is mostly on the Edwards Plateau, but it also extends into the Trans-Pecos area. The aquifer is located in the Great Plains Physiographic Province except for a small part that is in the Basin and Range Physiographic Province.

The topography of much of the area is characterized by flat to rolling, largely rocky plains that are dissected in places to form steep-walled canyons (**fig. 85**). The area is bounded on the west by mountain ranges. The altitude of the land surface ranges from about 1,000 feet at the Rio Grande in Val Verde County to more than 4,500 feet in the Davis Mountains in Jeff Davis County. Average annual precipitation ranges from about 12 inches in the west to about 30 inches in the east. Average annual runoff ranges from about 0.2 inch in the west to about 5 inches in the east. The Edwards–Trinity aquifer supplies large amounts of water for irrigation, particularly in the northwestern area; it also provides water to many small towns and cities.

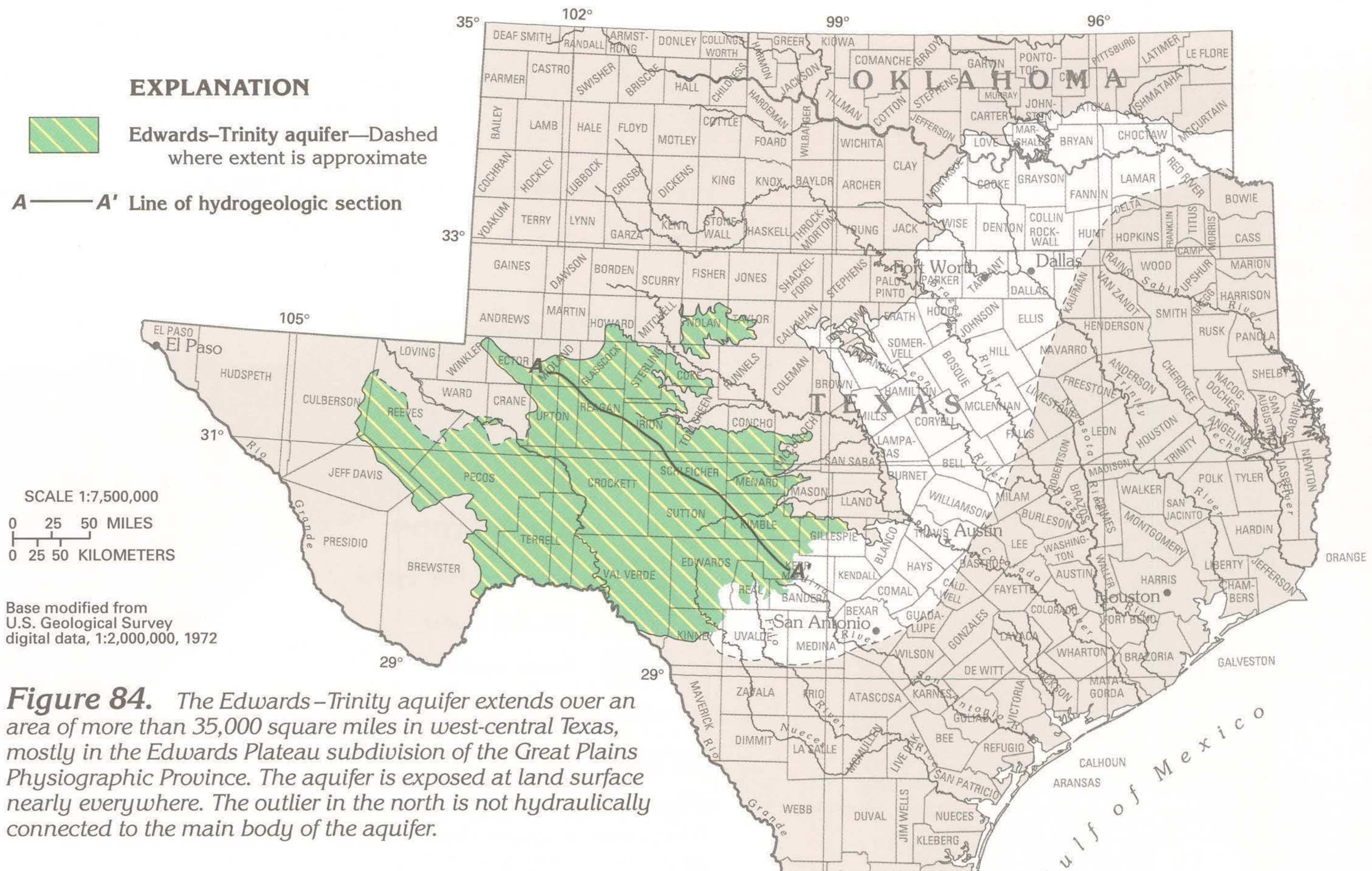


Figure 84. *The Edwards–Trinity aquifer extends over an area of more than 35,000 square miles in west-central Texas, mostly in the Edwards Plateau subdivision of the Great Plains Physiographic Province. The aquifer is exposed at land surface nearly everywhere. The outlier in the north is not hydraulically connected to the main body of the aquifer.*

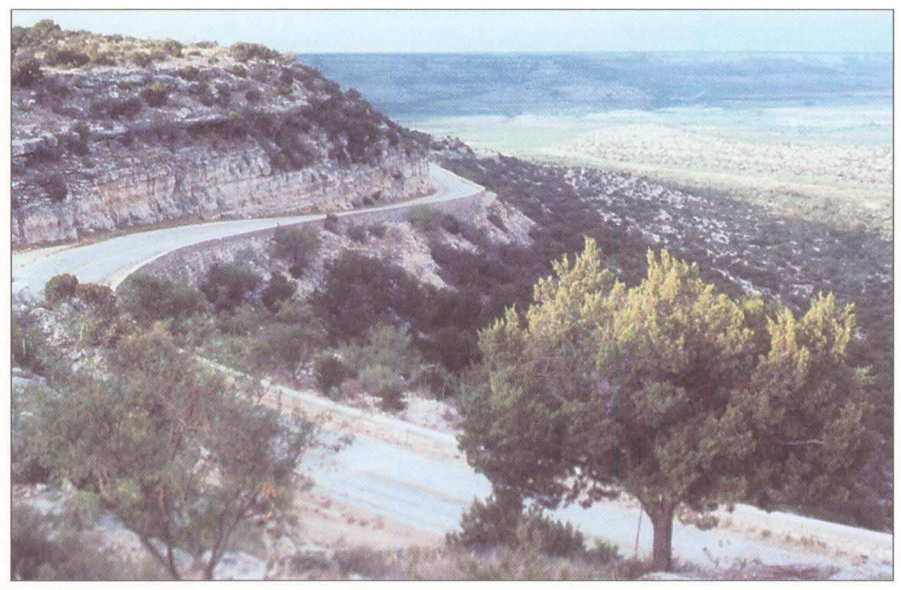


Figure 85. *The flat to gently rolling plains of the Edwards Plateau are locally interrupted by steep canyon walls. This view in western Crockett County is toward the southwest and the Pecos River Valley. The road cut shows the Fort Lancaster Formation.*

Hydrogeology

During Jurassic and very early Cretaceous time, the rocks in the area were subjected to erosion, and a flat to undulating plain was formed. This erosional surface, which underlies the Edwards–Trinity aquifer, was developed on rocks that range in age from Cambrian to Triassic (**fig. 86**). The early Cretaceous sea then advanced northward from the Gulf of Mexico across Texas. Deposition of clastic and carbonate rocks accompanied repeated advances and retreats of the ancient sea. The rocks that compose the Edwards–Trinity aquifer are generally limestone in the upper part and sand and sandstone in the lower part. The rocks dip and thicken to the southeast. Thickness of the aquifer ranges from a few tens of feet to more than 1,000 feet (**fig. 87**).

The complex nomenclature and lithologic character of the many geologic formations that compose the Edwards–Trinity aquifer are discussed in detail in several of the reports listed in the "References" section. The nomenclature is generalized for use in this Atlas (**see fig. 80**) and follows the local practice in which Early Cretaceous rocks are discussed in terms of provincial stratigraphic stages or series. The rocks of the Washita Stage and the Fredericksburg Stage consist generally of thin-bedded to massive limestone; the rocks of the Trinity Stage and the Coahuilan Series consist mostly of sand and sandstone, with some limestone and shale.

The base of the aquifer slopes generally to the south and southeast. The altitude of the base ranges from about 2,000 feet below sea level in the south to more than 3,000 feet above sea level in the west (**fig. 88**). Most of the rocks that underlie the Edwards–Trinity aquifer are much less permeable than those that compose the aquifer and, thus, serve as a barrier to ground-water flow. Locally, however, the underlying rocks are permeable and are hydraulically connected to the Edwards–Trinity aquifer, thus extending the thickness of the flow system.

The top of the aquifer is at land surface with the exception of areas capped with small, scattered remnants of Del Rio Clay or Buda Limestone and about 1,500 square miles in the northwest where the aquifer is covered by thick deposits of Pecos River alluvium.

The aquifer is generally recharged by direct precipitation on the land surface. Water is mostly unconfined in the shallow parts of the aquifer and is confined in the deeper zones.

The altitude of the potentiometric surface of the Edwards–Trinity aquifer during the winter of 1974–75 ranged from about 1,000 feet to more than 3,500 feet above sea level (**fig. 89**). Ground water in the extreme west moves generally toward the Pecos River; elsewhere, the regional movement of water is toward the southeast. Much of the natural discharge from the aquifer is as spring flows along the southeastern edge of the Edwards Plateau where erosion has cut the rocks of the Edwards Group down to the water table. Springs that are present at the headwaters of many streams in these areas contribute substantially to stream base flow.

Depths of producing wells completed in the Edwards–Trinity aquifer typically range from 150 to 300 feet. Wells commonly yield from 50 to 200 gallons per minute. Well yields can vary greatly depending on the amount of development of secondary permeability in the limestone; yields from jointed and cavernous limestone can be as much as 3,000 gallons per minute. The water is generally a hard, calcium bicarbonate type and typically has concentrations of dissolved solids that range from 400 to 1,000 milligrams per liter.

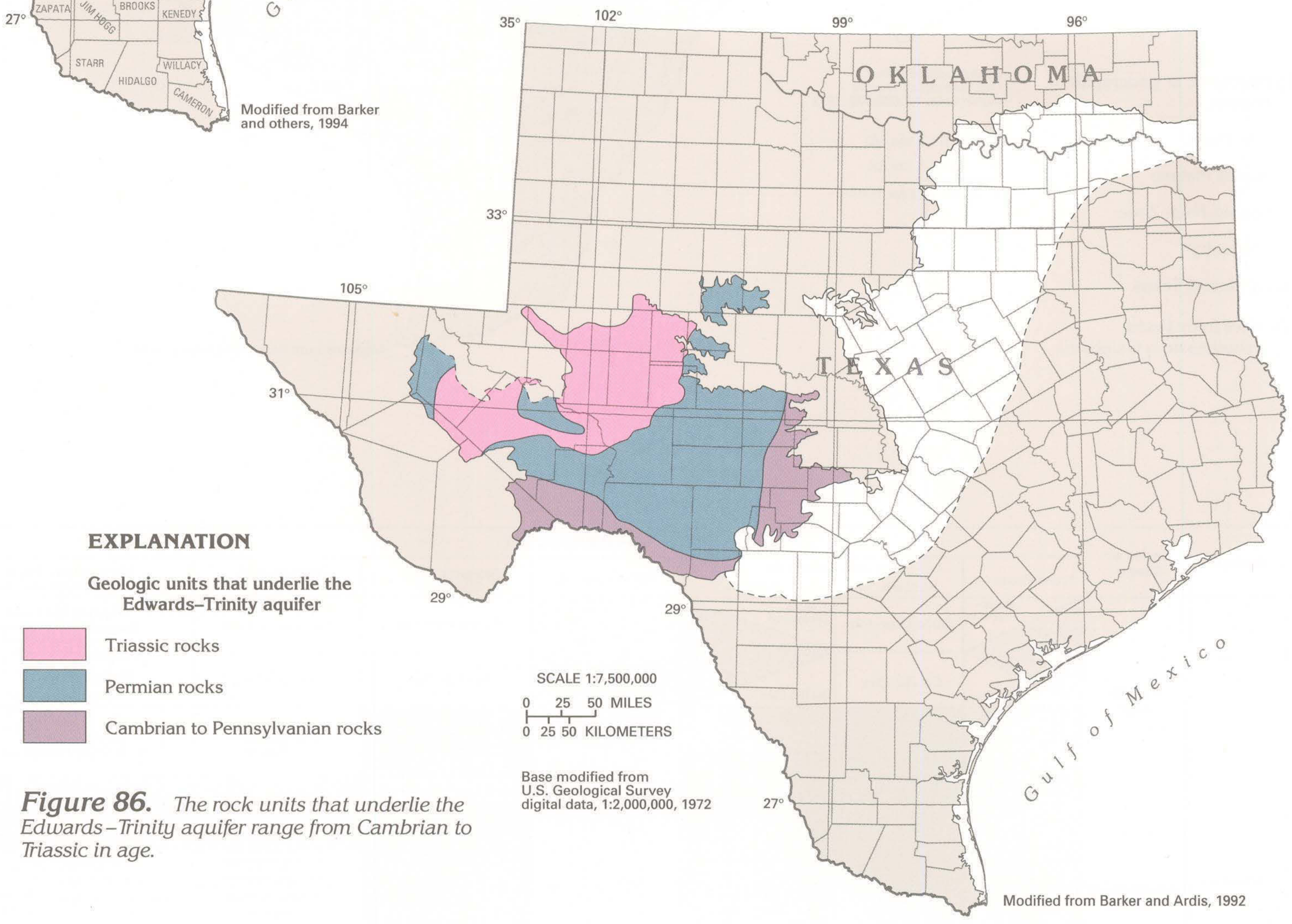


Figure 86. *The rock units that underlie the Edwards–Trinity aquifer range from Cambrian to Triassic in age.*

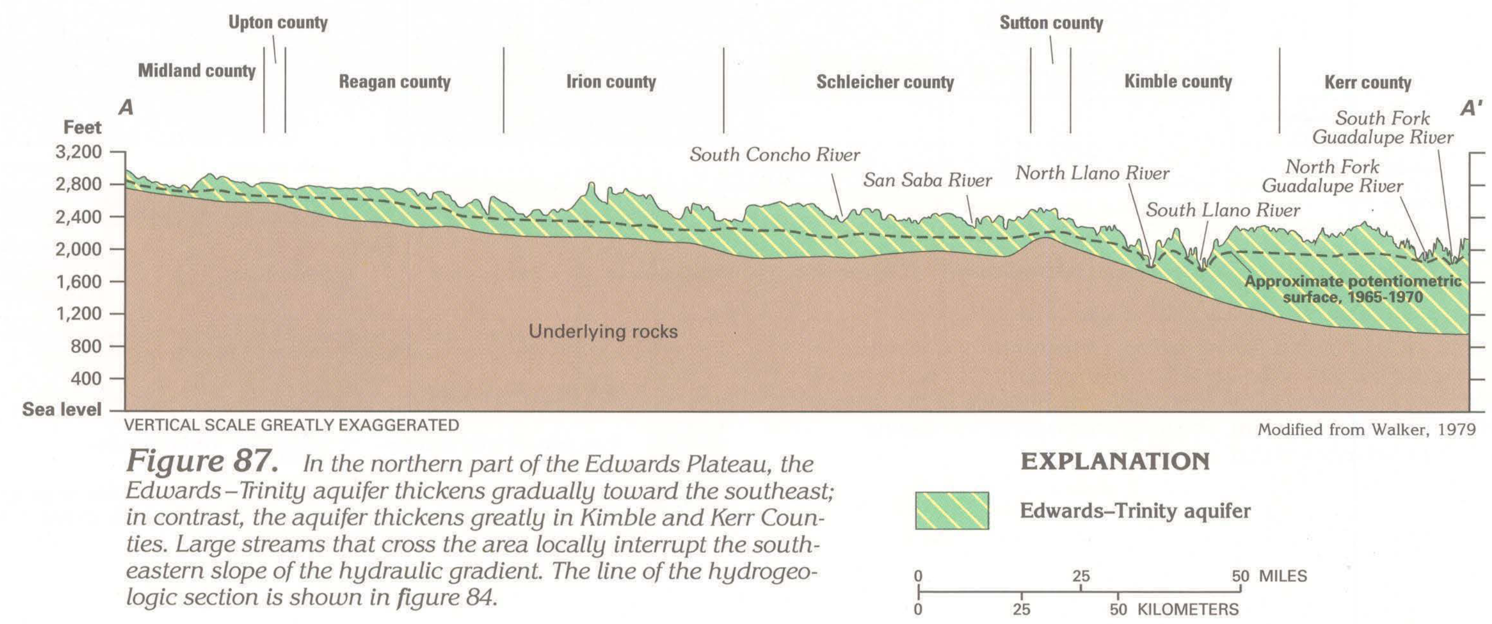


Figure 87. *In the northern part of the Edwards Plateau, the Edwards–Trinity aquifer thickens gradually toward the southeast; in contrast, the aquifer thickens greatly in Kimble and Kerr Counties. Large streams that cross the area locally interrupt the southeastern slope of the hydraulic gradient. The line of the hydrogeologic section is shown in figure 84.*

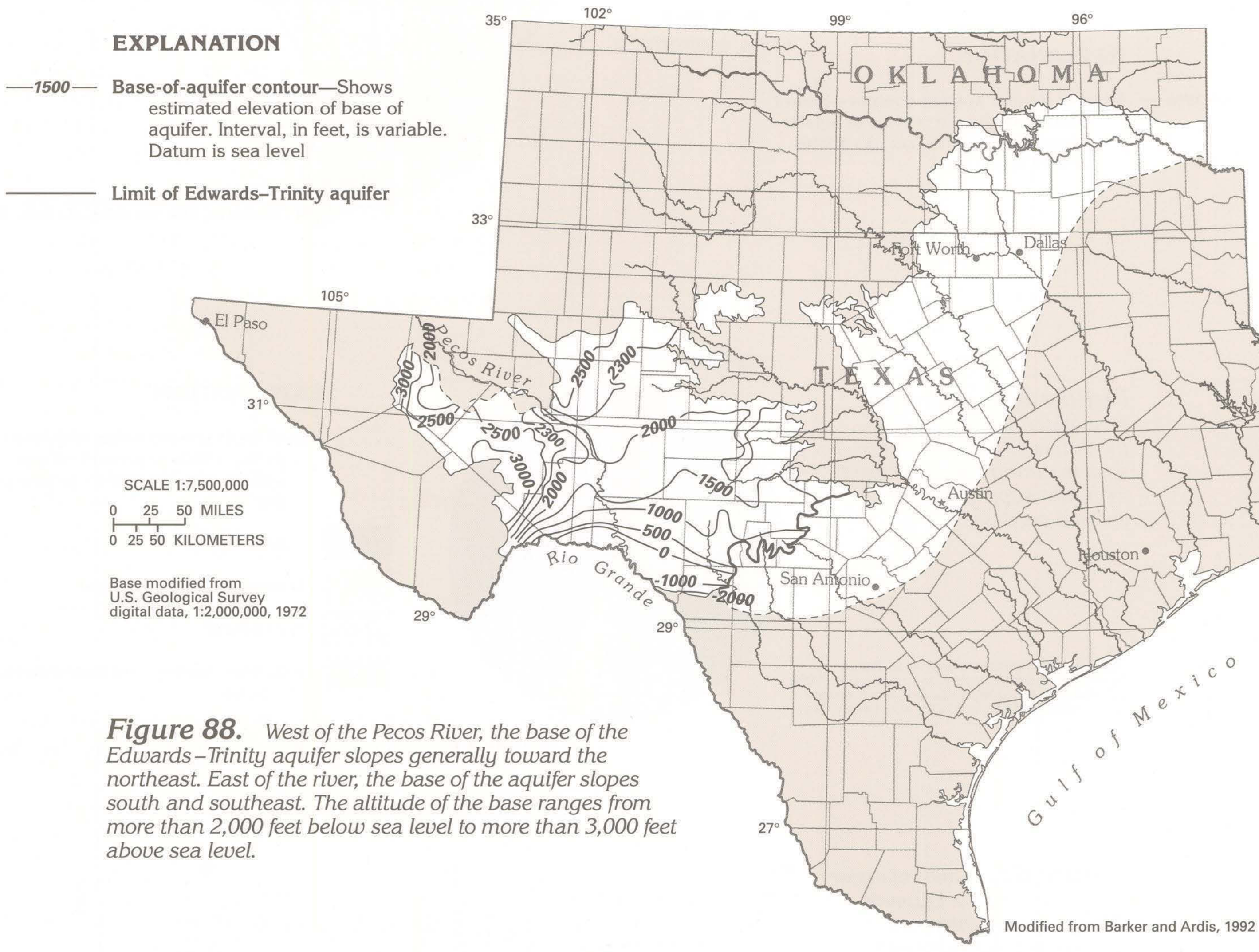


Figure 88. *West of the Pecos River, the base of the Edwards–Trinity aquifer slopes generally toward the northeast. East of the river, the base of the aquifer slopes south and southeast. The altitude of the base ranges from more than 2,000 feet below sea level to more than 3,000 feet above sea level.*

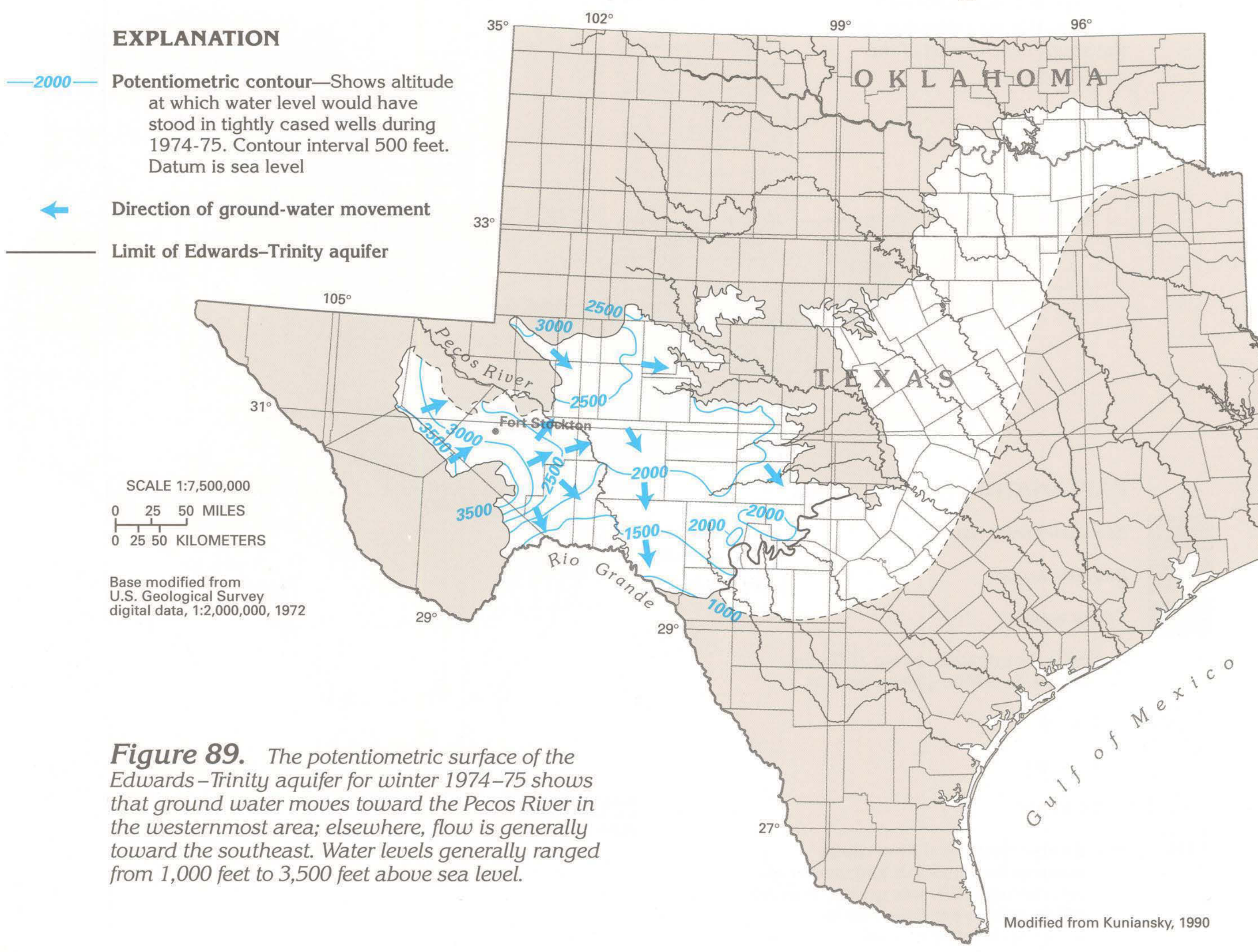


Figure 89. *The potentiometric surface of the Edwards–Trinity aquifer for winter 1974–75 shows that ground water moves toward the Pecos River in the westernmost area; elsewhere, flow is generally toward the southeast. Water levels generally ranged from 1,000 feet to 3,500 feet above sea level.*

Ground-Water Development

Irrigation constitutes the most important use of water withdrawn from the Edwards–Trinity aquifer. Irrigation is concentrated in the northwestern part of the area where soil conditions are particularly favorable for farming. For much of the area, the lack of soil cover and the generally rocky terrain are the factors that limit the use of ground water for irrigation, rather than lack of water in the aquifer.

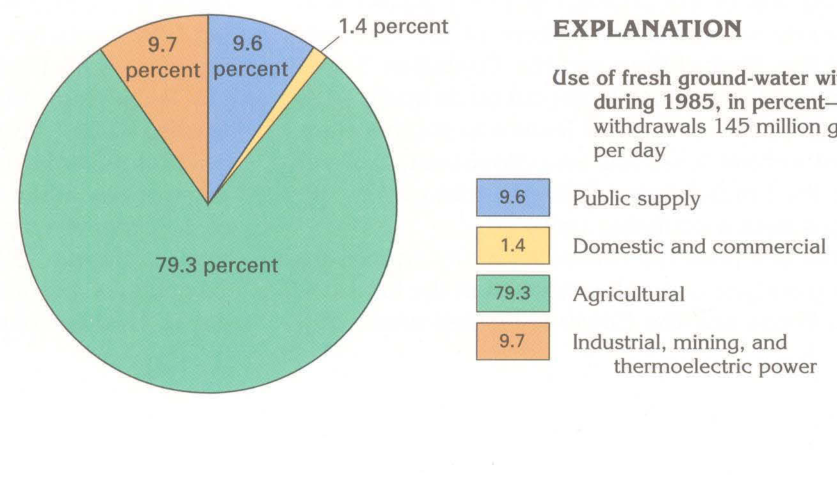
In the Trans-Pecos area, major irrigation areas are in southeastern Reeves County and northern Pecos County. In these areas, pumpage from the aquifer for irrigation in the 1960's and 1970's was about 89 million gallons per day. Ground-water levels declined nearly 150 feet from the late 1950's to the early 1970's in an irrigated area about 15 miles west-northwest of Fort Stockton. Withdrawals in this area were about 8 million gallons per day during 1974. Intense pumpage around Fort Stockton, particularly southwest of the city, has caused the cessation of flow from Comanche Springs at Fort Stockton. The springs once flowed at about 29 million gallons per day.

During 1972, withdrawal from the Edwards–Trinity aquifer for irrigation in the Edwards Plateau area was about 55 million gallons per day, or about 70 percent of the total water withdrawn in that area. Glasscock, Midland, and Reagan Counties are the principal users of irrigation water in the Edwards Plateau. Declining water levels and decreasing well yields have accompanied development. In southern Glasscock County, the ground-water level declined more than 100 feet from 1937 to 1966. In northern Reagan County, the water level declined 95 feet from 1954 to 1969 and another 50 feet from 1970 to 1987.

Fresh Ground-Water Withdrawals

Withdrawals of freshwater from the Edwards–Trinity aquifer totaled about 145 million gallons per day during 1985 (**fig. 90**). About 115 million gallons per day was withdrawn for agricultural purposes, the principal water use. About 14 million gallons per day was withdrawn for each of two use categories: public supply and industrial, mining, and thermoelectric-power use. About 2 million gallons per day was withdrawn for domestic and commercial uses.

Figure 90. *Most of the freshwater withdrawn from the Edwards–Trinity aquifer during 1985 was used for agricultural purposes.*



Data from N.L. Barber and D.L. Lurry, U.S. Geological Survey, written communication, 1989; and William Moltz, Texas Water Development Board, written communication, 1989

EDWARDS AQUIFER

The Edwards aquifer consists of highly faulted and fractured carbonate rocks of Cretaceous age in an area of about 4,000 square miles in south-central Texas (**fig. 91**). This aquifer is referred to in some reports as the "Edwards (Balcones Fault Zone) aquifer." Most of the aquifer is within the Coastal Plain Physiographic Province, although some updip areas are in the Great Plains Physiographic Province.

The area underlain by the Edwards aquifer is a combination of agricultural and ranch land and areas of dense population, including the cities of Austin in Travis County and San Antonio in Bexar County. The topography consists of a gently rolling plain to the east and moderately hilly country to the west. The altitude of the land surface ranges from about 500 feet above sea level at the Colorado River at Austin to about 1,500 feet above sea level in Uvalde County.

Average annual precipitation ranges from about 22 inches in the west to about 34 inches in the east. Average annual runoff ranges from about 1 inch in the west to about 6 inches in the northeast. Major streams that cross the area flow southward and southeastward and include the Nueces, the Frio, the Medina, the Guadalupe, the Blanco, the Colorado, and the San Gabriel Rivers.

The aquifer underlies parts of 10 counties and is separated into northern and southern parts by a ground-water divide in about the middle of Hays County. The northern part is called the Austin area and consists of Bell, Travis, and Williamson Counties. The southern part, called the San Antonio area, consists of Bexar, Comal, Hays, Kinney, Medina, and Uvalde Counties. The aquifer also underlies an extremely small part of northwestern Guadalupe County; because pumpage in this county is negligible, it is excluded from further discussion.

The 1985 population in the three-county Austin area was about 810,000. During 1985, withdrawals from the Edwards aquifer in the Austin area were about 17 million gallons per day. The six-county San Antonio area had a 1985 population of about 1.3 million. Withdrawals from the Edwards aquifer in the San Antonio area during 1985 were about 450 million gallons per day. The city of San Antonio, which has a population of nearly 1 million, derives its entire water supply from the Edwards aquifer.

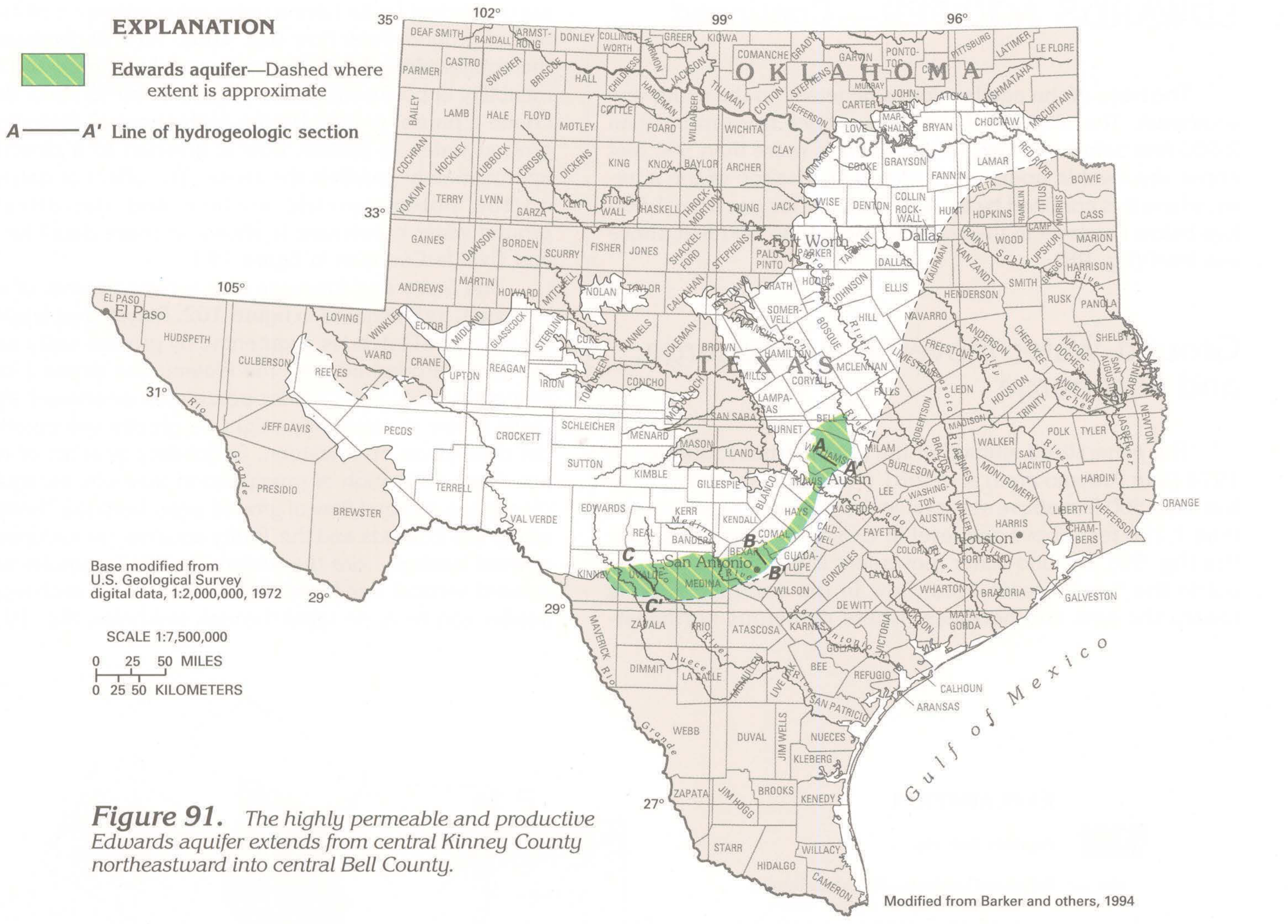


Figure 91. The highly permeable and productive Edwards aquifer extends from central Kinney County northeastward into central Bell County.

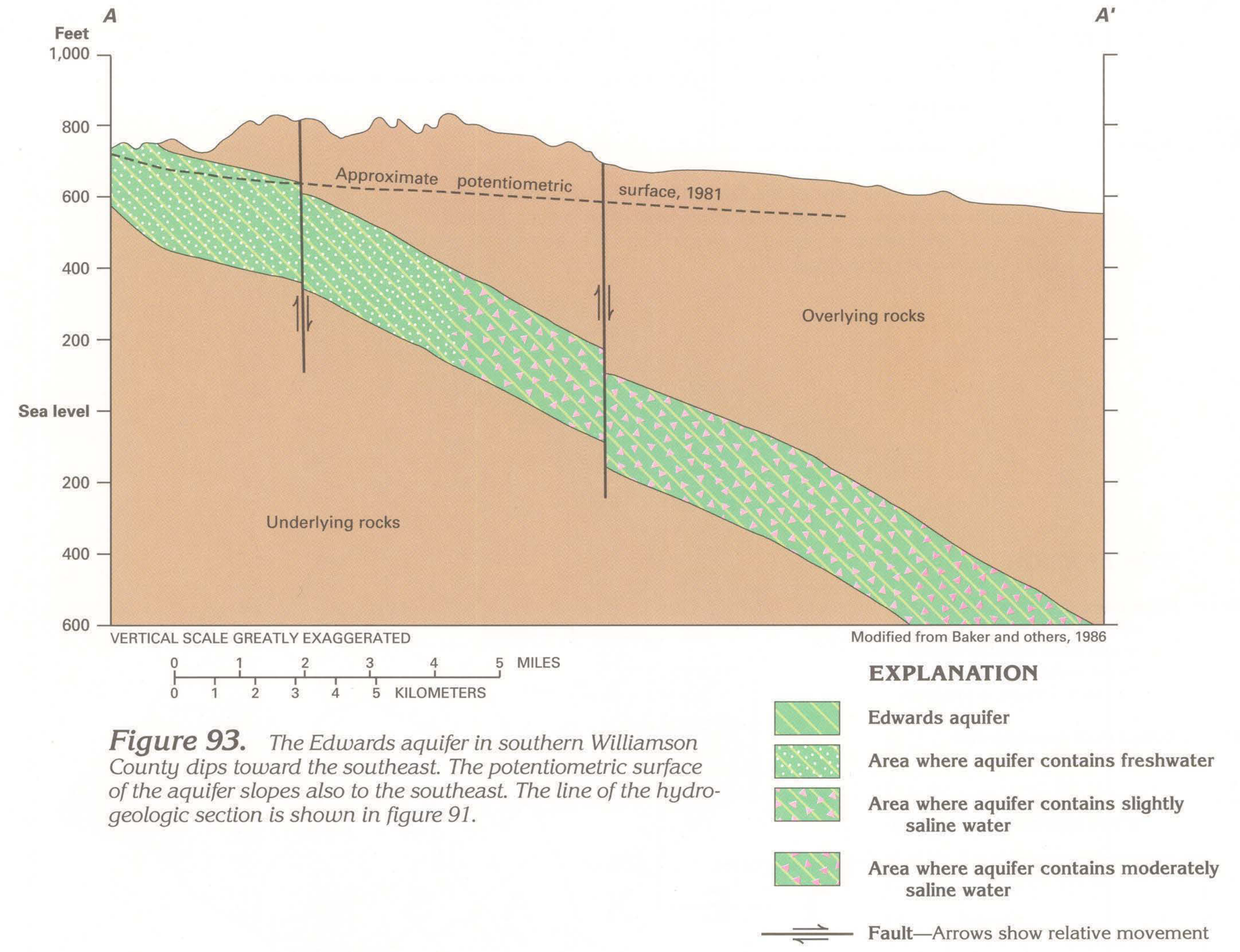


Figure 93. The Edwards aquifer in southern Williamson County dips toward the southeast. The potentiometric surface of the aquifer slopes also to the southeast. The line of the hydrogeologic section is shown in figure 91.

Figure 92. The chemical quality of water in the Edwards aquifer changes greatly across a narrow zone called the "bad-water line." These two test wells, completed in the same part of the aquifer, straddle the zone. The well in the foreground yields freshwater, whereas the one in the background (only about 100 feet away) yields saline water.

James A. Miller, U.S. Geological Survey

Hydrogeologic Framework

The Edwards aquifer consists of limestone and dolomite of the Washita and the Fredericksburg Stages. The complex nomenclature and lithologic character of the formations that compose the aquifer are generalized for purposes of this Atlas, but are discussed in detail in several of the reports listed in the "References" section. The aquifer generally consists of the Kainer and the Person Formations of the Edwards Group and the Georgetown Formation (**fig. 80**).

After deposition of Cretaceous rocks in west-central Texas, tectonic movement caused the relative uplift of the Edwards Plateau and subsidence of the Gulf of Mexico. Structural forces caused deformation and fracturing of the rocks, and a number of en echelon, northeastward-trending faults formed in the region known as the Balcones Fault Zone. The numerous faults have formed wedges or blocks of rock that are generally downthrown to the south and southeast in the form of stairsteps. The Edwards aquifer is generally coincident with the fault zone. The length of the arc-shaped aquifer is about 240 miles. The northern boundary is in central Bell County where the thickness of the aquifer and its importance as a source of ground water are diminished.

The width of the aquifer ranges from about 4 miles at the Colorado River at Austin to about 30 miles in Medina and Williamson Counties. The updip boundary of the aquifer in most places is the farthest updip extent of the Edwards Group, except in the westernmost area where the updip boundary is determined by a decreased incidence of faulting. From Kinney County eastward and northward to the Colorado River at Austin, the updip boundary generally coincides with the Balcones Escarpment.

The downdip boundary of the aquifer is largely fault controlled. As a result of the faulting, the chemical quality of the water in the Edwards aquifer can change abruptly in a very short distance across a zone often referred to as the "bad-water line." Along this line, the water is fresh on the upthrown side of a fault and very saline (usually a sodium- or calcium-sulfate type water) on the downthrown side (**fig. 92**). The downdip boundary of the aquifer in the San Antonio area is the downdip extent of water that contains less than 1,000 milligrams per liter of dissolved solids, whereas in the Austin area, it is the downdip extent of water that contains less than 3,000 milligrams per liter of dissolved solids.

The Edwards aquifer is underlain by the much less permeable Walnut Formation or Glen Rose Limestone of the Trinity aquifer. Where the Edwards aquifer does not crop out, it is confined above by the Del Rio Clay (**fig. 80**). The aquifer dips to the south and southeast, and is offset by numerous faults (**figs. 93 through 95**). The aquifer thickens from northeast to southwest and ranges in thickness from a few feet in outcrop areas to about 800 feet in Medina and Uvalde Counties (**fig. 96**).

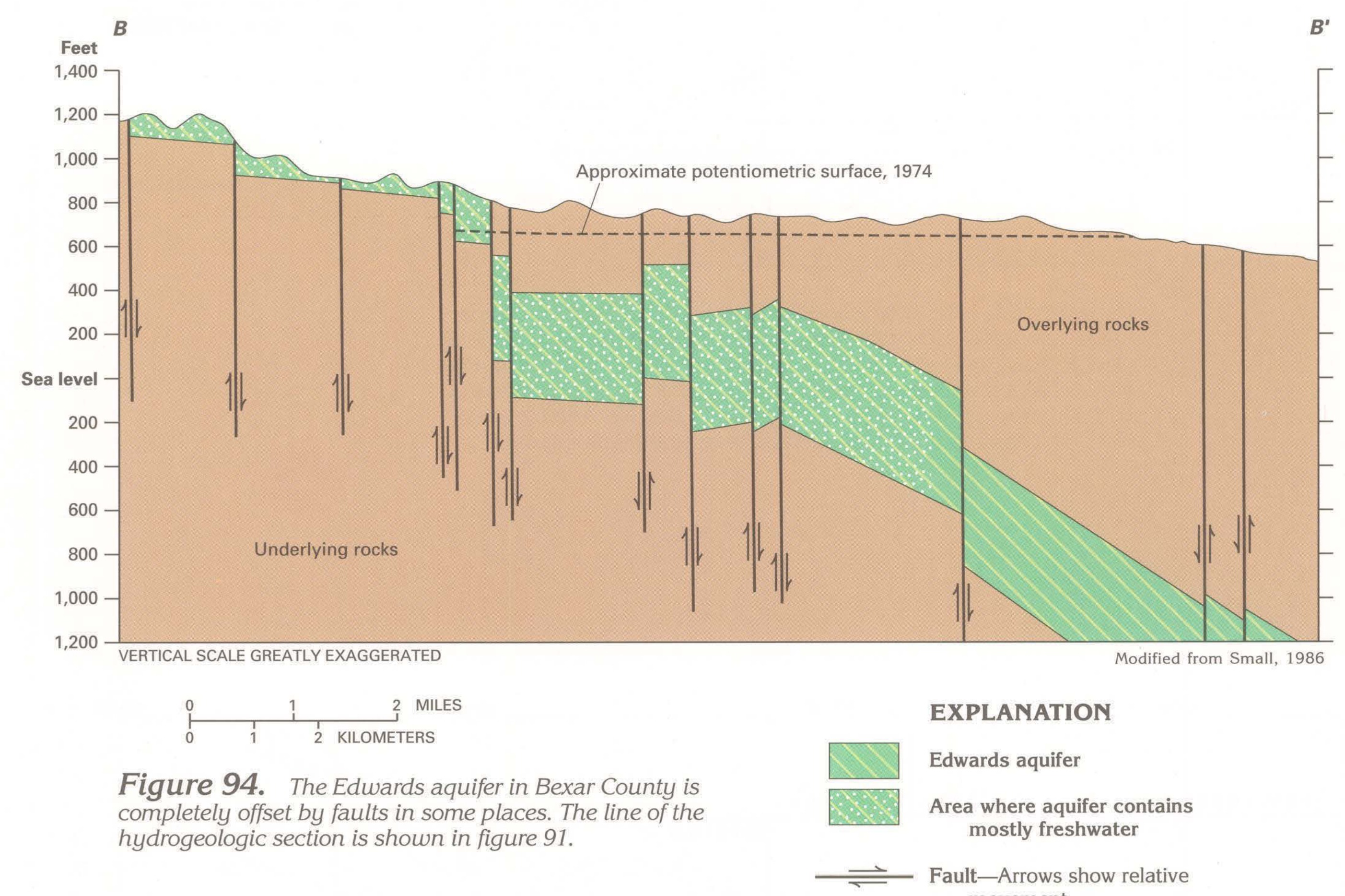


Figure 94. The Edwards aquifer in Bexar County is completely offset by faults in some places. The line of the hydrogeologic section is shown in figure 91.

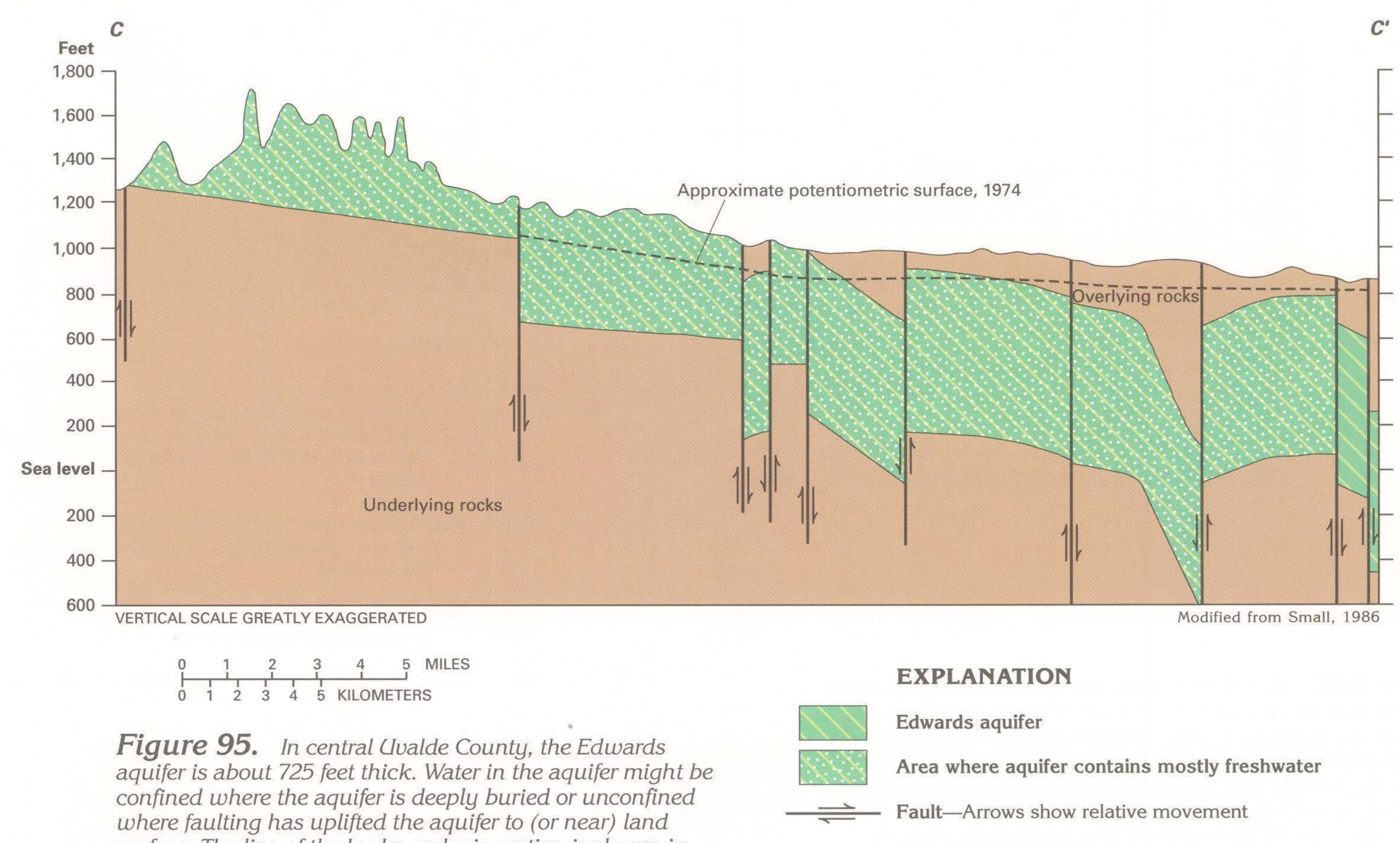


Figure 95. In central Uvalde County, the Edwards aquifer is about 725 feet thick. Water in the aquifer might be confined where the aquifer is deeply buried or unconfined where faulting has uplifted the aquifer to (or near) land surface. The line of the hydrogeologic section is shown in figure 91.

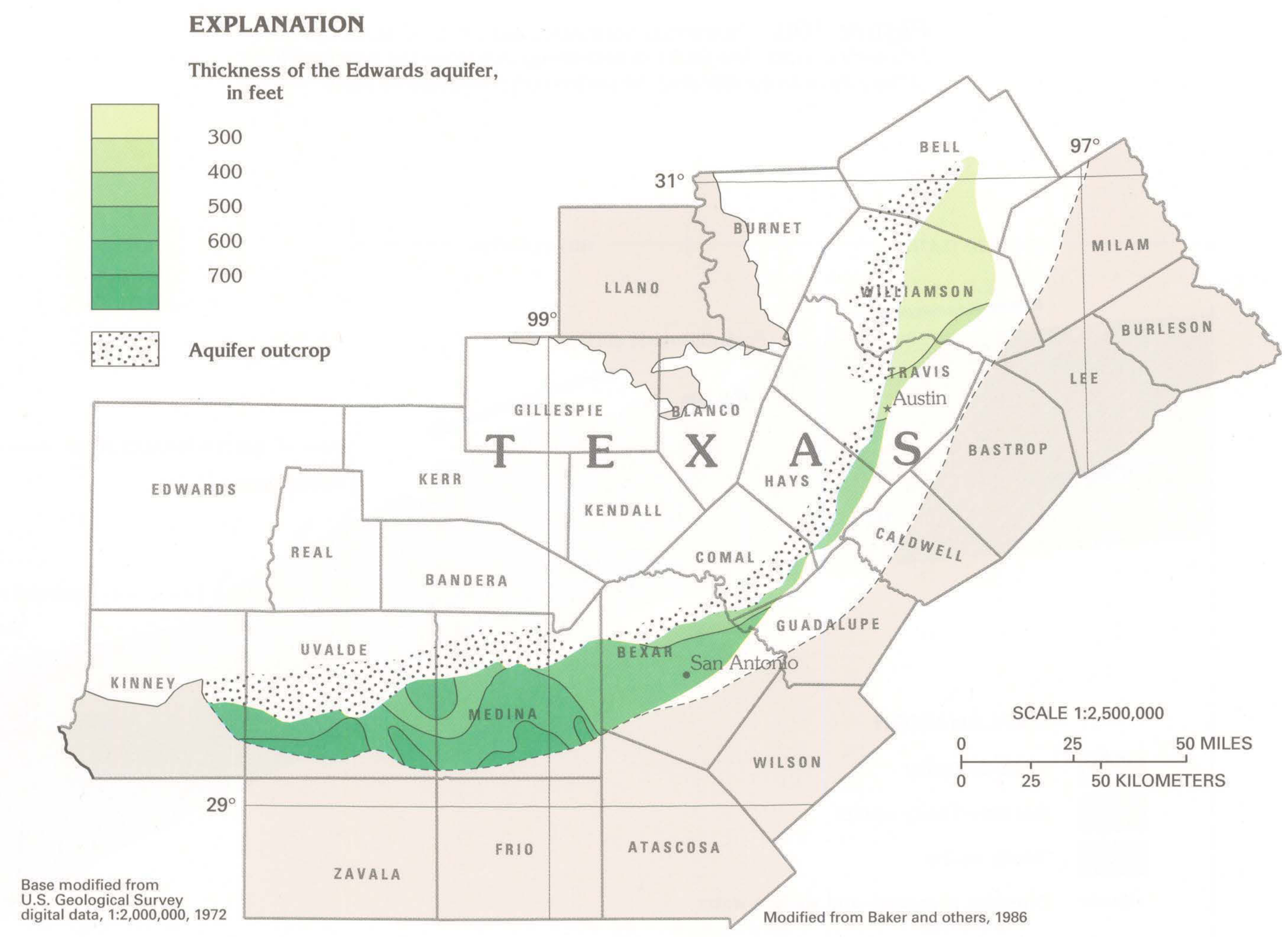


Figure 96. The thickness of the Edwards aquifer ranges from a few feet in outcrop areas to nearly 800 feet in the south-west. The aquifer thickens generally from northeast to southwest.

EDWARDS AQUIFER— Continued

The base of the aquifer slopes generally to the south and southeast. The altitude of the base ranges from more than 2,000 feet below sea level in the south to more than 500 feet above sea level in updip areas (**fig. 97**). The top of the aquifer, where it is confined by the Del Rio Clay, ranges from 1,500 feet below sea level in the south to more than 500 feet above sea level (**fig. 98**).

Ground-Water Movement, Recharge, and Discharge

The generalized altitude of the potentiometric surface in 1974 (San Antonio area) and 1981 (Austin area) ranged from less than 500 feet above sea level at the Colorado River to more than 1,100 feet above sea level in Uvalde and Kinney Counties (**fig. 99**). Ground-water movement is generally downdip, but in the San Antonio area, flow in the confined zone is toward the east and northeast where numerous northeast-ward-trending faults have a substantial influence on the direction of ground-water flow (**fig. 100**). Vertical displacement of the aquifer along faults may place rocks of high and low permeability opposite each other (**figs. 94 and 95**) and, thus, may create a partial or total barrier to the normal downdip flow of ground water. In places, flow is diverted to a direction that approximately parallels the faults. The effect of barrier faults on the potentiometric surface and the direction of ground-water movement is shown in more detail for Medina and Uvalde Counties in **figure 101**.

The faults and fractures also serve as points of entry for recharge, as illustrated in **figure 102**. Runoff that originates on the Edwards Plateau is augmented by ground-water discharge along the eroded edge of the Plateau. As streams cross the Balcones Fault Zone, water percolates downward along the faults where permeability might be greatly enhanced by partial dissolution of limestone. Secondary sources of recharge are direct infiltration of precipitation that falls on aquifer outcrop areas, internal flow of ground water from the Trinity aquifer where the Edwards and the Trinity aquifers are juxtaposed, and upward leakage from the underlying Trinity aquifer where an upward vertical head gradient exists. Direct recharge to the aquifer can be quite rapid through sinkholes (**fig. 103**).

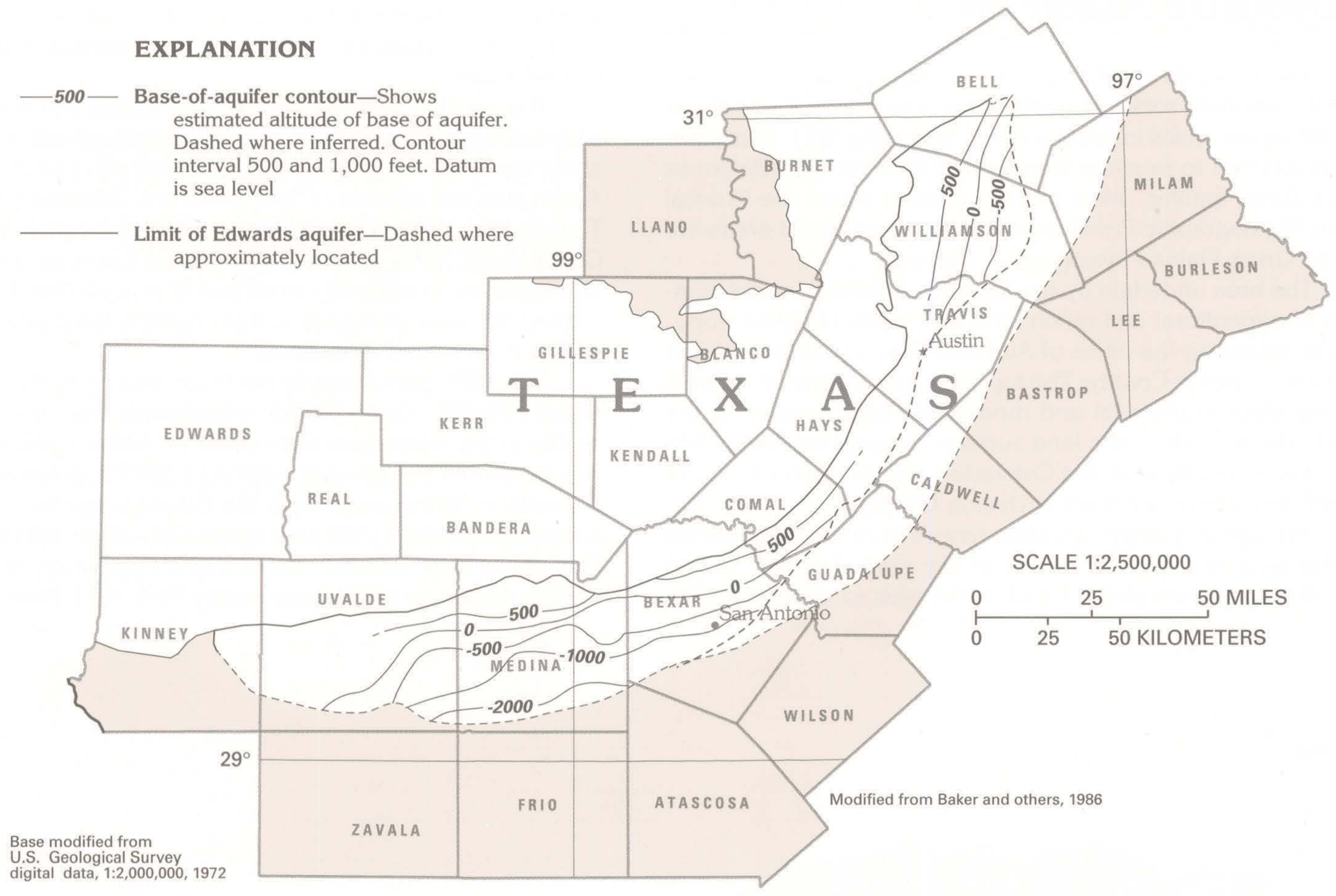


Figure 97. The base of the Edwards aquifer slopes toward the south-southeast. The altitude of the base ranges from greater than 2,000 feet below sea level to greater than 500 feet above sea level updip in Medina County.

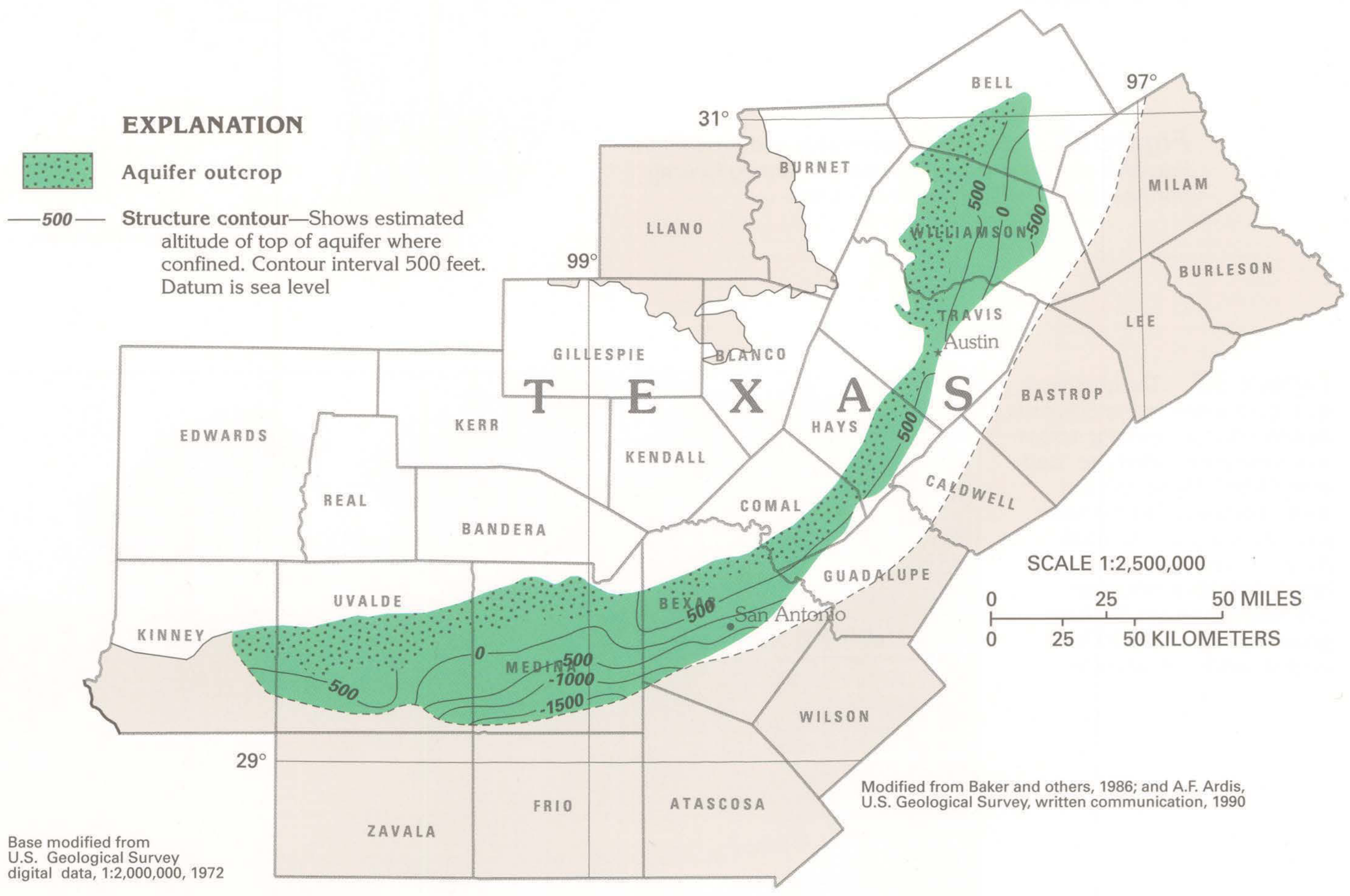


Figure 98. Where the Edwards aquifer is confined, the top of the aquifer ranges from more than 1,500 feet below sea level to more than 500 feet above sea level. The top of the aquifer slopes downdip toward the south and southeast.

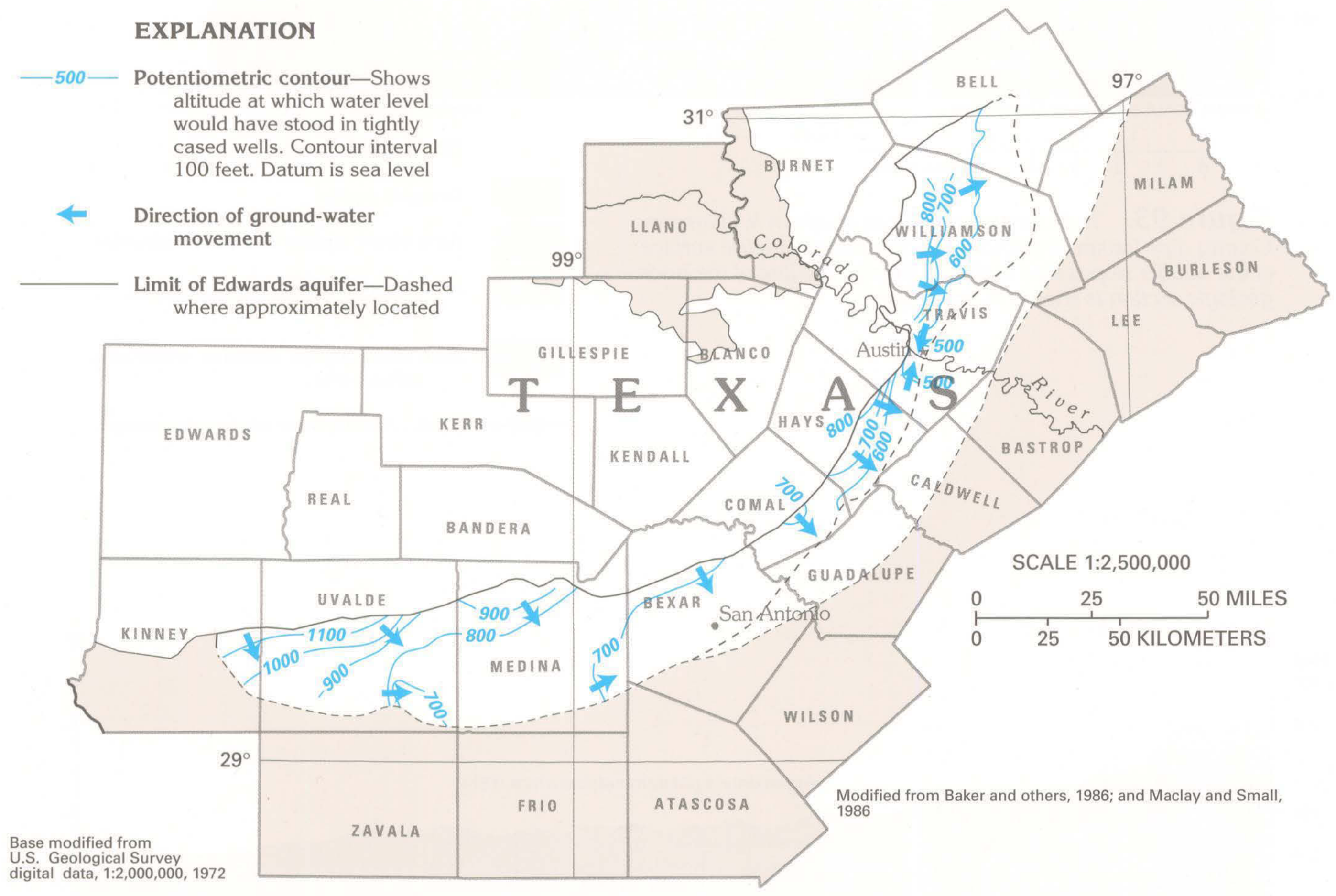


Figure 99. The potentiometric surface of the Edwards aquifer in the summer of 1974 (San Antonio area) and in the winter of 1981 (Austin area) ranged from less than 500 feet above sea level to more than 1,100 feet above sea level. The effect of barrier faults is shown by the northeastward component of flow in the San Antonio area. Flow converges at the Colorado River in central Travis County.

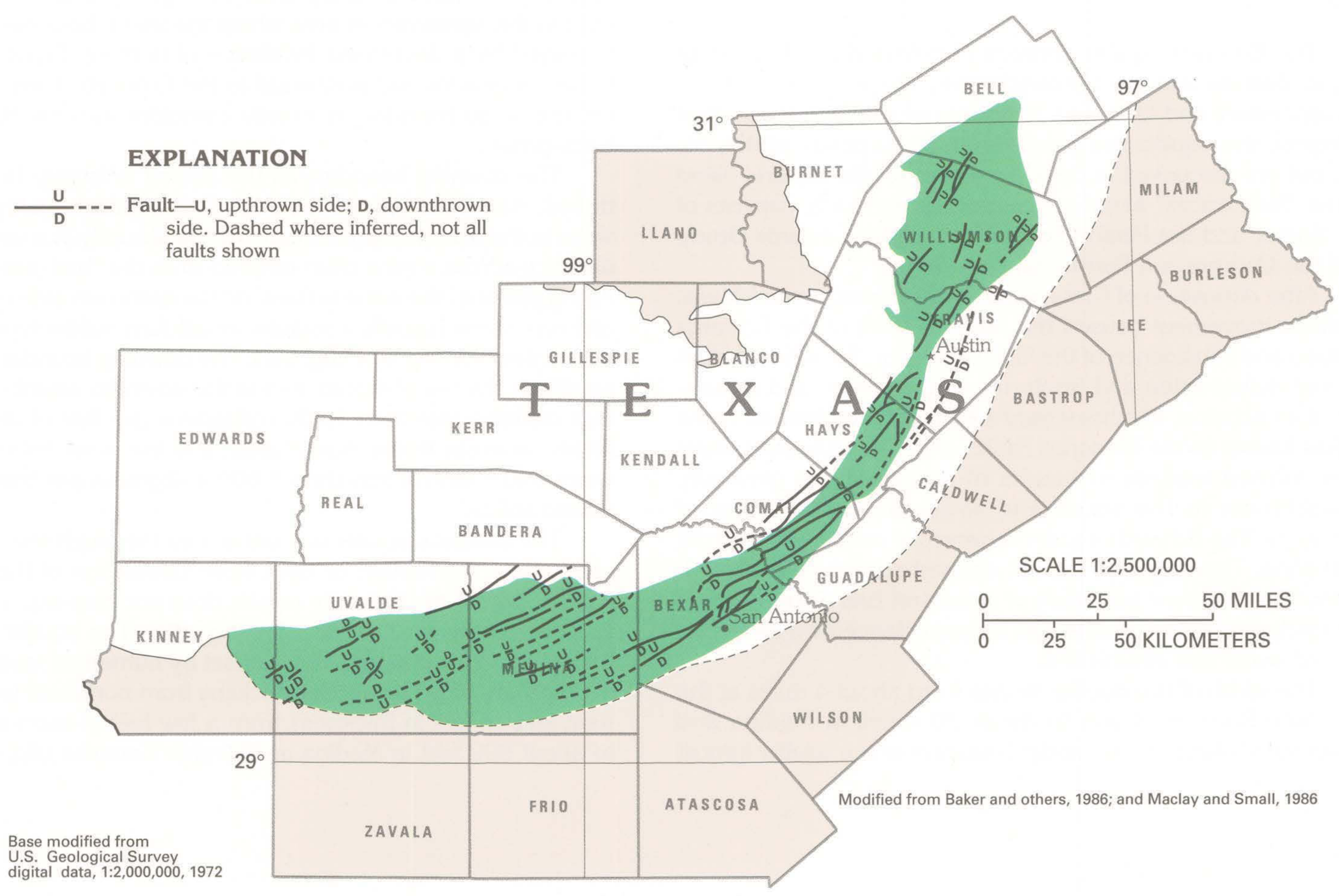


Figure 100. Numerous northeastward-trending faults cut the Edwards aquifer. The faults substantially influence the permeability of the Edwards aquifer and the pattern of ground-water flow.

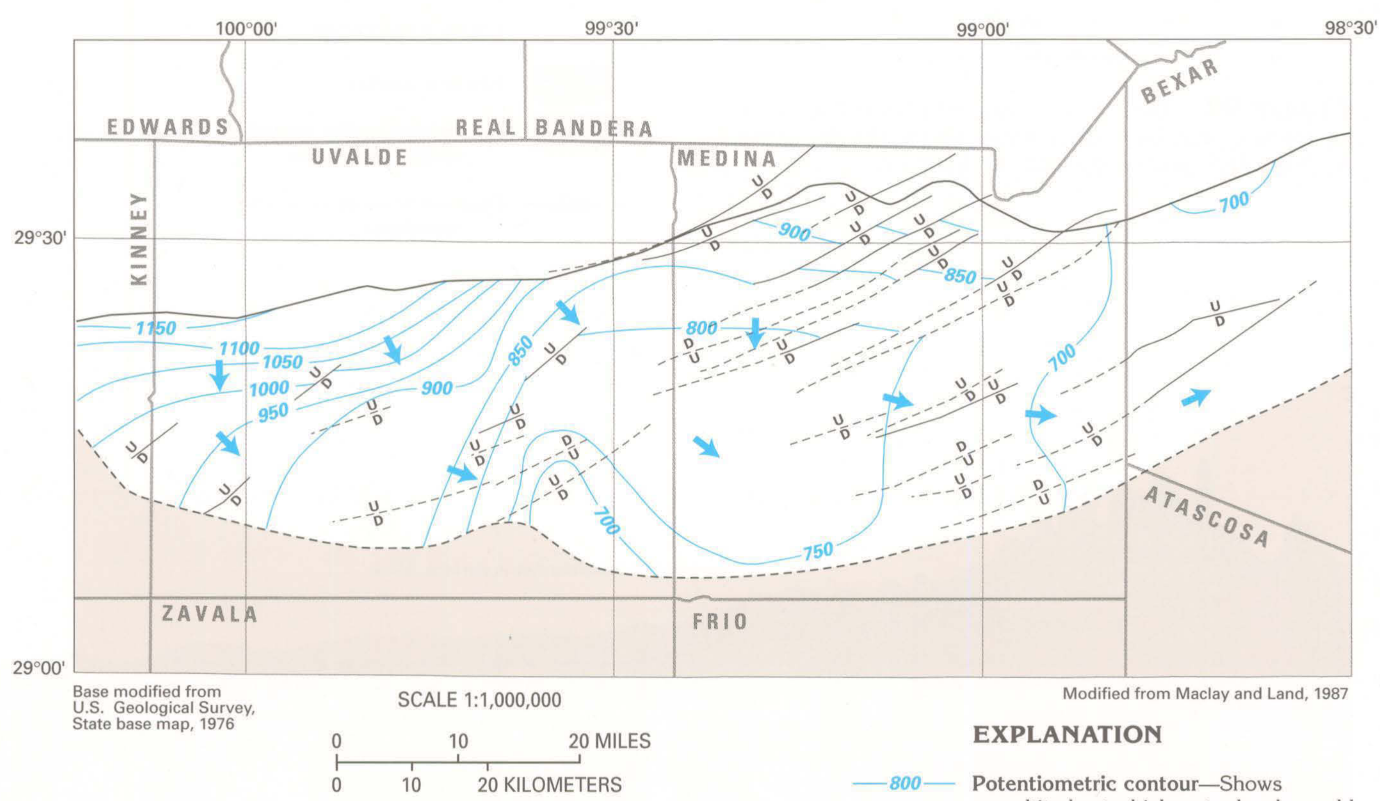


Figure 101. Potentiometric contours for the winter of 1973 are offset along barrier faults in Medina and Uvalde Counties.

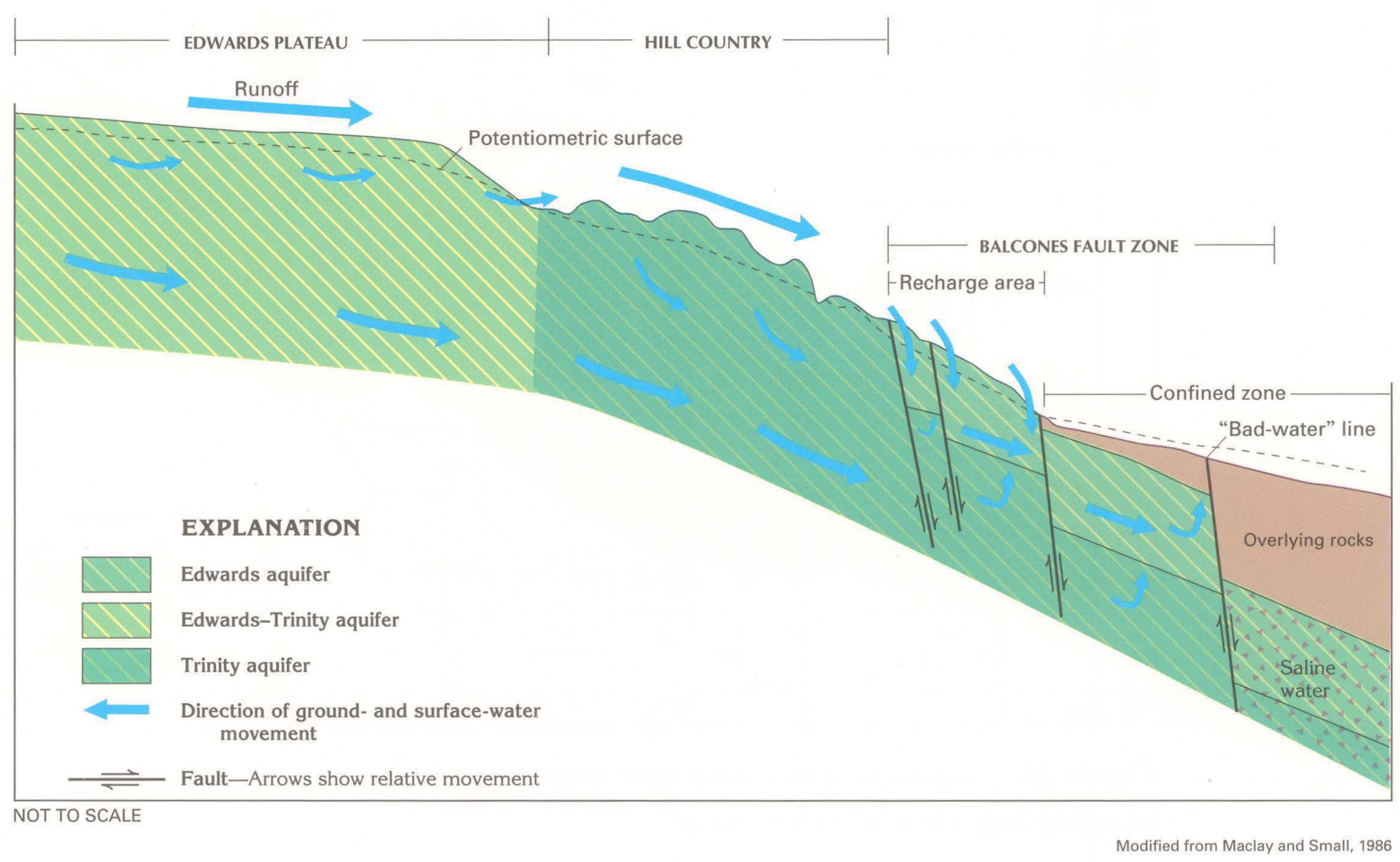


Figure 102. Runoff that originates on the Edwards Plateau enters the Hill Country where it is augmented by ground-water discharge along the edge of the plateau. As streams cross the Balcones Fault Zone, water percolates downward along faults to become the primary source of recharge to the Edwards aquifer. Secondary sources of recharge are lateral flow from the Trinity aquifer where the Trinity and the Edwards aquifers are juxtaposed and upward flow where the Trinity underlies the Edwards.

Ground-Water Movement, Recharge, and Discharge—Continued

Water levels in wells completed in the Edwards aquifer rise immediately and springflows increase quickly after major recharge events, thus attesting to a dynamic flow system and the rapid movement of large volumes of water. Because of the great depth of the water table below land surface in most of the area, ground-water losses to evapotranspiration are assumed to be minor. Diffuse leakage into or out of the aquifer also is assumed to be minor. Recharge from streams and precipitation, and discharge from springs and wells can be measured. Thus, an estimated water budget can be computed for the Edwards aquifer for any period for which records are available.

An analysis of long-term (between 1917 and 1987) records provides an estimate of a long-term average water budget for the Edwards aquifer. Total recharge to the aquifer averaged 686 million gallons per day; average discharge to springs was 425 million gallons per day, and well withdrawals averaged 251 million gallons per day for a total average discharge of 676 million gallons per day. Thus, the small net increase in storage of 10 million gallons per day was small. Withdrawals from the aquifer have been increasing over the years and are now substantially greater than the long-term average presented here. This is clearly shown for the San Antonio area by the graph in **figure 104**.

The water budget varies considerably from the average during any given month or year, depending largely on the amount and distribution of precipitation. During 1956, which was the final year of a long drought, recharge to the aquifer was only about 7 percent of the long-term average. In contrast, during 1987, which was an exceptionally wet year, recharge was more than 3 times the long-term average. In years of below-normal precipitation and recharge, the ratio of well discharge to spring discharge tends to increase, and water that is stored in the aquifer may be substantially depleted. For example, during 1980, annual precipitation was about 3 or 4 inches less than average. Recharge was only about 380 million gallons per day, or about 55 percent of the long-term average. Discharge to springs was about 300 million gallons per day and about 460 million gallons per day was withdrawn from wells during 1980. Depletion of water from storage in the aquifer was about 380 million gallons per day.

The amount of recharge and discharge varies substantially from county to county within the area because of such factors as topography, streamflow characteristics, soil type, geology, faulting, solution openings, distribution of precipitation, land-use patterns, and so forth. During 1980, about 70 percent of the total recharge to the Edwards aquifer was in Kinney, Uvalde, and Medina Counties. About 84 percent of the total withdrawal from wells was from Bexar (58 percent) and Uvalde (26 percent) Counties. Nearly 70 percent of the total spring discharge was from two springs: 48 percent from Comal Springs in Comal County (**fig. 105**), and 22 percent from San Marcos Springs in Hays County. Spring locations are shown in **figure 106**.

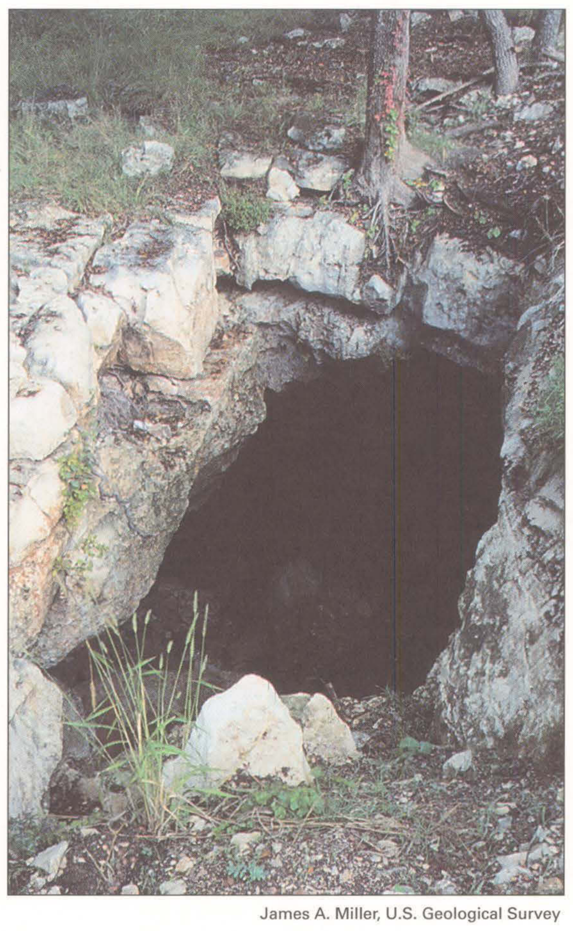


Figure 103. Sinkholes such as this one in the Edwards aquifer in northeastern Medina County can quickly receive large volumes of recharge during rainstorms, and transmit the recharge directly into the aquifer. Some sinkhole openings in the Edwards aquifer are about 50 feet in diameter.

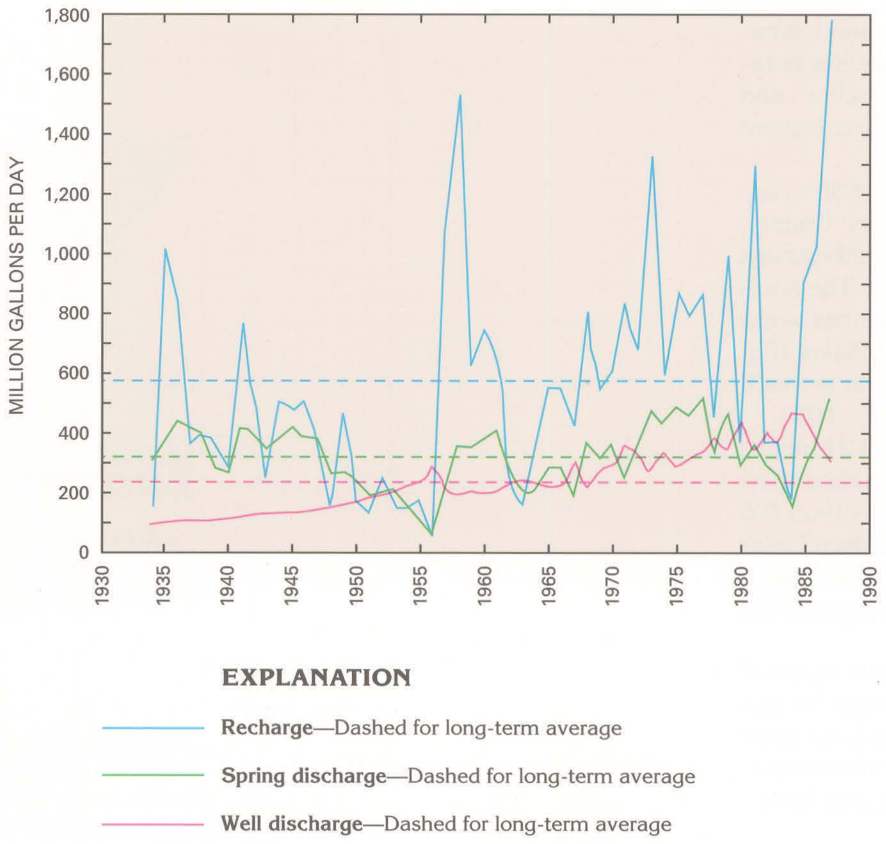


Figure 104. Long-term rates of recharge, spring discharge, and well discharge in the San Antonio area are extremely variable. However, the increase in well discharge has been steady over the years.

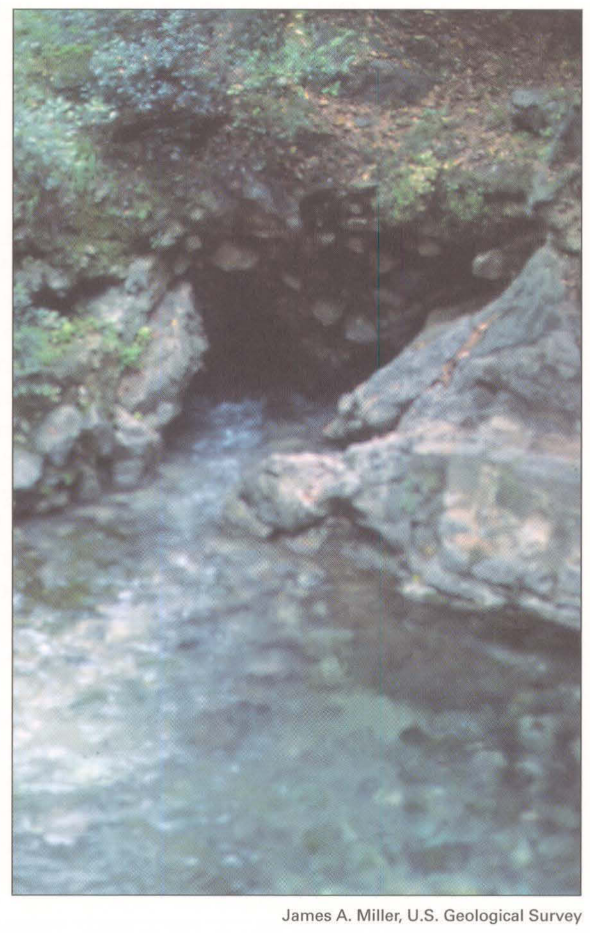


Figure 105. At Comal Springs, several springs issue from the Edwards aquifer. One of the larger spring vents is shown here.

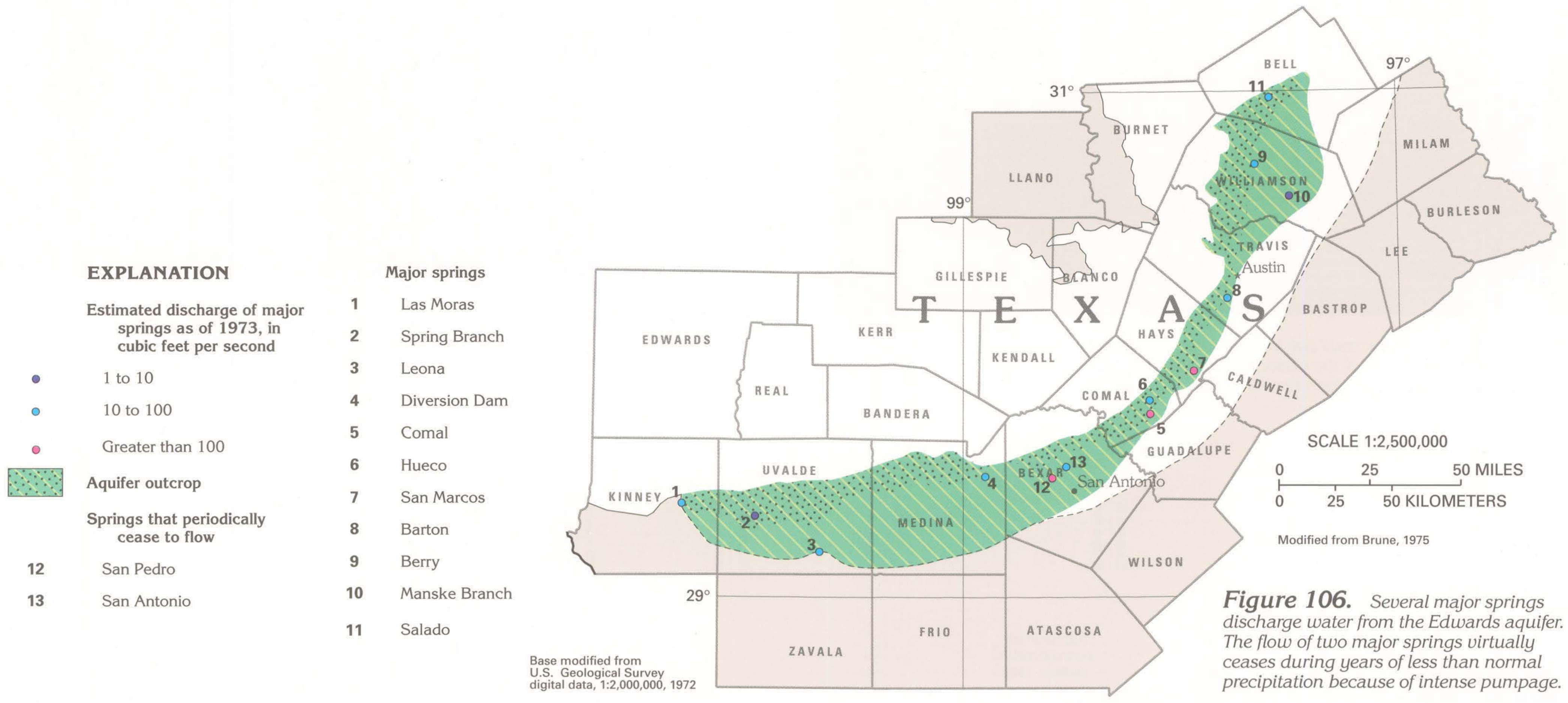


Figure 106. Several major springs discharge water from the Edwards aquifer. The flow of two major springs virtually ceases during years of less than normal precipitation because of intense pumpage.

Aquifer Hydraulic Properties and Water Quality

The Edwards aquifer is the most transmissive of all the aquifers in Texas and Oklahoma. Estimates of transmissivity values for the Edwards aquifer in most of the San Antonio area range from about 200,000 to 2,000,000 feet squared per day. Variations in transmissivity are considerable over relatively short distances and depend upon the amount of development of solution openings along fractures and faults. Large discharges from springs and from flowing and pumped wells attest to the highly permeable nature of the aquifer.

For 61 years of record, Comal Springs, which is the largest spring that issues from the Edwards aquifer, had an average discharge of 185 million gallons per day; a maximum daily discharge of 434 million gallons per day was recorded on November 25, 1985. Some individual wells operated by the city of San Antonio yield more than 16,000 gallons per minute, which ranks them among the largest-yielding wells in the world. Many species of subterranean aquatic organisms exist in the large solution openings deep within the aquifer; for example, toothless, blind catfish live more than 1,900 feet beneath the land surface and are occasionally discharged from flowing or pumped wells.

The aquifer becomes less transmissive toward the Austin area, particularly north of the Colorado River where the aquifer is thinner and less permeable. Estimated transmissivity values in this area range from less than 2 to about 40,000 feet squared per day.

The average specific yield in the unconfined zone of the Edwards aquifer in the San Antonio area is estimated to be 3 to 4 percent. The storage coefficient in the confined zone is estimated to range from about 1×10^{-5} to 1×10^{-4}. The estimated volume of water in storage in the confined freshwater zone of the aquifer in the San Antonio area is 19.5 million acre-feet (6.4×10^{12} gallons).

The concentration of dissolved solids in water from the Edwards aquifer typically ranges from 300 to 1,200 milligrams per liter. The dissolved-solids concentration increases from a few hundred milligrams per liter in the recharge zone to more than 1,000 milligrams per liter at varying distances downdip. The transition from water with a dissolved-solids concentration of 1,000 milligrams per liter to water with a concentration of 3,000 milligrams per liter is generally sharp. The width of this transition zone ranges from less than 1 or 2 miles in most of the area to about 11 miles in Williamson County.

Ground-Water Development

To prehistoric man, Indian tribes, Spanish explorers, cattle drivers, immigrant pioneers, and the present population, the springs and spring-fed rivers and underground water from the Edwards aquifer have been, and continue to be, an attractive and vital resource in this region. Today, many uses compete for water from the aquifer, including public and industrial supplies, agriculture, tourism, and ecosystems associated with the springs and spring-river systems.

Development of water from the Edwards aquifer has been unequal in a geographical sense. Development in the Austin area has been minor, primarily because of reliance on surface-water supplies for most needs, particularly for the city of Austin. During 1985, ground-water withdrawals in Bell, Travis, and Williamson Counties totaled 17 million gallons per day for mostly smaller public supplies (**table 6**).

Table 6. During 1985, withdrawals from the Edwards aquifer in the San Antonio area were much larger than those in the Austin area. Public supply was the principal use of the water in most of the counties, but withdrawals for irrigation in Uvalde and Medina Counties were large

Data from
[William Moltz, Texas Water Development Board, written commun., 1990]

County	Withdrawals from Edwards aquifer during 1985 (million gallons per day)	Principal use
Bell	0.3	Public
Travis	4.2	Ditto
Williamson	12.5	Ditto
Subtotal	17.0	
Bexar	231.8	Public
Comal	11.3	Ditto
Hays	11.1	Ditto
Kinney	1.0	Ditto
Medina	54.3	Irrigation
Uvalde	140.2	Ditto
Subtotal	449.7	
Total (rounded)	467.0	

Development in the San Antonio area has been far greater, with a total withdrawal of about 450 million gallons per day during 1985. The largest user of ground water is Bexar County, where about 232 million gallons per day was withdrawn during 1985 (**table 6**). The city of San Antonio in Bexar County has a population of nearly 1 million and derives its total water supply of about 157 million gallons per day from the Edwards aquifer. Another important use of water from the aquifer in the San Antonio area is for agricultural purposes. During 1985 in Uvalde and Medina Counties, withdrawals, which were mostly for irrigation, totaled about 140 million and 54 million gallons per day, respectively (**table 6**). Withdrawals in the San Antonio area of about 450 million gallons per day during 1985 were more than four times the rate of withdrawal in the 1930's. The increase in withdrawals was relatively steady from 1934 to 1987 (**fig. 104**).

A prolonged drought can severely stress the aquifer because of increased ground-water withdrawals. After a prolonged drought that culminated in 1956, regional ground-water levels and springflows reached record lows. Most springs ceased to flow, including Comal Springs where zero flow was recorded from June 13 to November 4, 1956. San Marcos and Barton Springs continued to flow, but at greatly reduced rates. Greater-than-normal precipitation that began in 1957 led to a recovery of water levels and springflow to predrought conditions in less than 2 years (**fig. 104**).

Fresh Ground-Water Withdrawals

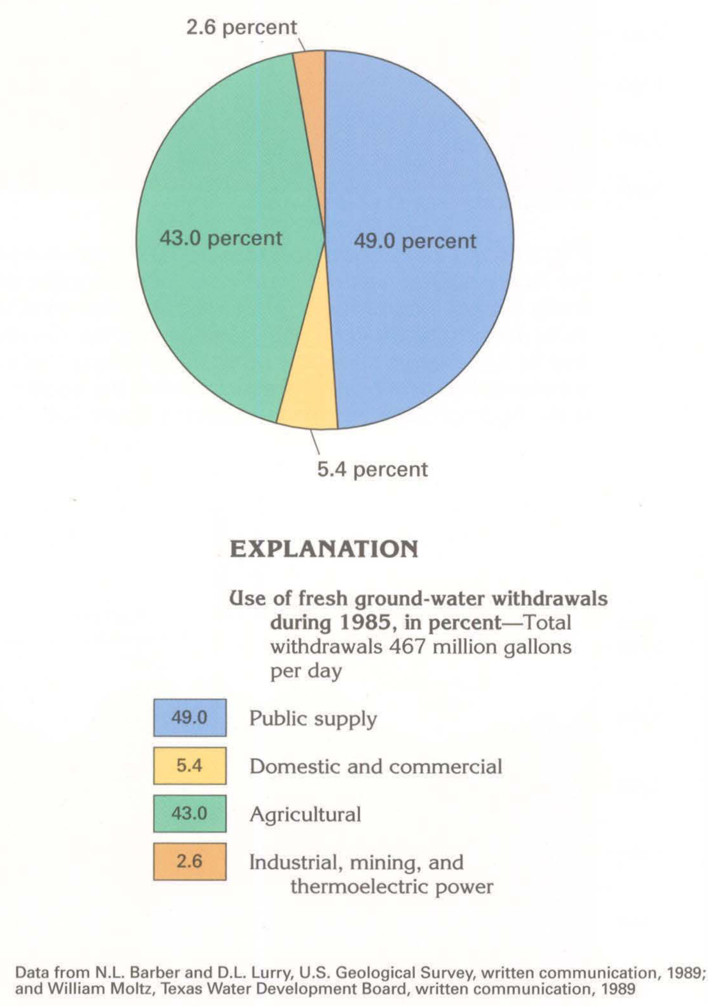
Withdrawals of freshwater from the Edwards aquifer totaled about 467 million gallons per day during 1985 (**fig. 107**). About 229 million gallons per day was withdrawn for public supply, and about 201 million gallons per day was withdrawn for agricultural purposes. About 25 million gallons per day was withdrawn for domestic and commercial uses, and withdrawals for industrial, mining, and thermo-electric-power uses were about 12 million gallons per day.

Potential for Development

Although well withdrawals have been increasing over the years, the Edwards aquifer has the capacity to sustain the withdrawals during times of normal or above-normal precipitation. During times of below-normal precipitation, water from storage in the aquifer is temporarily depleted; this water is replenished with the onset of increased precipitation. During times of severe, prolonged drought, concern for declining ground-water levels, decreased springflows, and the possibility of saltwater intrusion from downdip parts of the aquifer is heightened among water managers, government agencies, recreational establishments, conservationists, irrigators, and individuals.

In order to better manage and protect the aquifer, the creation of two local units of government was authorized by the Texas Legislature—the Edwards Underground Water District for the southern area and the Barton Springs/Edwards Aquifer Conservation District for northern Hays and southern Travis Counties. These agencies are empowered to conduct ground-water investigations and to develop comprehensive plans for the protection and most efficient use of the ground-water resource. The tasks of these agencies are often accomplished in cooperation with local, State, and Federal agencies.

Some measures that have been adopted or are in the construction or planning stage to better manage the ground-water resource include educating the public to the need for water conservation and water-quality protection, constructing dams in the recharge zone to collect and hold water for the enhancement of recharge to the aquifer, and constructing reservoirs to impound surface water and, thus, to augment ground-water withdrawals during drought periods. With proper planning and management, and with the cooperation of all concerned, water from the Edwards aquifer will continue to be a vital resource in the area.



Data from N.L. Barber and D.L. Lurry, U.S. Geological Survey, written communication, 1989; and William Moltz, Texas Water Development Board, written communication, 1989

Figure 107. Most of the freshwater withdrawn from the Edwards aquifer during 1985 was used for public supply and agricultural purposes.

TRINITY AQUIFER

The Trinity aquifer underlies an area of about 41,000 square miles that extends from south-central Texas to southeastern Oklahoma (**fig. 108**); the aquifer is also in a small area in southwestern Arkansas, as shown in Chapter F of this Atlas. The aquifer consists of interbedded sandstone, sand, limestone, and shale of Cretaceous age. The Trinity aquifer is referred to in many reports as the "Trinity Group aquifer" and the "Antlers aquifer"; the latter name is particularly prevalent in Oklahoma.

The Trinity aquifer, which underlies all or parts of 68 counties in Texas and Oklahoma, extends from Kinney County, Texas, in the southwest to McCurtain County in southeastern Oklahoma in an arcuate band about 550 miles long. The aquifer is within parts of three major physiographic provinces—the Coastal Plain, the Central Lowland, and the Great Plains (**fig. 3**). The topography ranges from a gently rolling plain in much of the area to the rugged Hill Country in Texas (**fig. 109**).

Average annual precipitation ranges from about 21 inches in the south and west to about 51 inches in southeastern Oklahoma. Average annual runoff ranges from less than 0.5 inch in the west to more than 20 inches in southeastern Oklahoma. Rivers that drain the area flow generally southeastward and include the Nueces, the Guadalupe, the Colorado, the Brazos, the Trinity, and the Red.

The Trinity aquifer underlies a densely populated part of Texas, which includes the large metropolitan areas of San Antonio, Austin, Fort Worth, and Dallas. The aquifer is far more important north of Austin, where it provides the total or partial water needs for many cities, towns, industries, and farms.

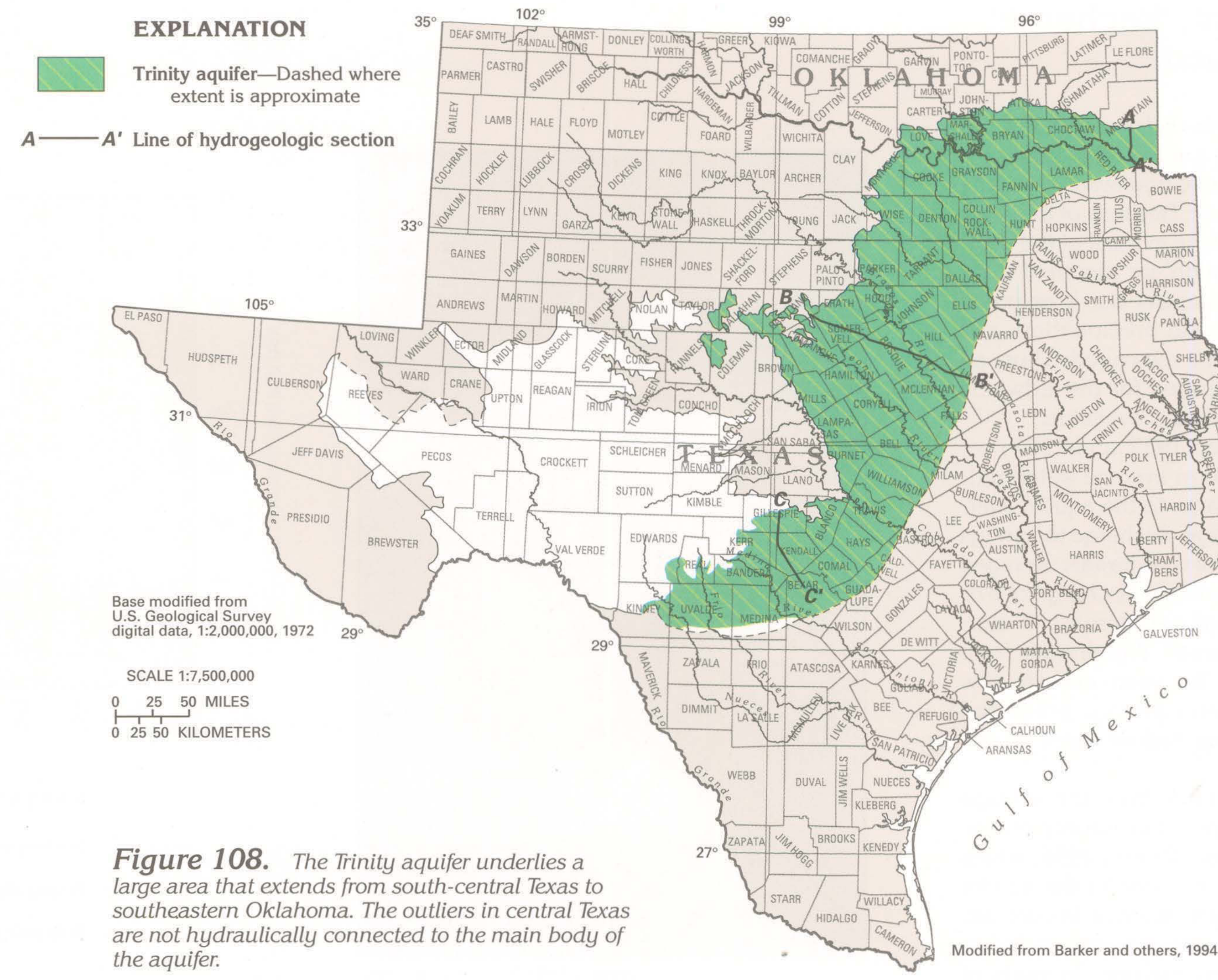


Figure 108. The Trinity aquifer underlies a large area that extends from south-central Texas to southeastern Oklahoma. The outliers in central Texas are not hydraulically connected to the main body of the aquifer.

Figure 109. Rocks of Cretaceous age that compose the Trinity aquifer are exposed along the rim of the dissected Edwards Plateau. This view of rocks of the Glen Rose Formation is in the Texas Hill Country.

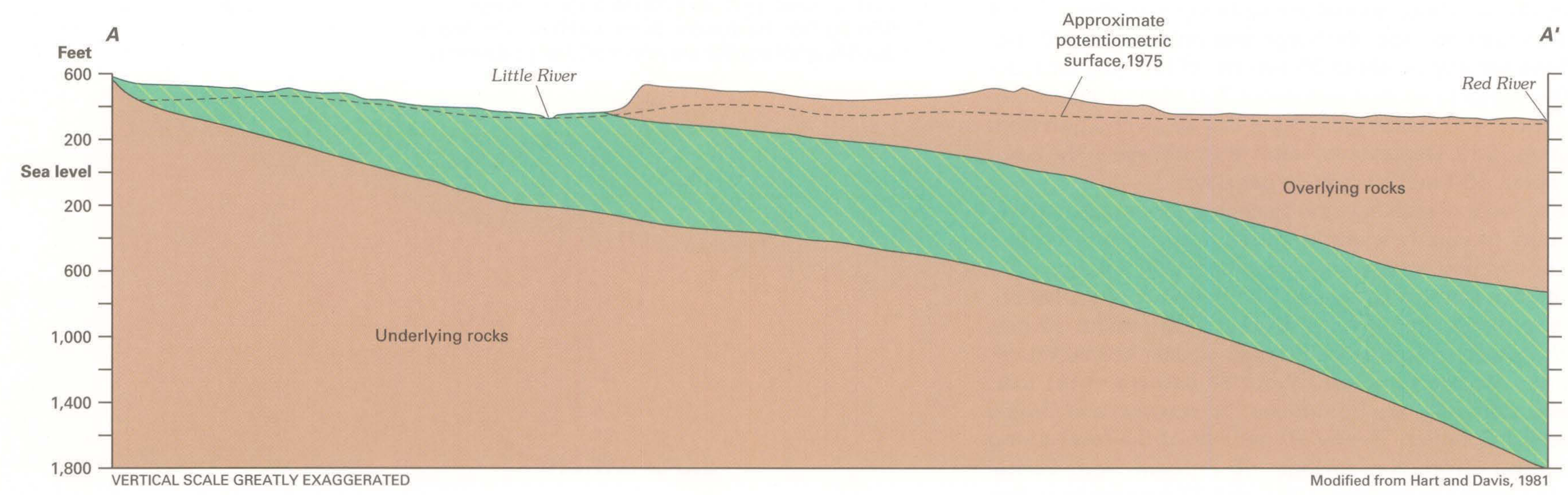


Figure 110. In southeastern Oklahoma, water in the Trinity aquifer becomes confined downdip from the outcrop area. The aquifer is overlain by a thick confining unit in the vicinity of the Red River. The line of the hydrogeologic section is shown in figure 108.

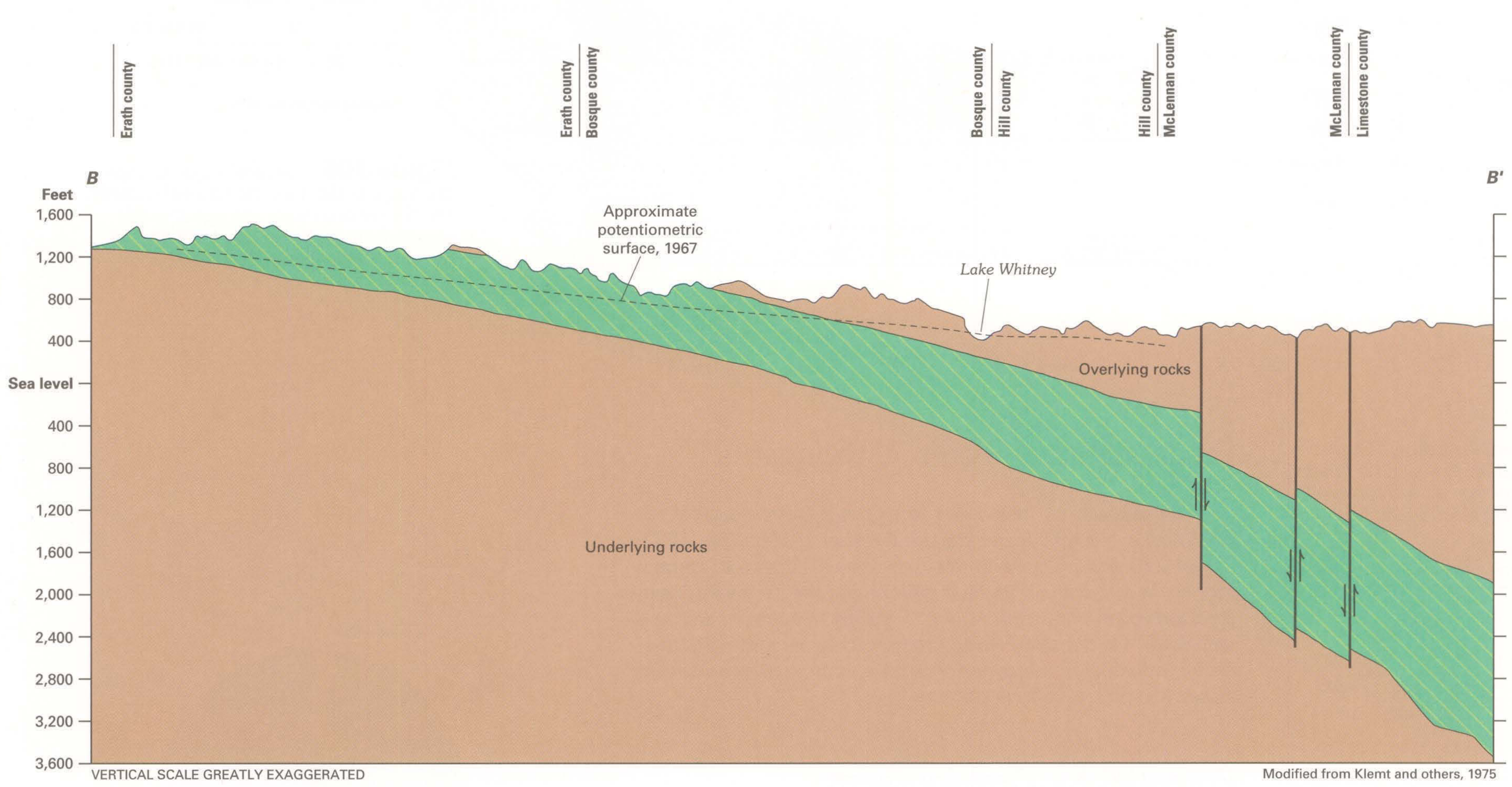


Figure 111. In central Texas, the 1967 potentiometric surface of the Trinity aquifer near the middle part of the aquifer slopes generally toward the southeast. The water becomes confined about 60 miles from the updip limit of the aquifer outcrop. Generally, the aquifer has a large amount of vertical anisotropy that can cause substantial vertical head differences within the aquifer. The line of the hydrogeologic section is shown in figure 108.

0 5 10 MILES
0 5 10 KILOMETERS

EXPLANATION

Trinity aquifer

Fault—Arrows show relative movement

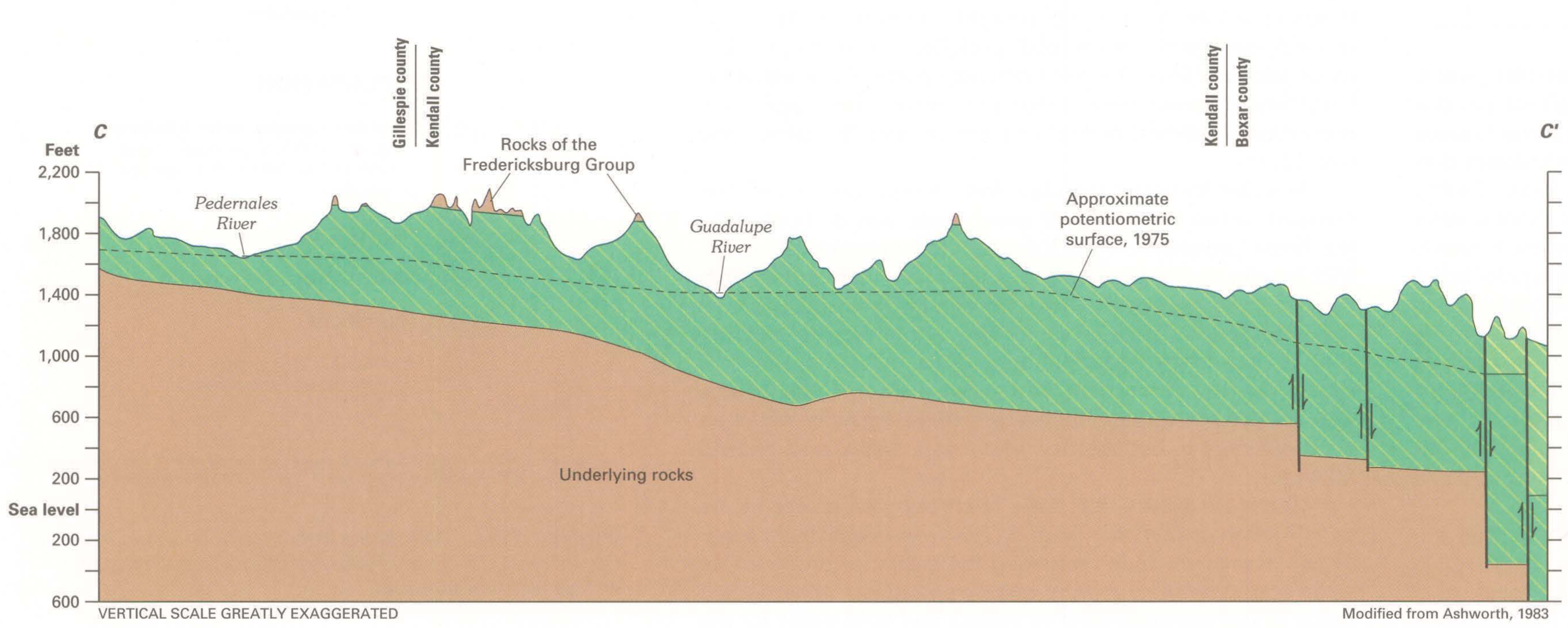


Figure 112. In the Hill Country of south-central Texas, the southward-dipping Trinity aquifer is juxtaposed with the highly permeable Edwards aquifer as a result of faulting. The line of the hydrogeologic section is shown in figure 108.

0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

EXPLANATION

Edwards aquifer

Trinity aquifer

Fault—Arrows show relative movement

Hydrogeology

The Trinity aquifer consists of sandstone, sand, silt, clay, conglomerate, shale, limestone, dolomite, and marl of the Trinity Stage and the Coahuilan Series (**fig. 80**). The complex nomenclature and lithologic character of the formations that compose the aquifer have been generalized for this chapter, but are discussed in detail in several of the reports listed in the "References" section. The aquifer consists generally of the Hosston and Sligo Formations (absent in northeastern Texas and southeastern Oklahoma) and overlying: (1) Travis Peak or Pearsall Formations and Glen Rose Limestone in the southern area; (2) Travis Peak, Glen Rose, and Paluxy Formations in the central area; and (3) Twin Mountains, Glen Rose, and Paluxy Formations in the northern area (**fig. 80**).

The Glen Rose Formation is not recognizable north and west of a line that runs through northern Brown, northern Comanche, and eastern Eastland Counties, Tex., north of a line that runs through central Wise, northern Denton, northern Collin, and northern Fannin Counties, Tex., and in southeastern Oklahoma. In these areas, the Paluxy and Travis Peak Formations or the Paluxy and Twin Mountains Formations coalesce to form an undifferentiated unit mostly of sand and sandstone that is referred to as the "Antlers Formation" in many reports.

The width of the Trinity aquifer ranges from less than 10 miles near its southern limit to about 170 miles in the central area. The updip boundary of the aquifer is the farthest updip extent of exposed rocks of the Trinity Stage. The downdip boundary is the approximate downdip extent of water that has less than 3,000 milligrams per liter of dissolved solids.

The aquifer is underlain and confined by low-permeability rocks that range in age from Precambrian to Jurassic. Where the aquifer does not crop out, it is confined above by the Walnut Formation in most of the area. In much of the Balcones Fault Zone, the upper part of the Glen Rose Limestone directly underlies the highly permeable Edwards aquifer.

The aquifer dips to the south and southeast (**figs. 110, 111, and 112**). Downdip parts of the aquifer extend into the Balcones Fault Zone in places and are offset by faulting. The thickness of the aquifer ranges from a few feet in aquifer outcrop areas to more than 1,000 feet in downdip areas. Water with a dissolved-solids concentration of less than 3,000 milligrams per liter may extend to about 3,500 feet below sea level in the aquifer (**fig. 111**). Data to define the downdip limit of water that has a dissolved-solids concentration of 10,000 milligrams per liter are lacking in this area.

The Trinity aquifer has a large amount of vertical anisotropy. This is particularly true in downdip areas where distinct shale facies may separate more permeable formations that lie above and below. For this reason, many published reports describe the hydrology of individual formations or group the rocks into an "upper," "middle," and "lower" Trinity aquifer. In general, the most productive part of the Trinity aquifer is the undifferentiated Trinity Group in the outcrop and adjacent confined part of the aquifer from Brown County, Tex., northeastward into northeastern Texas and southeastern Oklahoma, and in the Twin Mountains and Travis Peak Formations downdip of the Trinity Group. For purposes of this Atlas, the emphasis of the hydrologic description of the Trinity aquifer is on its most productive parts.

The base of the Trinity aquifer slopes generally to the south and southeast. The altitude of the base ranges from more than 5,000 feet below sea level in the north to more than 1,500 feet above sea level in the west-central area (**fig. 113**). The top of the aquifer in the confined zone ranges from more than 2,000 feet below sea level in the north to more than 1,500 feet above sea level in the west-central area (**fig. 114**).

Recharge to the Trinity aquifer is generally as precipitation that falls on aquifer outcrop areas and as seepage from streams and ponds where the head gradient is downward. In the Hill Country, water might flow laterally into the Trinity aquifer from the adjacent Edwards–Trinity aquifer. The aquifer discharges by evapotranspiration, spring discharge, diffuse lateral or upward leakage into shallower aquifers, and withdrawals from wells. A composite, representative potentiometric surface of the Trinity aquifer is shown in **figure 115**. The potentiometric contours shown in the figure are broken in places because the water levels for different areas were measured over a span of more than 20 years (1967–89) and reflect the effects of pumpage from the aquifer at the time of measurement. Also, the measurement of water levels in different units of the greatly anisotropic aquifer in adjacent areas can show differences in potentiometric surfaces. Water-level altitudes ranged from more than 500 feet below sea level in the Dallas–Fort Worth pumping center to more than 1,500 feet above sea level in central and southern outcrop areas. Ground water moves generally downdip and toward cones of depression developed around pumping centers.

Depths of wells completed in the Trinity aquifer commonly range between 50 and 800 feet, but some well depths exceed 3,000 feet; the deeper wells are in the confined zone; Wells commonly yield from 50 to 500 gallons per minute, and some yield as much as 2,000 gallons per minute. The concentration of dissolved solids in the water typically ranges from 500 to 1,500 milligrams per liter.

The transmissivity and hydraulic conductivity of the anisotropic Trinity aquifer can vary greatly within a geologic unit and among different units, as shown in **table 7**. The number of aquifer tests shown in the table is an indicator of which units and which areas are the most developed and productive. For the entire area, the transmissivity of the Trinity aquifer ranges from about 80 to 5,700 feet squared per day, the hydraulic conductivity ranges from about 1 to 31 feet per day, and the storage coefficient ranges from about 2×10^{-5} to 0.026. Because the materials that compose the aquifer are generally fine grained, clayey, and locally cemented, the transmissivity and hydraulic conductivity values are relatively low. Nevertheless, the aquifer is important and productive, particularly in eastcentral and northeast Texas.

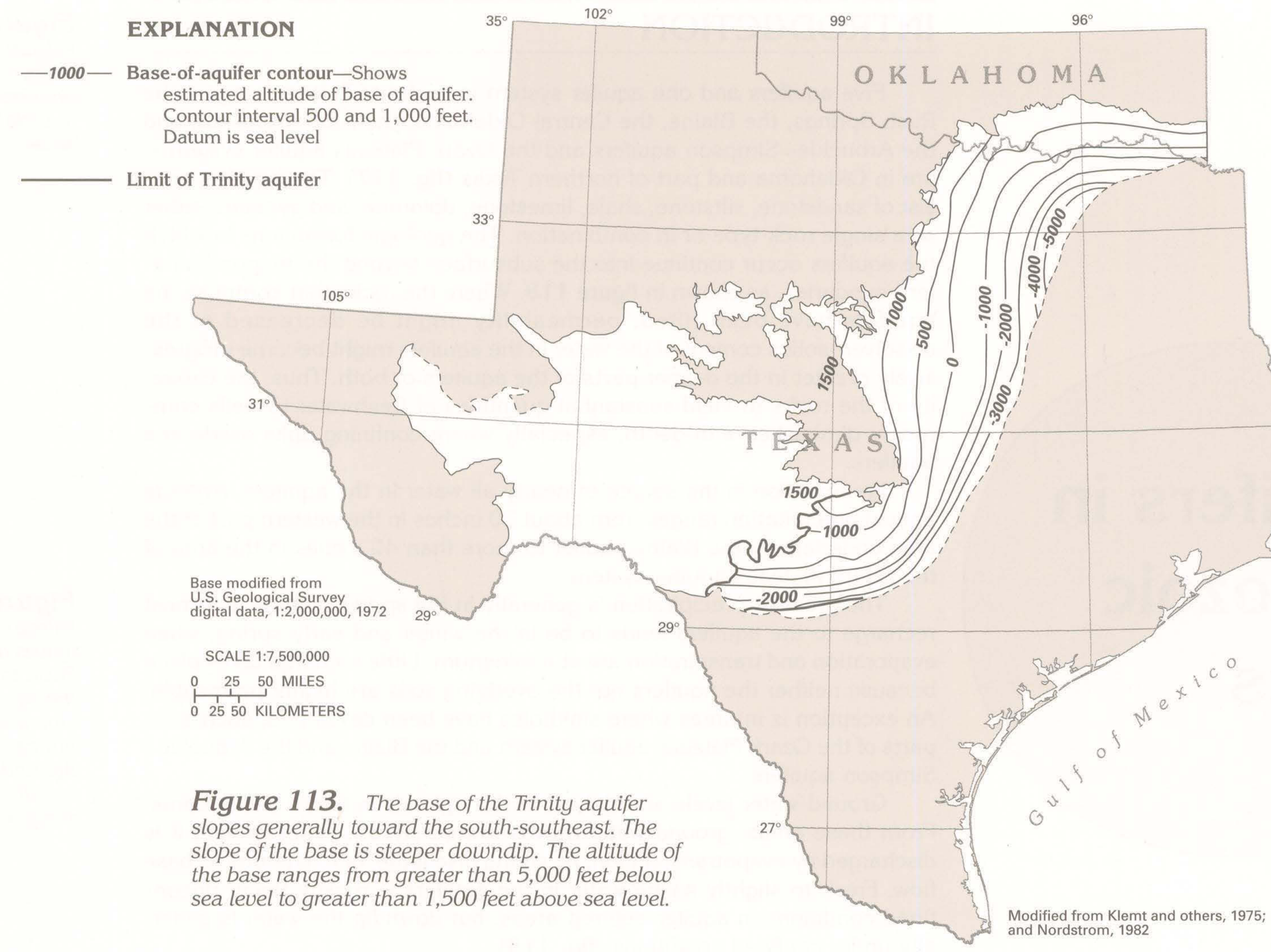


Figure 113. The base of the Trinity aquifer slopes generally toward the south-southeast. The slope of the base is steeper downdip. The altitude of the base ranges from greater than 5,000 feet below sea level to greater than 1,500 feet above sea level.

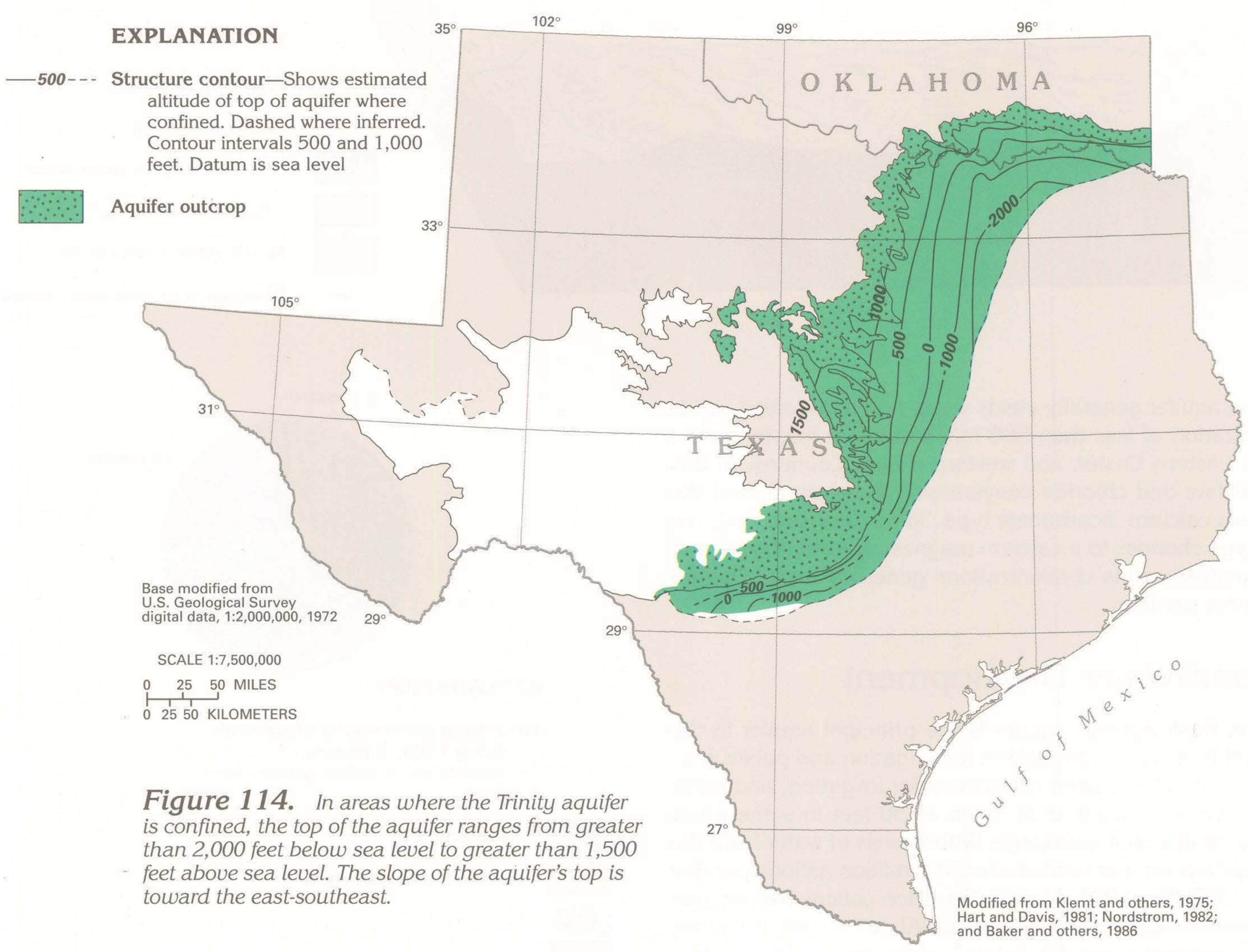


Figure 114. In areas where the Trinity aquifer is confined, the top of the aquifer ranges from greater than 2,000 feet below sea level to greater than 1,500 feet above sea level. The slope of the aquifer's top is toward the east-southeast.

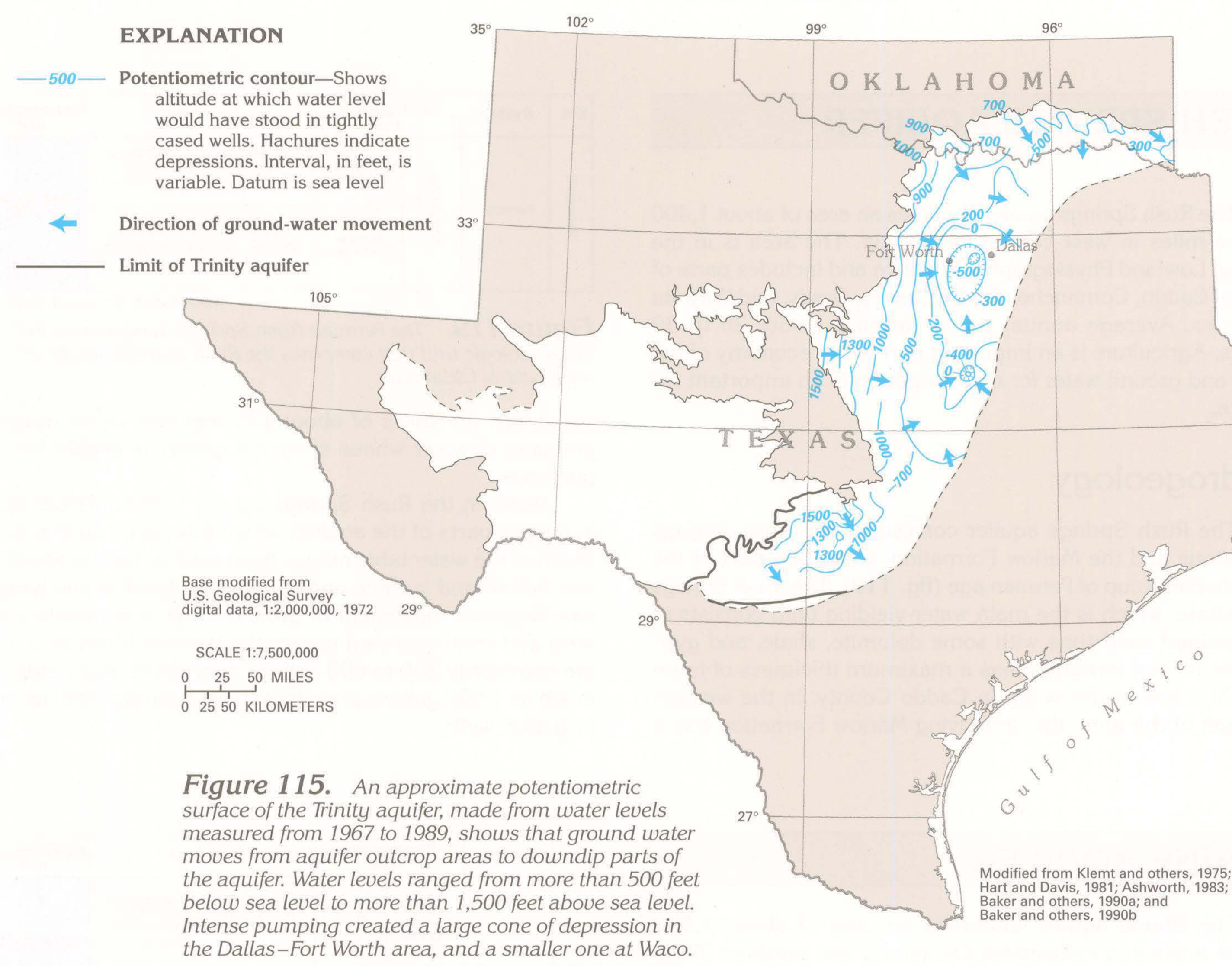


Figure 115. An approximate potentiometric surface of the Trinity aquifer, made from water levels measured from 1967 to 1989, shows that ground water moves from aquifer outcrop areas to downdip parts of the aquifer. Water levels ranged from more than 500 feet below sea level to more than 1,500 feet above sea level. Intense pumping created a large cone of depression in the Dallas–Fort Worth area, and a smaller one at Waco.

Table 7. Hydraulic properties determined from aquifer tests in the Trinity aquifer vary considerably. The number of aquifer tests is indicative of where the Trinity aquifer is most used and which formations included in the aquifer are most productive. Transmissivity and hydraulic conductivity values are generally small compared with values for some other aquifers. This reflects the fine-grained and locally cemented nature of the materials that compose the Trinity aquifer

[Sources: Hart and Davis, 1981; Nordstrom, 1982; Klemt and others, 1975; Ashworth, 1983]

Area	Formation or Group	Approximate number of tests	Range in transmissivity (feet squared per day)	Average transmissivity (feet squared (per day)	Range in hydraulic conductivity (feet per day)	Average hydraulic conductivity (feet per day)	Range in storage coefficient
Southeast Oklahoma	Trinity Group	21	400–2,600	—	—	—	1.3×10^{-4} to 1×10^{-3}
Northeast Texas	Trinity Group (undifferentiated)	19	150–2,400	840	0.7–9	4	1×10^{-4} to 2×10^{-4}
	Paluxy Formation	25	170–1,850	600	.8–20	8	2×10^{-5} to 3.4×10^{-4}
	Twin Mountains Formation	59	200–4,000	1,300	1.1–22	9	4×10^{-5} to 2×10^{-4}
East–Central Texas	Travis Peak Formation (all or part)	60	80–5,700	1,200	2-31	11	2.3×10^{-5} to 0.026
Hill Country	Glen Rose Limestone and/or Hensel Sand	4	80–950	400	—	—	2×10^{-5} to
	Sligo and/or Hosston Formations	7	120–3,200	1,950	—	—	7.4×10^{-4}

Table 8. Withdrawals from the Trinity aquifer during 1985 were widely scattered. Public supply was the principal use of the water in 8 of the 10 most intensively pumped counties. Withdrawals for irrigation were large in Comanche and Erath Counties

[Data from William Moltz, Texas Water Development Board, written commun., 1990]

County (all in Texas)	Major metropolitan area	Withdrawals from Trinity aquifer during 1985 (million gallons per day)	Principal use
Comanche	(Not applicable)	21.2	Irrigation
Cooke	ditto	5.7	Public
Dallas	Dallas	17.2	ditto
Denton	ditto	6.8	ditto
Ellis	ditto	5.2	ditto
Erath	(Not applicable)	10.7	Irrigation
Grayson	Sherman–Denison	9.7	Public
Johnson	Fort Worth–Arlington	6.6	ditto
McLennan	Waco	11.1	ditto
Tarrant	Fort Worth–Arlington	15.9	ditto
Total		110.1	

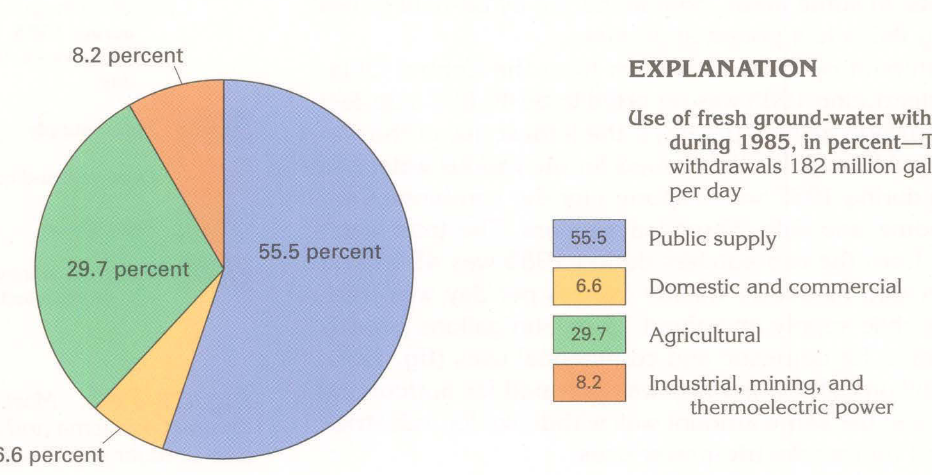


Figure 116. More than one-half of the freshwater withdrawn from the Trinity aquifer during 1985 was used for public supply; agricultural withdrawals were the second largest use of the water.

Data from N.L. Barber and D.L. Lurry, U.S. Geological Survey, written communication, 1989; U.S. Geological Survey, Tulsa Oklahoma, written communication, 1989; and William Moltz, Texas Water Development Board, written communication, 1989

Ground-Water Development

Since the beginning of development of the Trinity aquifer, water levels have declined hundreds of feet in the artesian zone in east-central and northeast Texas, including large areas of Dallas, Denton, Ellis, Grayson, Hill, Johnson, McLennan, and Tarrant Counties. Seven of these counties are among the 10 where withdrawals from the Trinity aquifer were greatest in 1985 (**table 8**). Withdrawals in this area of large water-level declines are mainly for public supply. The large declines have resulted from a combination of large withdrawals, low permeability and transmissivity of the aquifer, and distance from the aquifer outcrop or recharge area.

Water-level declines have been especially large in eastern Tarrant County where withdrawals by smaller cities in the Dallas–Fort Worth area caused declines of more than 550 feet between 1955 and 1976. Many ground-water users in the Dallas–Fort Worth area have converted to surface-water supplies. The area with the 550-foot water-level decline experienced a water-level rise of more than 100 feet between 1976 and 1989. However, this does not reflect a large regional recovery of ground-water levels, but rather a shifting pattern of ground-water use as water-level declines continue in other areas.

Another area of especially large water-level decline in the Trinity aquifer is in McLennan County where the city of Waco and its suburbs withdraw ground water for public supply. Water levels in the aquifer declined more than 300 feet between 1900 and 1967, and another 400 feet between 1967 and 1988.

Although Comanche and Erath Counties in east-central Texas withdraw considerable amounts of water from the Trinity aquifer principally for agricultural purposes (**table 8**), they are located mostly on the outcrop of the aquifer, where recharge from natural sources and irrigation return flow readily occurs. Thus, ground-water level declines in these areas are not great. Water from the Trinity aquifer is used in other areas, including southeastern Oklahoma and the Hill Country of south-central Texas, but not as intensively as in the areas described above.

Fresh Ground-Water Withdrawals

Withdrawals of freshwater from the Trinity aquifer totaled about 182 million gallons per day during 1985 (**fig. 116**). About 101 million gallons per day was withdrawn for public supply, the principal water use. About 54 million gallons per day was withdrawn for agricultural purposes, and about 15 million gallons per day was withdrawn for industrial, mining, and thermoelectric-power uses. Withdrawals for domestic and commercial uses were approximately 12 million gallons per day.

Potential for Development

The part of the Trinity aquifer in Oklahoma has considerable potential for future development. Potential recharge to the aquifer is far in excess of usage. Withdrawals from the aquifer in this area are small (less than 6 million gallons per day) because of an abundance of available surface water.

The Trinity aquifer has been intensively developed in northeast and east-central Texas. Ground water has been favored over surface-water sources to supply the needs of cities, towns, and industries because of the great expense of reservoir construction, transmission lines, and treatment facilities associated with the latter. However, annual withdrawals from the aquifer have far exceeded annual replenishment from recharge, resulting in continued declines of ground-water levels and depletion of ground water in storage.

Over the last several years, the trend has been away from ground-water use and toward surface-water use. An effective management scheme could utilize the ground- and surface-water resources so that the benefits derived from each are optimized. One method is to extend the usability of the aquifer by increasing the amount of recharge to it. This could be done by the use of runoff control structures in the outcrop area to retard runoff and allow more time for it to percolate downward to the water table. For the downdip or confined part of the aquifer, surface water, when available and of suitable chemical quality, could be used to recharge the aquifer through injection wells.

In the Hill Country, the largest yields from wells completed in the Trinity aquifer are in the outcrop areas of the lower part of the Glen Rose Limestone and the upper part of the Travis Peak Formation. Areas near creeks may have better development of the solution channels that are necessary for large yields. Careful planning is needed to construct a well properly for its intended purpose and yield, and wells need to be spaced properly to avoid ground-water depletion that results from overly concentrated pumpage.

Aquifers in Paleozoic rocks

INTRODUCTION

Five aquifers and one aquifer system in rocks of Paleozoic age—the Rush Springs, the Blaine, the Central Oklahoma, the Ada–Vamoosa, and the Arbuckle–Simpson aquifers and the Ozark Plateaus aquifer system—are in Oklahoma and part of northern Texas (**fig. 117**). The aquifers consist of sandstone, siltstone, shale, limestone, dolomite, and gypsum, either as a single rock type or in combination. The geologic formations in which the aquifers occur continue into the subsurface beyond the mapped aquifer boundaries, as shown in **figure 118**. Where the rocks that compose the aquifers have been tilted, permeability might be decreased or the dissolved-solids content of the water in the aquifers might become progressively greater in the deeper parts of the aquifers or both. Thus, the capacity of the rocks to yield substantial quantities of freshwater to wells commonly diminishes with depth, especially where confining units overlie the aquifers.

Precipitation is the source of nearly all water in the aquifers. Average annual precipitation ranges from about 20 inches in the western part of the area underlain by the Blaine aquifer to more than 40 inches in the area of the Ozark Plateaus aquifer system.

The greatest precipitation is generally in the spring months, but most recharge to the aquifers tends to be in the winter and early spring, when evaporation and transpiration are at a minimum. Little recharge takes place because neither the aquifers nor the overlying soils are highly permeable. An exception is in areas where sinkholes have been developed, such as in parts of the Ozark Plateaus aquifer system and the Blaine and the Arbuckle–Simpson aquifers.

Ground-water levels are highest in the uplands between the streams. From these areas, ground water moves toward stream valleys where it is discharged by evapotranspiration, by spring discharge, or to streams as base flow. Fresh to slightly saline water in the aquifers is mostly under unconfined conditions in aquifer outcrop areas, but downdip the water is generally under confined conditions (**fig. 118**).

Because the permeability of the rocks that compose the aquifers is generally low, well yields are generally small. The aquifers are nevertheless important; the aggregate pumpage from them during 1985 was 141 million gallons per day.

Figure 117. *Aquifers in Paleozoic (Permian to Cambrian) rocks compose five important aquifers and one aquifer system in Oklahoma and northern Texas.*

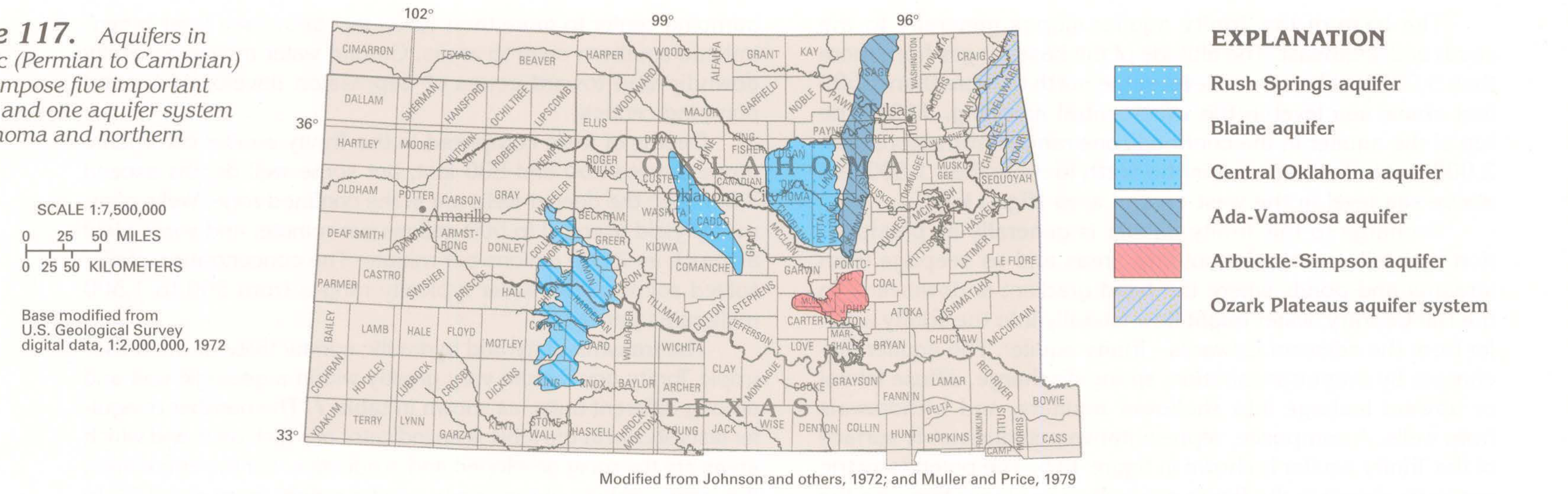
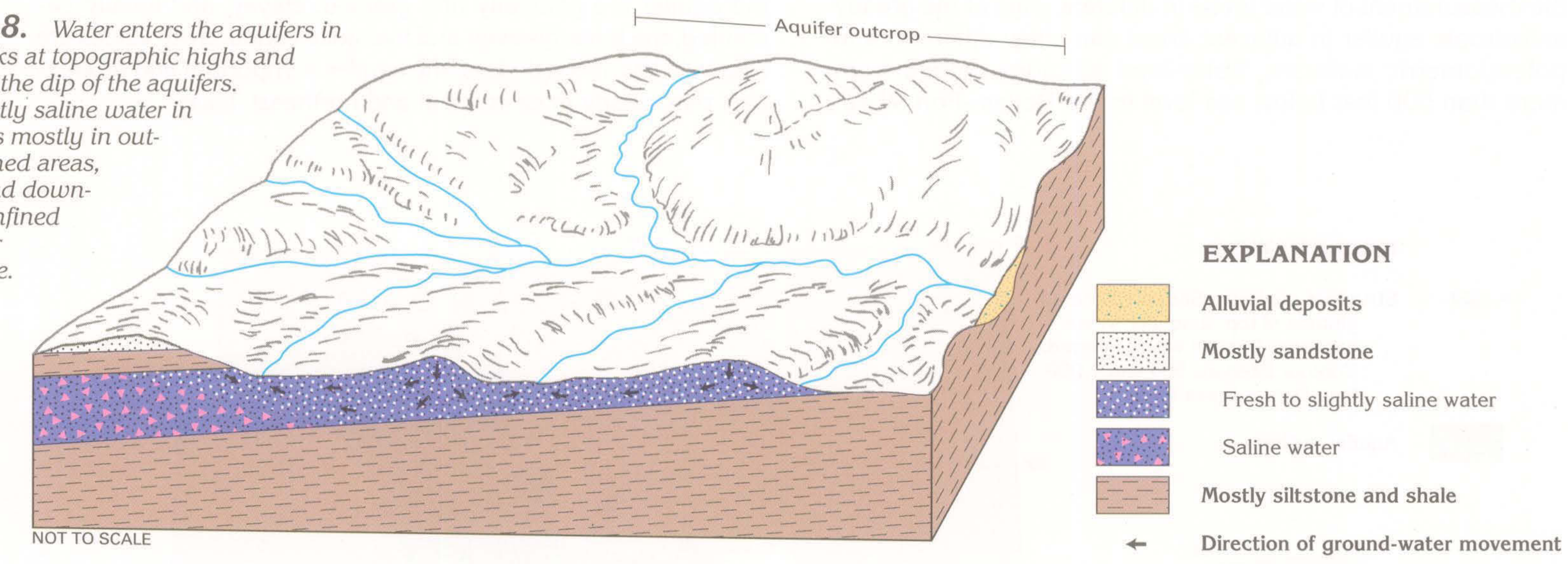


Figure 118. *Water enters the aquifers in Paleozoic rocks at topographic highs and moves down the dip of the aquifers. Fresh to slightly saline water in the aquifers is mostly in outcrop unconfined areas, but can extend downdip under confined conditions for some distance.*



RUSH SPRINGS AQUIFER

The Rush Springs aquifer underlies an area of about 1,400 square miles in west-central Oklahoma. The area is in the Central Lowland Physiographic Province and includes parts of Blaine, Caddo, Comanche, Custer, Dewey, Grady, and Washita Counties. Average annual precipitation is about 26 to 30 inches. Agriculture is an important part of the economy of the area, and ground water for crop irrigation is an important resource.

Hydrogeology

The Rush Springs aquifer consists of the Rush Springs Sandstone and the Marlow Formation, which are part of the Whitehorse Group of Permian age (**fig. 119**). The Rush Springs Sandstone, which is the main water-yielding unit, consists of fine-grained sandstone with some dolomite, shale, and gypsum beds. The formation has a maximum thickness of more than 300 feet in the south in Caddo County. In the western one-half of the area, the underlying Marlow Formation has a maximum thickness of about 125 feet and yields moderate amounts of water whose chemical quality is usable for most purposes.

Era	System	Stratigraphic unit		Lithology	Hydrogeologic unit
Paleozoic	Permian	Whitehorse Group	Rush Springs Sandstone	Fine-grained, cross-bedded to even-bedded sandstone. Some dolomite, shale, and gypsum beds	Rush Springs aquifer
			Marlow Formation	Fine-grained sandstone and siltstone. Some shale, gypsum, and dolomite beds	

Modified from Tanaka and Davis, 1963

Figure 119. *The Permian Rush Springs Sandstone is the main geologic unit that composes the Rush Springs aquifer in west-central Oklahoma.*

Water in the Rush Springs aquifer is unconfined, except in deeper parts of the aquifer, where it is partly confined. The depth of the water table ranges from land surface to about 150 feet below land surface and is generally least in low-lying areas. Regional movement of ground water is generally southward and southeastward toward the Washita River. Well yields are commonly 200 to 600 gallons per minute, but yields of as much as 1,000 gallons per minute have been reported for some irrigation wells.

The aquifer generally yields water with a dissolved-solids concentration of less than 500 milligrams per liter in central Caddo, eastern Custer, and western Blaine Counties. In this area, sulfate and chloride concentrations are small, and the water is a calcium bicarbonate type. To the west and east, the water type changes to a calcium magnesium sulfate type, and the dissolved-solids concentrations generally exceed 1,000 milligrams per liter.

Ground-Water Development

The Rush Springs aquifer is the principal aquifer in the area and is an important source for irrigation and public supplies. The aquifer is used extensively for irrigation, and water levels have been lowered as much as 50 feet in some areas because of irrigation pumpage. Withdrawals of water from the Rush Springs aquifer totaled about 52 million gallons per day during 1985 (**fig. 120**). Almost 43 million gallons per day was withdrawn for agricultural purposes. About 6 million gallons per day was withdrawn for public supply and about 2 million gallons per day was pumped for domestic and commercial uses. Less than 1 million gallons per day was withdrawn for industrial, mining, and thermoelectric-power uses.

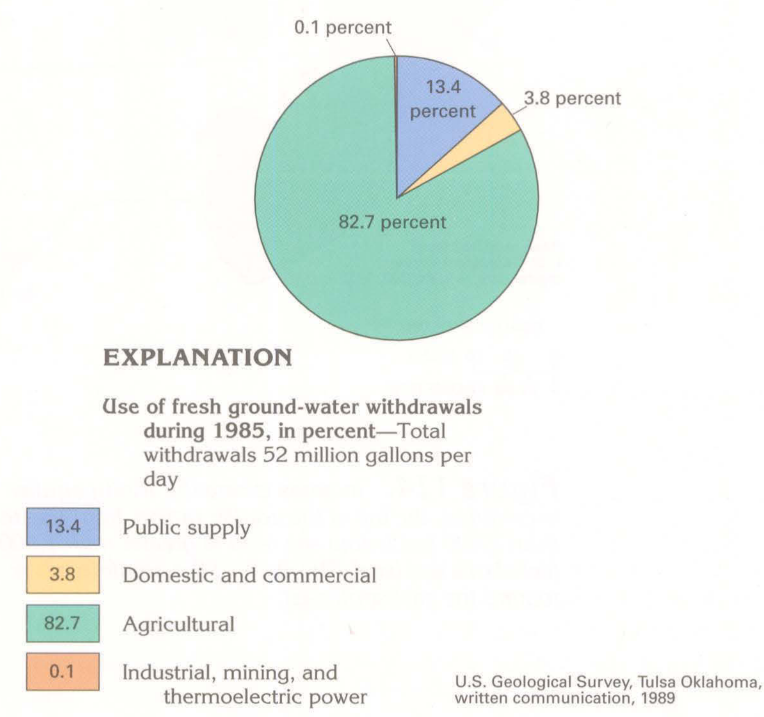


Figure 120. *Most of the freshwater withdrawn from the Rush Springs aquifer during 1985 was used for agricultural purposes.*

BLAINE AQUIFER

The Blaine aquifer underlies an area of about 3,500 square miles in southwestern Oklahoma and northern Texas (**fig. 117**). The area is in the upper part of the Red River Basin in the Central Lowland Physiographic Province. It includes parts of Childress, Collingsworth, Cottle, Foard, Hardeman, King, Knox, and Wheeler Counties in Texas and parts of Beckham, Greer, Harmon, and Jackson Counties in Oklahoma. Average annual precipitation is about 20 to 24 inches. The Blaine aquifer is a major source of water for crop irrigation.

Hydrogeology

The Blaine aquifer, also cited in the literature as the "Blaine Gypsum aquifer" and the "Dog Creek–Blaine aquifer," consists of the Dog Creek Shale and the Blaine Gypsum or Formation, which are part of the Permian Pease River Group in Texas and the El Reno Group in Oklahoma (**fig. 121**). The formations consist of anhydrite and gypsum, shale, and dolomite. The anhydrite and gypsum are commonly cavernous. The caverns, cavities, and sinkhole development are the result of partial dissolution of the water-soluble rocks by circulating ground water.

Era	System	Stratigraphic unit		Lithology	Hydrogeologic unit
Paleozoic	Permian	Pease River Group (Texas)	Dog Creek Shale	Shale, anhydrite and gypsum, and dolomite. Anhydrite and gypsum commonly cavernous	Blaine aquifer
		El Reno Group (Oklahoma)	Blaine Gypsum or Formation	Anhydrite and gypsum, shale, and dolomite. Anhydrite and gypsum commonly cavernous	

Modified from Baker and others, 1963

Figure 121. *The Permian Dog Creek Shale and Blaine Gypsum or Formation are the geologic units that compose the Blaine aquifer in southwestern Oklahoma and northern Texas.*

The Blaine aquifer has a maximum thickness of about 400 feet. Water in the aquifer is mainly in porous dolomite and in solution openings in gypsum beds, and is generally under unconfined conditions. In places, the Dog Creek Shale is poorly permeable and confines water in the underlying Blaine Gypsum or Formation. Other Permian shales confine the aquifer from below. Wells completed in the Blaine aquifer commonly yield from 100 to 500 gallons per minute, but yields are as much as 1,500 gallons per minute in Texas and 2,500 gallons per minute in Oklahoma.

Water from the Blaine aquifer is a calcium-magnesium-sulfate type and is generally not suitable for public supply or for many industrial uses because of its mineral content. Concentrations of dissolved solids are generally between 2,000 and 6,000 milligrams per liter, and the sulfate concentration ranges from about 1,000 to 2,000 milligrams per liter. The chloride content also can be large (a concentration of more than 1,000 milligrams per liter has been reported). Pumpage from the Blaine aquifer is almost exclusively for irrigation and livestock watering purposes.

Ground-Water Development

The Blaine aquifer is locally very permeable; in other areas, well yields might be small and insufficient for irrigation. This wide range in permeability is characteristic of aquifers that contain solution openings. Problems associated with development of the Blaine aquifer, aside from the marginal quality of the water as described above, include the possibility of inducing deeper-lying, moderately saline water into the pumped zone.

Withdrawals of water from the Blaine aquifer totaled about 24 million gallons per day during 1985 (**fig. 122**); about 17 million gallons per day were withdrawn in Oklahoma and about 7 million gallons per day in Texas. About 99 percent of the total was withdrawn for agricultural purposes, and the remaining 1 percent was withdrawn for public supply.

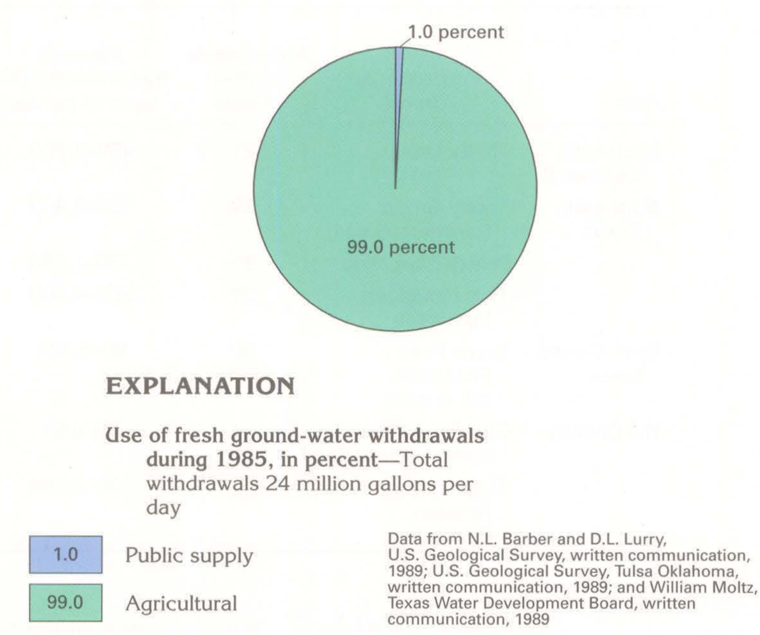


Figure 122. *Practically all the freshwater withdrawn from the Blaine aquifer during 1985 was used for agricultural purposes.*

CENTRAL OKLAHOMA AQUIFER

The Central Oklahoma aquifer underlies an area of about 2,900 square miles in central Oklahoma (**fig. 117**). The aquifer is in the Central Lowland Physiographic Province and underlies all or parts of Canadian, Cleveland, Kingfisher, Lincoln, Logan, Oklahoma, Payne, and Pottawatomie Counties. It is an important public supply for several suburban communities in the Oklahoma City area and is a source for numerous domestic water supplies.

Hydrogeology

The Central Oklahoma aquifer, also known locally as the "Garber–Wellington aquifer," consists mainly of the Garber Sandstone and the Wellington Formation which are part of the Sumner Group of Permian age (**fig. 123**). Also included in the aquifer are the older Chase, the Council Grove, and the Admire Groups of Permian age. The aquifer consists of massive to cross-bedded, fine-grained sandstone that is interbedded with shale and siltstone.

The Central Oklahoma aquifer has a maximum thickness of about 1,000 feet and a saturated thickness that ranges from 150 to 650 feet. In places, the aquifer is overlain by the alluvial aquifers along the North Canadian and the Canadian Rivers, and water is available from both aquifers. Water in the Central Oklahoma aquifer is generally unconfined in about the upper 200 feet of the aquifer and partly confined or confined at greater depths.

Era	System	Stratigraphic unit		Lithology	Hydrogeologic unit
Paleozoic	Permian	Sumner Group	Garber Sandstone	Massive and cross-bedded fine-grained sandstone interbedded with shale and siltstone	Central Oklahoma aquifer
			Wellington Formation	Massive and cross-bedded fine-grained sandstone irregularly interbedded with red, purple, maroon, and gray shale	
		Chase, Council Grove, and Admire Groups	Undivided	Fine-grained, cross-bedded sandstone, shale, and thin limestone	

Modified from Wood and Burton, 1968; and Christenson and Parkhurst, 1987

Figure 123. *The Permian Garber Sandstone and Wellington Formation are the main geologic units that compose the Central Oklahoma aquifer. In places, Permian rocks of the Chase, the Council Grove, and the Admire Groups are part of the aquifer.*

Generally, the Central Oklahoma aquifer yields a calcium-magnesium carbonate-bicarbonate type water that contains less than 500 milligrams per liter of dissolved solids. Water in the aquifer becomes more mineralized with depth. The depth to the base of freshwater in most of the area is between 500 and 1,000 feet. Wells completed in the aquifer commonly yield 100 to 300 gallons per minute and locally yield more than 500 gallons per minute.

Ground-Water Development

The Central Oklahoma aquifer is an important source for domestic and public supplies. With the exception of Oklahoma City, all the major communities in central Oklahoma rely either solely on ground water or on a combination of ground- and surface-water supplies. The quantity of ground water withdrawn from the Central Oklahoma aquifer approximately doubled between 1970 and 1985.

The potentiometric surface of the aquifer has been lowered from 100 to 200 feet in areas of locally intense pumpage. In such areas, underlying saline water might move upward and result in deterioration of the chemical quality of the freshwater in the aquifer. Other problems include the possibility of contamination of the ground water by potentially toxic substances, including trace elements, organic compounds, and radioactive constituents. In some areas, contamination by oil-field brines and drilling fluids is a potential problem.

The amount of water withdrawn from the Central Oklahoma aquifer during 1985 was reported to be 40,000 acre-feet (about 36 million gallons per day); the largest use of the water was for public supply. Withdrawals for the various water-use categories during 1985 were reported for the combined Central Oklahoma and Ada–Vamoosa aquifers. The total water withdrawn from the two aquifers during 1985 was 48 million gallons per day. About 31 million gallons per day was withdrawn for public supply and about 13 million gallons per day was withdrawn for domestic and commercial uses (**fig. 124**). About 2 million gallons per day was pumped for agricultural purposes, and the same amount was withdrawn for industrial, mining, and thermoelectric-power uses.

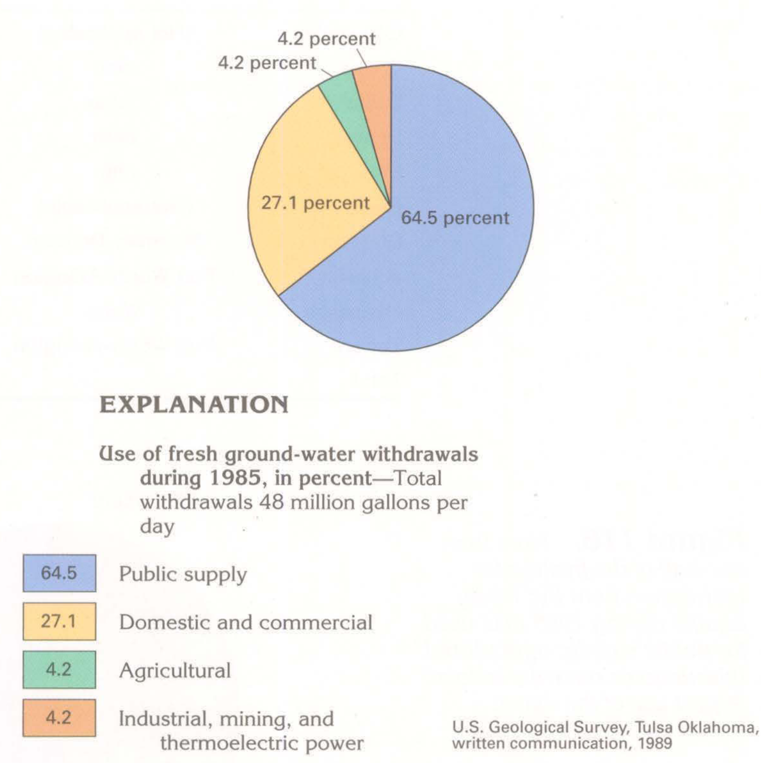


Figure 124. *Most of the freshwater withdrawn from the Central Oklahoma and Ada–Vamoosa aquifers during 1985 was used for public supply.*

ADA–VAMOOSA AQUIFER

The Ada–Vamoosa aquifer underlies an area of about 2,300 square miles in east-central Oklahoma (**fig. 117**). The aquifer is in the Central Lowland Physiographic Province and underlies parts of Creek, Lincoln, Okfuskee, Osage, Pawnee, Payne, Pontotoc, Pottawatomie, and Seminole Counties. The aquifer extends in a band about 10 to 20 miles wide from northern Pontotoc County northward into Kansas. Several towns in the area rely entirely or in part on ground water for municipal supply.

Hydrogeology

The Ada–Vamoosa aquifer, also cited in the literature as the "Vamoosa–Ada aquifer," consists mainly of layers of fine- to coarse-grained sandstone irregularly interbedded with shale and limestone. The rocks are in the Ada and the Vamoosa Groups of Pennsylvanian age (**fig. 125**). The maximum thickness of the aquifer is about 900 feet. Aggregate thickness of the more permeable water-yielding sandstones in the aquifer is greatest south of the Cimarron River, where the maximum thickness is 550 feet. North of the river, the average aggregate thickness of sandstones is about 100 feet. The aquifer is unconfined in the east where it is near land surface; in downdip areas to the west, it is confined.

The regional dip of the Ada–Vamoosa aquifer is toward the west at about 30 to 90 feet per mile. The regional easterly slope of the water table is similar to that of the land surface. The approximate maximum thickness of the zone that contains water with a dissolved-solids concentration of less than 1,500 milligrams per liter decreases from 900 feet in the southern part of the area to 400 feet in the northern part. The total amount of water with dissolved solids of less than 1,500 milligrams per liter that is stored in the sandstone layers is estimated to be 60 million acre-feet. The amount of water that is theoretically available from storage is estimated to be 36 million acre-feet.

Generally, the water in the Ada–Vamoosa aquifer is a sodium-potassium chloride-sulfate type with a concentration of dissolved solids of less than 500 milligrams per liter. Yields of wells completed in the aquifer are commonly 25 to 150 gallons per minute, and are as much as 300 gallons per minute.

Ground-Water Development

The Ada–Vamoosa aquifer is an important source of water for several towns in the area, as well as for some industries. Excessive pumpage may cause upward movement of saline water from the deeper, confined part of the aquifer. Brines and wastes from past oil-field operations might have caused some local contamination of the freshwater in the aquifer.

During 1980, withdrawals from the Ada–Vamoosa aquifer totaled 10 million gallons per day and were mostly for public and industrial supplies. During 1985, the withdrawals were reported for the combined Ada–Vamoosa and Central Oklahoma aquifers (see **figure 124** and discussion in preceding section). Withdrawals from the Ada–Vamoosa aquifer were about 12 million gallons per day during 1985.

Figure 125. *The Pennsylvanian Ada and Vamoosa Groups are the geologic units that compose the Ada–Vamoosa aquifer in north-central Oklahoma.*

Era	System	Stratigraphic unit		Lithology	Hydrogeologic unit
Paleozoic	Pennsylvanian	Ada Group	Various formations from Auburn Shale at top to Lecompton Limestone at base	Mainly orange-brown fine-grained sandstone and shale. Grades northward into shale with numerous limestone layers	Ada–Vamoosa aquifer
		Vamoosa Group	Composed of many formations in north. Called Vamoosa Formation in south	Alternating layers of fine- to coarse-grained sandstone and sandy, silty shale that contains some chert conglomerate. Some thin limestone in north	

Modified from Bingham and Moore, 1975; and Bingham and Bergman, 1980

ARBUCKLE–SIMPSON AQUIFER

The Arbuckle–Simpson aquifer is in an area of about 800 square miles in the Arbuckle Mountains and the Arbuckle Plains of south-central Oklahoma (**fig. 117**). The area is in the Central Lowland Physiographic Province and includes parts of Carter, Coal, Johnston, Murray, and Pontotoc Counties. Average annual precipitation is about 34 to 39 inches. The aquifer supplies small, but important, quantities of water, mainly for public supply.

Hydrogeology

The Arbuckle–Simpson aquifer consists of limestone, dolomite, and sandstone within the Simpson and the Arbuckle Groups of Ordovician and Cambrian age (**fig. 126**). The aquifer is as much as 9,000 feet thick. Its high permeability is the result of the enlargement of fractures, joints, and solution channels by partial dissolution of the rocks. The average transmissivity of the aquifer is estimated to be 15,000 feet squared per day and the average storage coefficient where the aquifer is confined is estimated to be 8×10^{-3}; in unconfined areas, the aquifer has an estimated specific yield of 20 percent. Freshwater may extend to depths of greater than 3,000 feet. Wells completed in the Arbuckle–Simpson aquifer commonly yield from 100 to 500 gallons per minute and locally yield as much as 2,500 gallons per minute. Springs that issue from the aquifer discharge from 50 to 18,000 gallons per minute. The water is a calcium bicarbonate type and commonly is hard but has a dissolved-solids concentration of generally less than 500 milligrams per liter.

In much of the area, the erosional remnants of the Arbuckle Mountains form a rugged surface with as much as 600 feet of relief. Recharge to the aquifer occurs from precipitation that falls on the higher elevations of the aquifer outcrop areas and is estimated to be 4.7 inches per year. Intense faulting of the rocks affects the ground-water flow system because faults might act as barriers to ground-water movement or as conduits through which water travels to the surface. Water is discharged naturally from the aquifer by numerous springs and seeps; much of this discharge becomes the base flow of streams. The base flow of streams that drain the aquifer is estimated to be about 60 percent of the total annual runoff from the Arbuckle–Simpson outcrop area.

Ground-Water Development

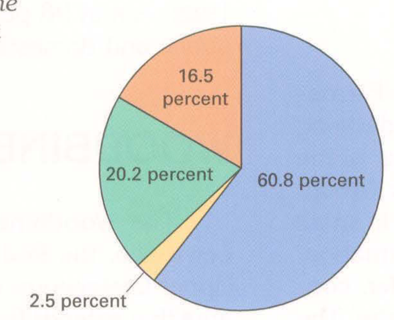
The largely undeveloped Arbuckle–Simpson aquifer is estimated to have 9 million acre-feet of freshwater in storage. The water is usually a calcium-magnesium bicarbonate type that is suitable for most uses. An estimated 8 million gallons per day of freshwater was withdrawn from the Arbuckle–Simpson aquifer during 1985 (**fig. 127**). About 5 million gallons per day was withdrawn for public supply, and about 2 million gallons per day was withdrawn for agricultural purposes. About 1 million gallons per day was pumped for industrial, mining, and thermoelectric-power uses, and about 200,000 gallons per day was withdrawn for domestic and commercial uses.

Figure 126. *The Ordovician Simpson Group and the Ordovician and Cambrian Arbuckle Group compose the Arbuckle–Simpson aquifer in south-central Oklahoma.*

Era	System	Stratigraphic unit		Lithology	Hydrogeologic unit
Paleozoic	Ordovician	Simpson Group	Bromide Formation Tulip Formation McLish Formation	Limestone, shale, and sandstone	Arbuckle–Simpson aquifer
			Oil Creek Formation Joins Formation	Limestone, granular, with shale and fine- to medium-grained sandstone	
		Arbuckle Group	West Spring Creek Formation Kindblade Formation	Limestone, grading eastward into dolomite. Some sandstone and shale	
			Cool Creek Formation McKenzie Hill Formation	Limestone, cherty, grading eastward into dolomites and sandstones	
	Cambrian		Butterly Dolomite Signal Mountain Limestone Royer Dolomite Fort Sill Limestone	Fine-grained limestone, grading eastward into fine- to coarse-grained dolomites	

Modified from Hart, 1974

Figure 127. *Most of the freshwater withdrawn from the Arbuckle–Simpson aquifer during 1985 was used for public supply.*



U.S. Geological Survey, Tulsa Oklahoma, written communication, 1989

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total withdrawals 8 million gallons per day

- 60.8 Public supply
- 2.5 Domestic and commercial
- 20.2 Agricultural
- 16.5 Industrial, mining, and thermoelectric power

OZARK PLATEAUS AQUIFER SYSTEM

The Ozark Plateaus aquifer system underlies large areas of southern Missouri and northern Arkansas, and small areas of northeastern Oklahoma and southeastern Kansas. The aquifer system is discussed in detail in Chapters D and F of this Atlas. A brief description and discussion of the Oklahoma part of the aquifer system is presented here.

The Ozark Plateaus aquifer system consists mainly of Paleozoic carbonate rocks and underlies an area of about 2,400 square miles in northeastern Oklahoma (**fig. 117**). The area lies mostly in the Ozark Plateaus Physiographic Province, and includes all or parts of Adair, Cherokee, Craig, Delaware, Mayes, and Ottawa Counties. The northwestern corner of the area lies in the Central Lowland Physiographic Province, where the topography is mostly flat. The remainder of the area is relatively hilly and has springs, sinkholes, and caverns that are characteristic of karst topography. Average annual precipitation is about 40 to 44 inches. The aquifer system provides modest amounts of water whose chemical quality is suitable for most uses, including public supply.

Hydrogeology

The Ozark Plateaus aquifer system consists mostly of carbonate rocks that are Cambrian through Mississippian in age (**fig. 128**). The sedimentary rocks are on the western flank of the Ozark Uplift, which is a dissected dome centered in Missouri. The regional dip of the rocks is westward and southwestward. The aquifer system consists of two aquifers and an intervening confining unit.

The uppermost aquifer is the Springfield Plateau aquifer, which is exposed at the surface in Oklahoma and consists of the Keokuk Limestone and the Reeds Spring and the St. Joe Limestone members of the Boone Formation. The rocks are mainly chert and limestone with solution-enlarged openings and local cavernous zones. The Springfield Plateau aquifer has a maximum thickness of about 500 feet in Oklahoma and contains water under unconfined to confined conditions. Yields of wells completed in the aquifer range from a few gallons per minute to more than 80 gallons per minute, whereas springs that issue from the aquifer might discharge as much as 3,500 gallons per minute. Water in the aquifer is a calcium-magnesium bicarbonate type, is typically hard, and generally has a dissolved-solids concentration of less than 500 milligrams per liter. The Springfield Plateau aquifer has been referred to locally as the "Keokuk–Reeds Spring (Boone) aquifer."

A confining unit that consists of rocks of Ordovician, Devonian, and Mississippian age and is called the Ozark confining unit separates the Springfield Plateau aquifer from the Ozark aquifer (**fig. 128**). The Ozark aquifer, which is known locally as the Roubidoux aquifer, consists of dolomites and sandstones within the Roubidoux, the Gasconade, the Eminence, and the Potosi Formations of Ordovician and Cambrian age. The Ozark aquifer is not exposed at the surface in Oklahoma. The thickness of the Ozark aquifer ranges from 200 to 500 feet. Much of the water in the aquifer is in fractured dolomite and sandy zones where it is under confined conditions. Wells completed in the Ozark aquifer commonly yield from 50 to 250 gallons per minute and locally yield as much as 1,000 gallons per minute. Recharge to the aquifer is derived from precipitation that falls on aquifer outcrop areas in Missouri, about 50 to 100 miles east of the Oklahoma State line. The calcium-magnesium bicarbonate water in the Ozark aquifer is suitable for most uses; concentrations of dissolved solids in the water commonly range from 150 to 1,500 milligrams per liter. The Ozark aquifer is the principal public water supply for Ottawa County and nearby areas.

Ground-Water Development

The chemical quality of water from the Ozark Plateaus aquifer system is suitable for most purposes, although the water may be moderately hard to very hard. Water in the Springfield Plateau aquifer, which is directly connected to the surface in places by sinkholes and caverns, is susceptible to contamination from surface sources. Withdrawals of water from the Ozark Plateaus aquifer system in Oklahoma totaled about 9 million gallons per day during 1985 (**fig. 129**). About 6 million gallons per day was withdrawn for public supply and about 2 million gallons per day was withdrawn for domestic and commercial uses. About 1 million gallons per day was pumped for industrial, mining, and thermoelectric-power uses, and about 100,000 gallons per day was withdrawn for agricultural purposes.

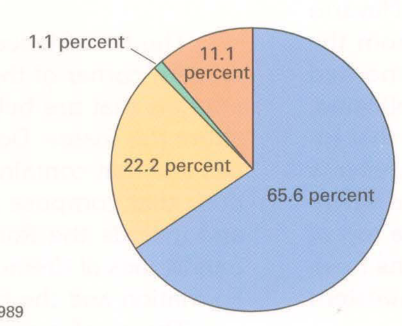
Figure 128. *The Ozark Plateaus aquifer system consists mainly of Cambrian, Ordovician, and Mississippian carbonate rocks. The aquifer system consists of the Springfield Plateau and the Ozark aquifers, which are separated by the Ozark confining unit.*

Era	System	Stratigraphic unit		Lithology	Hydrogeologic unit	
Paleozoic	Mississippian	Keokuk Limestone		Chert and limestone	Ozark Plateaus aquifer system	Springfield Plateau aquifer
		Boone Formation	Reeds Spring Member	Chert and limestone		
			St. Joe Limestone Member	Limestone and shale		
	Mississippian and Devonian	Chattanooga Shale		Shale and minor sandstone		Ozark confining unit
	Ordovician	Fernvale Limestone		Limestone		
		Fite Limestone		Limestone		
		Tyner Formation		Shale and dolomite		
		Burgen Sandstone		Sandstone, minor dolomite and shale		
		Cotter Dolomite[1]		Dolomite, minor sandstone		
		Jefferson City[1] Formation		Cherty dolomite		
		Roubidoux Formation[1]		Dolomite with minor sandstone		Ozark aquifer
		Gasconade Dolomite[1]		Cherty dolomite, sandstone		
	Cambrian	Eminice and Potosi Dolomites[1]		Cherty dolomite		

[1]Not exposed at land surface in Oklahoma

Modified from Reed and others, 1955; Marcher and Bingham, 1971; and Johnson, 1983

Figure 129. *Most of the freshwater withdrawn from the Ozark Plateaus aquifer system in Oklahoma during 1985 was used for public supply.*



U.S. Geological Survey, Tulsa Oklahoma, written communication, 1989

EXPLANATION

Use of fresh ground-water withdrawals during 1985, in percent—Total withdrawals 9 million gallons per day

- 65.6 Public supply
- 22.2 Domestic and commercial
- 1.1 Agricultural
- 11.1 Industrial, mining, and thermoelectric power

Minor aquifers in Texas

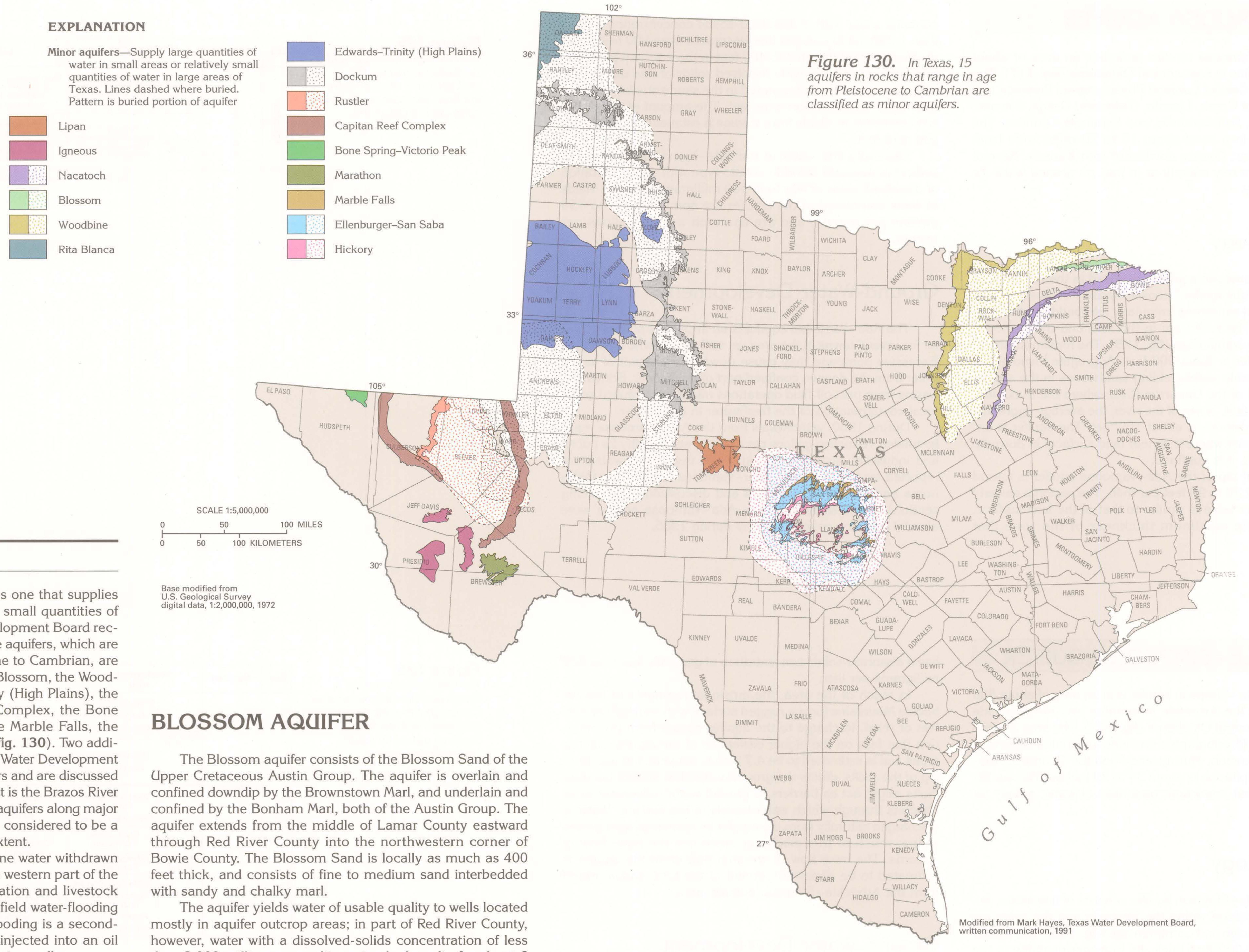


Figure 130. *In Texas, 15 aquifers in rocks that range in age from Pleistocene to Cambrian are classified as minor aquifers.*

INTRODUCTION

In Texas, a minor aquifer is defined as one that supplies large quantities of water in small areas or small quantities of water in large areas. The Texas Water Development Board recognizes and names 15 such aquifers. These aquifers, which are in rocks that range in age from Pleistocene to Cambrian, are the Lipan, the Igneous, the Nacatoch, the Blossom, the Woodbine, the Rita Blanca, the Edwards–Trinity (High Plains), the Dockum, the Rustler, the Capitan Reef Complex, the Bone Spring–Victorio Peak, the Marathon, the Marble Falls, the Ellenburger–San Saba, and the Hickory (**fig. 130**). Two additional minor aquifers mapped by the Texas Water Development Board are considered to be principal aquifers and are discussed in previous sections of this chapter. The first is the Brazos River alluvial aquifer, which is part of the alluvial aquifers along major streams. The second is the Blaine aquifer, considered to be a major aquifer because of its large areal extent.

Some freshwater and moderately saline water withdrawn from the minor aquifers, particularly in the western part of the State, is used almost exclusively for irrigation and livestock watering purposes and some is used in oilfield water-flooding operations and mining activities. Water flooding is a secondary recovery operation in which water is injected into an oil reservoir to force additional oil into producing wells.

LIPAN AQUIFER

The Lipan aquifer consists mostly of the Leona Formation of Pleistocene age, but locally includes the underlying Choza Formation and the Bullwagon Dolomite Member of the Vale Formation, which are in the Permian Clear Fork Group. The aquifer is mostly in Tom Green County, but also is in small parts of Runnels and Concho Counties. The Leona Formation, which is the most productive part of the Lipan aquifer, consists of gravel, conglomerate, sand, silty clay, and caliche. The thickness of the aquifer ranges from a few feet to about 125 feet. Well yields are highly variable, and range from about 100 to 7,000 gallons per minute. Water from the Lipan aquifer generally has a dissolved-solids concentration of between 1,000 and 3,000 milligrams per liter.

Most recharge to the aquifer is from local precipitation and return flow from applied irrigation water. Ground water is discharged by seepage to the Concho River and its major tributaries and by springflow, evapotranspiration, and withdrawals from wells. During 1985, reported withdrawal from the aquifer in Tom Green County was about 15 million gallons per day, about 95 percent of which was used for irrigation.

IGNEOUS AQUIFER

Water-yielding intrusive and extrusive igneous rocks of Tertiary age are in Brewster, Jeff Davis, and Presidio Counties. Ground water is in the fissures and fractures of lava flows, tuffs, and related igneous rocks, including the Petan Basalt, the Tascotal Formation, the Barrel Springs Formation, the Cottonwood Spring Basalt, the Sheep Canyon Basalt, and the Crossen Trachyte. The igneous rocks supply small to large volumes of water of chemical quality that is suitable for public supplies, irrigation, and other uses. About 4 million gallons per day was withdrawn from the igneous rocks during 1985; of that, about 60 percent was used for public and domestic supplies.

NACATOCH AQUIFER

The Nacatoch aquifer consists of the Nacatoch Sand that lies beneath the Corsicana Marl and above the Neylandville Marl; the three formations are in the Upper Cretaceous Navarro Group. The southeastward-dipping aquifer extends from the Limestone–Navarro County line northeastward to the Red River. The aquifer consists of unconsolidated to consolidated, massive, glauconitic, calcareous sand and mudstone that locally are as much as 500 feet thick. The Nacatoch aquifer is generally unconfined in the outcrop area and confined where it dips beneath younger formations. The depth to the top of the aquifer in downdip areas where the aquifer contains fresh to slightly saline water is as much as 800 feet in southwestern Bowie County.

Wells completed in the Nacatoch aquifer yield as much as 500 gallons per minute; flowing wells are in Bowie and Red River Counties. Generally, water in the aquifer has dissolved-solids concentrations that range from 400 to 1,000 milligrams per liter. Pumpage in excess of annual effective recharge has caused water levels to decline since the beginning of development. About 4.5 million gallons per day was withdrawn from the Nacatoch aquifer during 1985, about 59 percent of which was used for public and domestic supplies.

BLOSSOM AQUIFER

The Blossom aquifer consists of the Blossom Sand of the Upper Cretaceous Austin Group. The aquifer is overlain and confined downdip by the Brownstown Marl, and underlain and confined by the Bonham Marl, both of the Austin Group. The aquifer extends from the middle of Lamar County eastward through Red River County into the northwestern corner of Bowie County. The Blossom Sand is locally as much as 400 feet thick, and consists of fine to medium sand interbedded with sandy and chalky marl.

The aquifer yields water of usable quality to wells located mostly in aquifer outcrop areas; in part of Red River County, however, water with a dissolved-solids concentration of less than 3,000 milligrams per liter extends downdip for about 6 miles south of the outcrop. Slightly more than 1 million gallons per day was withdrawn from the Blossom aquifer during 1985. About 98 percent of the water withdrawn was used for public and domestic supplies.

WOODBINE AQUIFER

The Woodbine aquifer consists of the Templeton, the Lewisville, the Red Branch, and the Dexter Members of the Upper Cretaceous Woodbine Formation, and is present in an area that extends from northern McLennan County in the south to the Red River in the north. The aquifer consists of fine to coarse ferruginous sand and sandstone, clay, shale, and sandy shale and some lignite and gypsum. The aquifer is hydraulically connected to overlying alluvium along the Red River. The thickness of the aquifer ranges from a few feet in outcrop areas to about 700 feet near the downdip limit of slightly saline water in Fannin County. Maximum depth to the top of the aquifer is about 2,000 feet below land surface. In downdip areas, the Woodbine aquifer is confined above by shales of the Upper Cretaceous Eagle Ford Group and below by the Buda Formation or the Grayson Marl and the Mainstreet Limestone, all of Cretaceous age.

Recharge to the aquifer is by precipitation that falls on aquifer outcrop areas and by seepage from lakes and streams where there is a downward gradient to the aquifer. Water moves through the aquifer from the outcrop in an east-southeast direction and generally follows the dip of the beds. Water from the aquifer in the outcrop area has an average dissolved-solids concentration of about 550 milligrams per liter; the concentration increases downdip to more than 3,000 milligrams per liter. Locally, the water has objectionable concentrations of iron, sodium, and chloride.

Wells completed in the Woodbine aquifer yield from about 100 to about 700 gallons per minute. A large cone of depression on the potentiometric surface of the aquifer is located near the middle of Grayson County and is the result of withdrawals for public supply. About 16 million gallons per day was withdrawn from the Woodbine aquifer during 1985. The principal use of the water was for public and domestic supply (49 percent), followed by withdrawal for agricultural (primarily irrigation) use (39 percent).

RITA BLANCA AQUIFER

The Rita Blanca aquifer, which is in the extreme northwestern corner of the Panhandle, consists of all geologic formations that are below the Miocene Ogallala Formation and above the Triassic Dockum Group in Dallam and Hartley Counties and that contain fresh to slightly saline water. The formations that compose the aquifer are mostly in the subsurface and include the Romeroville, the Mesa Rica, and the Lytle Sandstones of Cretaceous age, and equivalents of the Morrison Formation and the Exeter Sandstone of Jurassic age.

The aquifer consists mostly of fine- to medium-grained sandstone, with some shale, clay, conglomerate, and limestone. The thickness of the Rita Blanca aquifer is locally as much as 250 feet. In places, the aquifer is hydraulically connected to the overlying High Plains aquifer and the underlying Dockum aquifer, and the total thickness of water-yielding rocks in such places is accordingly much greater. Well yields as large as 500 gallons per minute are possible. About 4.5 million gallons per day was withdrawn from the aquifer during 1985, 98 percent of which was used for irrigation.

EDWARDS–TRINITY (HIGH PLAINS) AQUIFER

The Edwards–Trinity (High Plains) aquifer consists of sand and sandstone of the Trinity Stage and the younger limestone of the Fredericksburg and the Washita Stages, all of Cretaceous age. Despite its name, the aquifer is not part of either the Edwards–Trinity or the High Plains aquifers discussed previously in this chapter as principal aquifers. The aquifer underlies parts or all of 14 counties in the central part of the Southern High Plains. The aquifer is hydraulically connected to the overlying High Plains aquifer in many places. The average saturated thickness of rocks of the Trinity Stage is estimated to be 30 feet, and those of the Fredericksburg and the Washita Stages are estimated to be 20 feet. In most places, the sand and sandstone of the Trinity Stage are separated from the younger limestone strata by clay, marl, and shale beds. Water in the Trinity rocks is confined, as opposed to water-table conditions in the carbonate rocks. Regional ground-water movement is generally to the east-southeast and follows the dip of the rocks.

Yields of wells completed in the aquifer range from 50 to more than 1,000 gallons per minute; the largest yields are reported from wells in Hale and Lubbock Counties. Yields are largest where the water is in solution cavities, fractures, joints, and bedding planes in the carbonate rocks.

Water from the Edwards–Trinity (High Plains) aquifer usually is slightly to moderately saline and moderately to extremely hard, but the chemical quality is suitable for irrigation and secondary oil recovery. Withdrawal from the aquifer during 1985 was about 11.4 million gallons per day. About 89 percent of the water withdrawn was used for irrigation.

DOCKUM AQUIFER

The Dockum aquifer comprises all water-yielding units within the Dockum Group of Triassic age. The aquifer is in a large area that extends from the northwestern corner of the Panhandle southward to the northern part of the Edwards Plateau, and then westward into the Trans-Pecos area. In places, the Dockum aquifer is hydraulically connected to overlying aquifers, including the High Plains, the Pecos River alluvium, the Edwards–Trinity, the Edwards–Trinity (High Plains), and the Rita Blanca aquifers.

The Santa Rosa Formation, which is the most productive part of the Dockum aquifer, consists principally of interbedded shale, sand, sandstone, and conglomerate. The saturated thickness of the aquifer is as much as 700 feet in the Edwards Plateau area. Yields of wells completed in the aquifer are generally less than 300 gallons per minute. Dissolved-solids concentration of the water ranges from less than 100 to more than 4,000 milligrams per liter. About 33 million gallons per day was withdrawn from the Dockum aquifer during 1985, about 40 percent of which was withdrawn for mining and thermoelectric-power uses. Withdrawals for public and domestic supplies and agricultural (primarily irrigation) uses were about 29 percent each.

RUSTLER AQUIFER

The Rustler aquifer consists of water-yielding rocks of the Rustler Formation of Permian age. The rocks consist of dolomite; limestone; anhydrite; gypsum; a basal zone of sand, sandstone, siltstone, and shale; and minor amounts of halite or rock salt. Solution openings are in the dolomite, limestone, anhydrite, and gypsum. The aquifer crops out in eastern Culberson County and dips toward the east-southeast where the farthest downdip occurrence of usable-quality water is in Pecos County. In places, the aquifer is hydraulically connected to the overlying Pecos River Basin alluvial aquifer. In other downdip areas, the Rustler aquifer is confined by the overlying Permian Dewey Lake Red Beds. Maximum thickness of the aquifer is about 500 feet.

Most wells completed in the Rustler aquifer yield less than 300 gallons per minute; one well in Pecos County, however, had a reported yield of 4,400 gallons per minute. The dissolved-solids concentration of the water generally ranges from 2,000 to 6,000 milligrams per liter, with the principal ions being calcium and sulfate. The water is not suitable for human consumption, but is used for irrigation, livestock watering, and oilfield water-flooding operations. About 300,000 gallons per day was withdrawn from the Rustler aquifer during 1985. About 81 percent of the water withdrawn was used for agricultural purposes, and most of the remainder was used for oilfield water-flooding.

CAPITAN REEF COMPLEX AQUIFER

The Capitan Reef Complex aquifer consists of reef, fore-reef, and back-reef facies of Permian rocks that were deposited around the margin of the Delaware Structural Basin. The principal water-yielding formations are the Capitan Limestone and the underlying Goat Seep Limestone of the reef zone; also included in the aquifer are permeable zones in the limestone shelf facies immediately adjacent to the reef zone—the Tansil, the Yates, the Seven Rivers, the Queen, and the Grayburg Formations. The arc-shaped aquifer is about 10 to 14 miles wide and extends from northwestern Culberson County southeastward to Jeff Davis County and northward from Brewster County to northwestern Winkler County.

The aquifer generally contains highly mineralized water, except where it crops out in mountainous areas in Culberson, Brewster, and Pecos Counties. In an area along the Culberson–Hudspeth County line, the aquifer has been penetrated by wells to depths greater than 1,000 feet. Water levels range from about 100 to more than 200 feet below land surface. Wells completed in the aquifer commonly yield more than 1,000 gallons per minute; the yield from one well is estimated to be as great as 6,000 gallons per minute. The water is a calcium-magnesium bicarbonate type and has dissolved-solids concentrations that range from 850 to 1,500 milligrams per liter.

In a mountainous area of southeastern Culberson County, well depths range from 350 to about 1,700 feet, and water levels range from 280 to 1,000 feet below land surface. Wells completed in the aquifer in this area yield as much as 400 gallons per minute. The calcium-magnesium-bicarbonate water has a dissolved-solids concentration that ranges from 1,000 to 2,000 milligrams per liter.

About 200,000 gallons per day was withdrawn from the Capitan Reef Complex aquifer during 1985. About 81 percent of the water withdrawn was used for agricultural (primarily irrigation) purposes.

BONE SPRING–VICTORIO PEAK AQUIFER

The Bone Spring–Victorio Peak aquifer consists of the Bone Spring Limestone and the Victorio Peak Limestone of Permian age. The aquifer underlies an area in northern Hudspeth County. Water is in joints, fractures, and solution cavities in the limestone formations. The thickness of the aquifer is as much as 2,000 feet. The wide range in aquifer hydraulic conductivity is reflected in the yields of wells completed in the aquifer; yields range from about 150 to more than 2,200 gallons per minute.

The chemical quality of the water in the aquifer also is extremely variable. The water is generally not suitable for municipal and domestic supplies, but is used for irrigation. In 1948–49, water withdrawn from the aquifer for use in an intensively irrigated area had dissolved-solids concentrations of 1,100 to 1,800 milligrams per liter. By 1968, the dissolved-solids concentration in most of the water in the same area ranged from 3,000 to 5,000 milligrams per liter, which amounts to almost a threefold increase for many of the wells. The increased dissolved-solids concentration was probably caused by the concentration of salts in the return flow of applied irrigation water as a result of evapotranspiration and the leaching of additional salts from overlying shallow alluvial deposits. Further increases in the dissolved-solids concentration of the ground water were reported for the 1970's.

About 82 million gallons per day was withdrawn from the Bone Spring–Victorio Peak aquifer during 1985. More than 99 percent of the water withdrawn was used for irrigation.

MARATHON AQUIFER

The Marathon aquifer consists of tightly folded and faulted rocks of the Gaptank Formation and the Dimple Limestone of Pennsylvanian age; the Tesnus Formation of Pennsylvanian and Mississippian age; the Caballos Novaculite of Mississippian, Devonian, and Silurian age; and the Maravillas Chert, the Fort Pena Formation, and Marathon Limestone of Ordovician age. The aquifer underlies an area in north-central Brewster County.

The Marathon Limestone is the most productive part of the aquifer and is the source of municipal supply for the town of Marathon. The upfolded Marathon Limestone is at or near land surface, and water in the aquifer is under unconfined conditions in fractures, joints, and cavities. Maximum thickness of the aquifer is about 900 feet, and well depths are commonly less than 250 feet. Wells completed in the aquifer yield from less than 10 to more than 300 gallons per minute.

Water from the Marathon aquifer is very hard, but otherwise is generally suitable for most uses. The dissolved-solids concentration ranges from 500 to 1,000 milligrams per liter. About 700,000 gallons per day was withdrawn from the aquifer during 1985, of which about 81 percent was used for public supply.

MARBLE FALLS AQUIFER

The Marble Falls aquifer consists of the Marble Falls Limestone of Pennsylvanian age, which crops out along the flanks of the Llano Uplift, primarily in McCulloch, San Saba, Lampasas, and Burnet Counties. Water is in joints, fractures, and cavities in the limestone, which is locally as much as 600 feet thick. The aquifer is highly permeable in places, as indicated by wells that yield as much as 2,000 gallons per minute and the presence of large springs that issue from the aquifer.

The chemical quality of the ground water is generally suitable for most purposes. About 900,000 gallons per day was withdrawn from the Marble Falls aquifer during 1985. About 59 percent of the water withdrawn was used for agricultural purposes, and the remainder was used equally for public and industrial supplies.

ELLENBURGER–SAN SABA AQUIFER

The Ellenburger–San Saba aquifer consists of the Tanyard, the Gorman, and the Honeycut Formations of the Ellenburger Group of Ordovician age, and the San Saba Limestone Member of the Wilberns Formation of Ordovician and Cambrian age. The aquifer is a sequence of limestone and dolomite beds that crop out in a circular pattern around the Llano Uplift and dip radially into the subsurface away from the center of the uplift. The maximum thickness of the aquifer is about 2,000 feet. Water is in fractures, cavities, and solution channels and is commonly under confined conditions. The aquifer is highly permeable in places, as indicated by wells that yield as much as 1,000 gallons per minute and springs that issue from the aquifer, which maintains the base flow of streams in the area.

Although the ground water is hard, the dissolved-solids concentration is minimal in most places. Fresh to slightly saline water extends downdip to depths of approximately 3,000 feet below land surface. About 4.4 million gallons per day was withdrawn from the Ellenburger–San Saba aquifer during 1985. The water was used about equally for public supply and for agricultural (primarily irrigation) purposes.

HICKORY AQUIFER

The Hickory aquifer consists of the Hickory Sandstone Member of the Riley Formation of Cambrian age, which crops out in a circular pattern around the Llano Uplift and dips radially into the subsurface from the center of the uplift. The aquifer is underlain by Precambrian rocks and is overlain and separated from the Ellenburger–San Saba aquifer by the Cap Mountain Limestone and the Lion Mountain Sandstone Members of the Riley Formation. The Hickory aquifer is locally as much as 500 feet thick, and is extensively faulted. Wells completed in the aquifer commonly yield between 200 and 500 gallons per minute; a few wells yield more than 1,000 gallons per minute.

Dissolved-solids concentrations of the ground water commonly range from 300 to 500 milligrams per liter. Water that contains a dissolved-solids concentration of less than 3,000 milligrams per liter extends downdip to a maximum depth of about 5,000 feet below land surface. About 25.5 million gallons per day was withdrawn from the Hickory aquifer during 1985. About 82 percent of the water withdrawn was used for agricultural (primarily irrigation) purposes. Most of the remainder was used for public supply.

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