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Report 101

GROUND-WATER RESOURCES OF GREGG AND UPSHUR COUNTIES, TEXAS

OCTOBER 1969

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REPORT 101

GROUND-WATER RESOURCES OF GREGG AND UPSHUR COUNTIES, TEXAS

By

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United States Geological Survey

Prepared by the U.S. Geological Survey
in cooperation with the
Texas Water Development Board

October 1969

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Published and distributed
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Post Office Box 12386
Austin, Texas 78711

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ABSTRACT

Gregg and Upshur Counties, in northeast Texas, are underlain by two aquifers that are capable of sustaining additional development. The aquifers consist of the Wilcox Group and Carrizo Sand (Carrizo-Wilcox aquifer) and the Queen City Sand.

The Carrizo-Wilcox aquifer, the most productive of the two aquifers, underlies all of the 2-county area at increasingly greater depths toward the trough (East Texas Embayment) that trends northeasterly through the east-central part of Upshur County. Of the total pumpage of 3.02 mgd (million gallons per day) in 1966, 2.84 mgd was from the Carrizo-Wilcox aquifer. At the 1966 hydraulic gradient (8 feet per mile), about 12,000 acre-feet per year (10.9 mgd) was being transmitted through this aquifer. The amount that is perennially available is not known, but it is probably at least two times that pumped in 1966. In addition, 45 million acre-feet of fresh to slightly saline water is in transient storage in the Carrizo-Wilcox aquifer; however, much of this lies at a depth of more than 400 feet. The water in the Carrizo-Wilcox generally is soft, but the high chloride content in parts of Upshur and most of Gregg County may limit development of the ground-water supplies in the aquifer, particularly for municipal and domestic uses.

The Queen City Sand, which crops out over nearly 90 percent of the area, is relatively undeveloped. In 1966, only 200 acre-feet (0.18 mgd) was pumped from the aquifer. At the 1966 hydraulic gradient of 8 feet per mile, 2.4 mgd, or 2,700 acre-feet per year, was being transmitted through the aquifer. An estimated 25 million acre-feet of fresh water is in transient storage, of which 8 million acre-feet theoretically would be available from storage. Development of even half of this quantity would require a large number of small-capacity wells because of the low transmissibility of the aquifer, about 5,000 gpd (gallons per day) per foot as compared to 20,000 gpd per foot for the Carrizo-Wilcox. The water in the Queen City Sand is uniformly low in mineralization except for iron; because of iron content, the Queen City Sand may be less desirable as a source of water for municipal, industrial, and domestic uses than the Carrizo-Wilcox aquifer. However, the iron can be substantially removed with proper treatment.

GROUND-WATER RESOURCES OF GREGG AND UPSHUR COUNTIES, TEXAS

INTRODUCTION

Location and Extent of the Area

Gregg and Upshur Counties in northeast Texas are bordered by Camp County on the north, Harrison, Marion, and Morris Counties on the east, Rusk County on the south, Smith County on the southwest, and Wood County on the west (Figure 1). The city of Longview (Gregg County), the principal center of commerce and industry in the area, is 130 miles east of Dallas and 60 miles west of Shreveport, Louisiana.

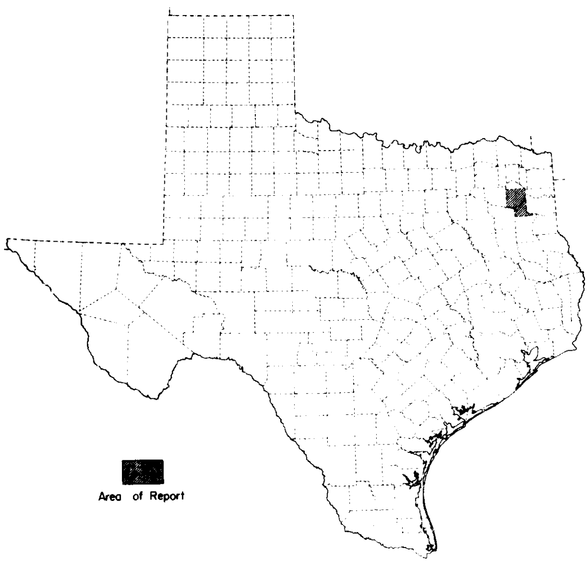

Figure 1.—Location of Gregg and Upshur Counties

The two counties comprise an area of 870 square miles, of which 284 are in Gregg County and 586 are in Upshur County.

Purpose and Scope

This is a report of a detailed investigation of the ground-water resources of Gregg and Upshur Counties begun in 1966 by the U.S. Geological Survey in cooperation with the Texas Water Development Board. The purpose of this report is to provide a guide for the optimum development of available ground-water resources in the report area.

Data are presented to show the vertical and lateral extent of the water-bearing formations or aquifers, the hydrologic properties of the aquifers, and the chemical quality of water in the aquifers. The report gives the quantities and uses of the ground water being withdrawn and the effects of these withdrawals on water levels. Problems associated with ground-water development are discussed, and estimates are given on ground water that is available for future development.

Methods of Investigation

The field data were collected mostly during the period from July 1966 to January 1967. Basic information, including depths of wells, water levels, methods of well construction and water lift, yield characteristics, and use of water, was collected for 157 wells. Information previously collected by the Texas Water Development Board and the U.S. Geological Survey was brought up-to-date. Well records are shown in Table 7 and well locations are shown on Figure 13.

Static water levels were measured with steel tape in 84 wells (Table 7). Altitudes not previously established at well sites were interpolated from Geological Survey 7½- and 15-minute topographic quadrangle maps (contour intervals 10 and 20 feet).

Ground-water samples were collected for chemical analysis from 66 wells and the results are shown in Table 9. Table 9 also includes analyses that were made previous to the present investigation.

Quantities of ground water pumped for public and industrial use (Table 4) were obtained largely from records. Quantities for domestic, livestock, and irrigation use were estimated from the number of users and normal rates of use.

The geologic map (Figure 2) is from the Geologic Atlas of Texas, Tyler Sheet (University of Texas, Bureau of Economic Geology, 1964).

Subsurface control for the geologic sections (Figures 14, 15, and 16), for the maps showing the altitudes of and depths to the top or base of the aquifers (Figures 4 and 5), and for maps showing the approximate sand thickness of the aquifers (Figures 11 and 12) were determined from electrical logs of oil, gas, and water tests. Additional subsurface information was provided by drillers' logs of wells, a representative number of which are given in Table 8.

Aquifer tests (Table 3) were analyzed by the Theis non-equilibrium method as modified by Cooper and Jacob (1946) and the Theis recovery method (Wenzel, 1942).

Previous Investigations

Deussen (1914), in his report on the geology and underground waters of the southeastern part of the Texas Coastal Plain, included a brief account of groundwater sources and development in Gregg and Upshur Counties. The geology of the report area was described in a report by Sellards and others (1932) on the regional geology of Texas.

Shafer and Lyle (1937) made an inventory of wells in Gregg County; a supplement to this inventory was made by Broadhurst (1943). Broadhurst (1942) made an inventory of wells in Upshur County. Broadhurst and Breeding (1945) reported on ground-water development and stream runoff in Gregg County. Sundstrom and others (1948), in a report on the public water supplies of East Texas, included information on the water supplies at Big Sandy and Gilmer in Upshur County, and Gladewater, Kilgore, and Longview in Gregg County.

Baker and others (1963) gave information on the aquifers in their ground-water reconnaissance report. Holloway (1964) reported on an alleged ground-water contamination case near Kilgore in Gregg County. Hughes and Leifeste (1965) gave information on the quality of surface water in their reconnaissance study of the chemical quality of surface water in the Sabine River basin.

Detailed ground-water investigations in counties adjacent to the report area have been made in Smith County (Dillard, 1963); Camp, Franklin, Morris, and Titus Counties (Broom and others, 1965); Harrison County (Broadhurst and Breeding, 1943b, and Broom and Myers, 1966); Marion County (Broadhurst and Breeding, 1943a); and Wood County (Broom, 1968). Smith and others (1966) made detailed base-flow studies of Little Cypress Creek along its reaches extending through Upshur, Gregg, and Harrison Counties.

Physiography and Climate

Gregg and Upshur Counties are in the West Gulf Coastal Plain physiographic province (Fenneman, 1938). The land surface, which slopes generally southeastward, supports a substantial growth of pine and hardwood. The area is drained in the northern half mostly by Little Cypress Creek and its tributaries, and in the southern half mostly by the Sabine River and its tributaries. Except for the relatively level flood plains of the principal streams, the terrain is gently rolling to hilly. Altitudes range from about 680 feet on the Little Cypress-Sabine drainage divide to about 240 feet along the downstream reaches of the Sabine River.

The U.S. Geological Survey maintains four stream-gaging stations in the area. The locations of the gaging stations are shown on Figure 13. Gaging-station data (U.S. Geological Survey, 1967) are summarized in the following table:

STREAM-GAGING STATION	DRAINAGE AREA (SQ MI)	AVERAGE DISCHARGE		
		YEARS OF RECORD	CUBIC FEET PER SECOND	ACRE-FEET PER YEAR
Sabine River near Gladewater* 8-0200	2,791	34	1,882	1,363,000
Big Sandy Creek near Big Sandy 8-0195	231	27	183	132,500
Little Cypress Creek near Ore City 7-3460.5	383	4	†	†
Rabbit Creek at Kilgore 8-0207	75.8	3	†	†

* Since October 1960, flow of the Sabine River at the Gladewater station has been affected by storage in and diversion from Lake Tawakoni near Wills Point, capacity, 936,200 acre-feet. In 1966, the city of Dallas diverted 29,950 acre-feet from Lake Tawakoni for municipal use.

† Average discharges are not given at stations having fewer than 5 years of complete record. During the time of available record, discharge at the Little Cypress Creek station ranged from 23,500 cfs (cubic feet per second) on April 24, 1966, to no flow at times; discharge at the Rabbit Creek station ranged from 15,200 cfs on April 24, 1966, to no flow at times in 1964.

The records of the U.S. Weather Bureau at Longview from 1889 to present provide the most complete climatological data for the area. The normal annual precipitation at Longview is 46.16 inches; and the norrnal monthly precipitation, in inches, is as follows:

January	4.27	May	5.67	September	2.62
February	3.76	June	3.36	October	3.07
March	3.84	July	3.52	November	4.12
April	4.79	August	2.56	December	4.58

The normal January temperature is 9°C (47.7°F), and the normal July temperature is 29° C (84.2 F°). The average date of the first killing frost is November 16 and the last is March 14. The average growing season is 250 days.

The annual gross lake surface evaporation in the report area during the period 1940-65 ranged from 38.0 inches in 1950, 1957, 1958, and 1959 to 57.0 inches in 1954 and averaged 44.5 inches (Kane, 1967, table E-13).

Population and Economy

The U.S. Bureau of the Census (1960) shows a population of 69,436 for Gregg County and 19,793 for Upshur County. The estimated population in 1965 of principal cities in Gregg County was: Longview (county seat), 45,100; Kilgore, 11,200; and Gladewater, 6,142. The estimated population in 1965 of principal cities in Upshur County was: Gilmer (county seat), 4,560; Big Sandy, 848; and Ore City, 819.

The economy of the area is based on industry and agriculture. However, most of the industry is located in Gregg County and most agriculture is located in Upshur County. This uneven distribution is due largely to the East Texas oil field, which extends through a substantial part of Gregg County, including the cities of Kilgore and Gladewater, but is present only in the southernmost part of Upshur County.

Industry in Gregg County is the production and processing of petroleum and related products. The production of oil in Gregg County in 1965 was 24,932,500 barrels, and the cumulative production to 1965 since oil was discovered in 1931 was 2,042,105,500 barrels (Railroad Commission of Texas, 1966). Less important industries in Gregg County include the manufacture of machinery, chemicals, and plastics. A very recent industry to locate in the county was a brewery at Longview. Agriculture in Gregg County is mostly limited to beef cattle and nursery products.

Industry in Upshur County, though localized, is chiefly the production of oil in the southern part and some production of gas in the east-central part of the county. The production of oil in Upshur County in 1965 was 3,104,OOO barrels, and the cumulative production in 1965 since oil was discovered in 1931 was 229,639,000 barrels. Less important industries in Upshur County include the production of steel conduits, lumber, pulp wood, pottery, and sand.

Agriculture is widespread in Upshur County and has evolved in recent years from predominately row-crop farming to inproved pastures and livestock. Beef cattle and poultry production provide most of the farm income. Other elements of the agricultural economy are dairy products, peach orchards, and truck crops.

Well-Numbering System

The well-numbering system used in this report is based on the divisions of latitude and longitude and was developed by the Texas Water Development Board for use throughout the State. Under this system, each l-degree quadrangle is given a number consisting of two digits from 01 to 89. These are the first two digits in the well number. Each l-degree quadrangle is divided into 7 1/2-minute quadrangles which are given 2-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7 1/2-minute quadrangle is subdivided into 2 1/2-minute quadrangles which are given a single digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2 1/2-minute quadrangle is given a 2-digit number in the order in which it was inventoried, starting with 01. These are the last two digits of the well number.

Only the last three digits of the well number are shown at the location of a well on Figure 13; the second two digits are shown in the northwest corner of each 7 1/2-minute quadrangle; and the first two digits are shown by the large block numerals 34 and 35.

In addition to the 7-digit well number, a 2-letter prefix is used to indentify the county. The letter prefix for Gregg County is KU, and for Upshur County it is YK. Thus, well YK-35-17-201 (a well for the city of Gilmer) is in Upshur County (YK), in the l-degree quadrangle 35, in the 7 1/2-minute quadrangle 17, in the 2 1/2-minute quadrangle 2, and was the first (01) well inventoried in that 2 1/2-minute quadrangle (Figure 13).

The well numbers used by the authors of previous reports and the corresponding numbers used in this report are given in Table 1.

Acknowledgments

The investigation was achieved largely through the cooperation of well owners and county, city, and industrial officials who allowed access to their property and permitted examination of pertinent records. Most of the data shown on the maps and cross sections in this report was obtained from the electrical logs of oil and gas tests.

Table 1.—Well Numbers Used by Shafer and Lyle (1937), Broadhurst (1943), and Broadhurst and Breeding (1945) in Gregg County and Corresponding Numbers Used in This Report; Well Numbers Used by Broadhurst (1942) in Upshur County and Corresponding Numbers Used in This Report

OLD NUMBER	NEW NUMBER	OLD NUMBER	NEW NUMBER	OLD NUMBER	NEW NUMBER
		Gregg County (KU)			
411	35-33-201	607	35-35-401	679	35-34-201
468	35-34-702	641	35-25-801	698	35-33-903
469	35-33-901	654	35-26-703	699	35-34-403
470	35-33-902	656	35-26-704	700	35-34-401
471	35-41-303	658	35-26-705	703	35-34-703
476	35-33-904	663	35-26-709	705	35-35-701
525	35-34-503	664	35-26-502		
		Upshur County (YK)			
12	35-17-201	49	35-25-501	66	34-23-601
14	35-17-202	54	35-18-701	68	34-32-402
15	35-17-203	62	35-17-701	75	35-25-401
33	35-18-201	63	34-24-901		

GEOLOGY AS RELATED TO GROUND WATER

Stratigraphy and Structure

Geologic units of Eocene age are the principal sources of ground water in Gregg and Upshur Counties. Alluvium of Pleistocene and Holocene age yield only small quantities of ground water. The geologic units and their water-bearing characteristics are summarized in Table 2. The outcrop areas of the geologic units are shown on Figure 2.

The Queen City Sand forms the most extensive outcrop in the area. With local exceptions, the units below the Queen City Sand crop out in northeasterly trending belts that extend both north and south of Gregg and Upshur Counties. Eocene units above the Queen City are very limited in extent and occur mostly as outliers across central parts of the area. The wider belts of alluvium are along the principal streams.

The geologic sections (Figures 14, 15, and 16) show the stratigraphic relationships of the units in the subsurface. The contacts between the units often are difficult to determine on drillers' and electrical logs; consequently, the contacts shown on the geologic sections and the thickness of the units shown on Table 2 are only approximate. The top of the Midway Group defines the approximate base of fresh to slightly saline water in the two-county area. The altitude and depth to the top of the Midway are shown in Figure 3. The Wilcox Group, the lowermost fresh water-bearing unit, comprises nearly half the available water-bearing sediments. The sediments above the Wilcox Group, except the alluvium, are assigned to the Claiborne Group which is divided in ascending order into the Carrizo Sand, Reklaw Formation, Queen City Sand, Weches Greensand, and Sparta Sand.

The major structural feature in the area is a trough-like depression whose long axis nearly coincides with a line extending from the northwest corner of Gregg County to the northeast corner of Upshur County. Southeast of the line the units generally dip northwest, and northwest of the line the units generally dip southeast, both towards the long axis (Figures 3 and 14) at about 15 feet per mile. The report area is part of an extensive area of downwarping which in its entirety is called the East Texas Embayment.

The trough or embayment is shown by the contours on the top of the Midway Group in Figure 3. The general pattern is locally altered in the western part of Upshur County by a south-plunging structural ridge which passes through the community of Kelsey. This structural ridge brings the Carrizo Sand and Reklaw Formation to the surface west and northwest of Gilmer (Figure 2). West of the structural ridge, the Midway

Table 2.—Geologic Units and Their Water-Bearing Characteristics, Gregg and Upshur Counties

SYSTEM	SERIES	GROUP	UNIT	APPROXIMATE MAXIMUM THICKNESS (FT)	CHARACTER OF ROCKS	WATER-BEARING PROPERTIES
Quaternary	Holocene and Pleistocene		Alluvium	60	Sand, silt, clay, and some gravel.	Not known to yield water to wells in Gregg and Upshur Counties; probably would yield small quantities.
Tertiary	Eocene	Claiborne	Sparta Sand	250	Sand, silt, and clay.	Known to yield only small quantities of fresh water to wells in Gregg and Upshur Counties.
			Weches Greensand	75	Glauconite, glauconitic clay, and sand; secondary deposits of limonite common in outcrop areas.	Not known to yield water to wells in Gregg and Upshur Counties.
			Queen City Sand	500	Sand, silt, clay, and some lignite.	Yields small to moderate quantities of fresh water to wells in Gregg and Upshur Counties.
			Reklaw Formation	110	Glauconitic clay and some sand and lignite; limonite is common in outcrop areas.	Not known to yield water to wells in Gregg and Upshur Counties.
			Carrizo Sand	150	Sand, silt, and clay.	Yields moderate to large quantities of fresh to slightly saline water to wells in Gregg and Upshur Counties.
		Wilcox		600	Sand, silt, clay, lignite, and limonite sand beds generally thin-bedded and discontinuous.	Yields moderate to large quantities of fresh to slightly saline water to wells in Gregg and Upshur Counties.
	Paleocene	Midway		880	Calcareous clay and minor amounts of limestone, silt, and glauconitic sand.	Yields no water to wells in Gregg and Upshur Counties.

Group and the younger units dip to the southwest at about 130 feet per mile.

No faults are known to have been mapped in the area. Deep-seated faults have been mapped in the Hawkins oil field in Wood County, but displacement along these faults decreases upward so that little or no displacement of the rocks occurs above the Midway Group.

Physical Characteristics and Water-Bearing Properties of the Geologic Units

Midway Group

The Midway Group crops out in counties northwest of Gregg and Upshur Counties. The unit, mostly marine in origin, is composed chiefly of calcareous clay which locally may contain thin stringers of limestone and glauconitic sand. The unit tends to become silty and slightly sandy in the upper part of the section.

The top of the Midway (Figure 3) ranges in altitude from about 300 feet below sea level (700 feet below land surface) in the northwestern and southeastern corners of the area to about 1,100 feet below sea level (1,500 feet below land surface) in the southwestern corner of Upshur County. The Midway Group is about 880 feet thick in the report area.

The Midway is not known to yield water to wells in the area. Nevertheless, it is hydrologically signifcant in that it forms the basal confining rock for the overlying Wilcox Group.

Wilcox Group

The Wilcox Group conformably overlies the Midway and crops out northwest and southeast of the report area. The unit has a maximum thickness of about 600 feet and is composed of interbedded sand, silt, clay, and some lignite with secondary deposits of limonite. Medium to very fine sand generally constitutes one-third to one-half of the unit. Individual beds of sand generally are thin bedded and discontinuous, although some may attain a thickness of nearly 100 feet (well YK-35-19-401, Figure 16). The geologic sections (Figures 14, 15, and 16) clearly show that few beds of sand in the Wilcox can be correlated from well to well. Also, because of the transitional change between the relatively sandy Wilcox and relatively clayey Midway, the stratigraphy of the Wilcox in some places is somewhat questionable as determined only from electrical logs. In fact, locally, the lowest practicable water sands in the Wilcox may exist as much as 200 feet above the actual base of the Wilcox. In order to maintain stratigraphic continuity as much as possible in this investigation, the base of the Wilcox was placed on occasion to include some silty sands which might, for practical purposes, be included in the Midway Group.

Because of the lenticularity of the sand beds, the yields of wells tapping the Wilcox can be expected to range over fairly wide limits. Most of the wells currently in use only partially penetrate the Wilcox. However, the Wilcox may be capable of yielding as much as 500 gpm (gallons per minute) or more if all sands in the unit are screened.

Clairborne Group

Carrizo Sand

The Carrizo Sand unconformably overlies the Wilcox Group and crops out in small areas in the northwestern and southeastern parts of the report area (Figure 2). The Carrizo reaches a maximum thickness of about 150 feet, and typically the unit is composed of massive to cross-bedded, coarse to fine sand. In places, however, the Carrizo is interbedded with silt and clay so that it is not easily distinguishable from the underlying Wilcox Group (well YK-34-32-601, Figure 15).

Most of the wells in use are multiscreened to tap both the Carrizo Sand and the Wilcox Group. The yields of these wells range from about 300 to 600 gpm, and in most wells, the Carrizo is believed to contribute most of the water. Locally, the Carrizo probably is capable of yielding as much as 500 gpm to wells.

Reklaw Formation

The Reklaw Formation conformably overlies the Carrizo Sand and crops out in small areas in the northwestern and southeastern parts of the report area (Figure 2). In the latter area, however, subsurface data indicate that a part of the sediments mapped as Reklaw (Figure 2) actually may be of Queen City age. The formation has a maximum thickness of about 110 feet, and typically it is composed of glauconitic clay and minor amounts of sand and lignite. Locally the Reklaw may show an apparent increase in sand content, particularly in the north and northeastern parts of the area (well YK-35-l l-701, Figure 16). However, the apparent increase in sand content may result from a thinning of the Reklaw, the additional sand being part of the overlying Queen City Sand.

The outcrop of the Reklaw is easily recognized because of its red clayey soil, which is in sharp contrast to the gray sandy soil of the underlying Carrizo Sand. Also, the outcrop is characterized by the occurrence of limonitic seams and concretions (ironstone) at or near the land surface.

The Reklaw Formation is not definitely known to yield water to any wells in the area, but it probably would yield small quantities to wells where the unit is locally sandy. It is significant hydraulically as a confining bed above the underlying Carrizo Sand.

Queen City Sand

The Queen City Sand conformably overlies the Reklaw Formation and crops out over 90 percent of Gregg and Upshur Counties (Figure 2). In contrast to the red clayey soil and the more gentle relief on the Reklaw, the outcrop of the Queen City is composed of gray sandy soil, and the relief ranges from moderate to hilly. Pine timber and perennial streams are more prevalent on the outcrop of the Queen City than on outcrops of the older units. The Queen City consists of massive to cross-bedded sediments, locally stratified. The sediments generally consist of about 80 percent medium to fine sand and about 20 percent silt and clay, with minor amounts of lignite. The Queen City has a maximum thickness of about 500 feet in the southwestern corner of Upshur County. In general, wells in the Queen City are capable of furnishing small to moderate quantities of fresh water.

Waches Greensand and Sparta Sand

The Weches Greensand and Sparta Sand have a very limited extent in Gregg and Upshur Counties. They crop out as scattered outliers having relatively sharp relief across the central part of the area (Figure 2).

The Weches Greensand attains a thickness of 75 feet and consists of interbedded glauconitic clay and sand. At the shallow depths and in outcrops the unit locally contains enough secondary deposits of limonite to make it a durable caprock. Consequently, a very hilly terrain is characteristic of the Weches outcrop. The formation is not known to yield water to wells in the report area.

The overlying Sparta Sand attains a thickness of 250 feet in the southwestern corner of Upshur County and generally consists of about 70 percent medium to fine sand and about 30 percent sandy clay and silt. The Sparta outcrops generally are excellent infiltration areas. Although the unit is known to yield only small quantities of fresh water to wells, water from springs at the base of the Sparta outcrop makes a significant contribution to the base flow of Big Sandy Creek.

Alluvium

Alluvial sediments occur in and near the floodplains of the principal streams (Figure 2). The sediments have a maximum thickness of about 60 feet, and generally consist of clay, silt, fine sand, and minor amounts of gravel. The alluvium is not known to yield water to wells, but it probably is capable of yielding at least small quantities of water.

HYDROLOGIC UNITS

The Wilcox Group, Carrizo Sand, and Queen City Sand constitute the significant water-bearing units in Gregg and Upshur Counties. The first two formations have similar hydrologic properties and are in hydraulic continuity. Consequently, they function as a single aquifer, which, for purposes of this report, is referred to as the Carrizo-Wilcox aquifer.

The Carrizo-Wilcox aquifer crops out between Longview and Kilgore in Gregg County and northwest of Gilmer in Upshur County. In the subsurface, the aquifer dips toward the northeasterly-trending trough (the East Texas Embayment) at about 15 feet per mile (Figure 4). In the southwestern part of Upshur County, the Carrizo-Wilcox dips steeply (about 130 feet per mile) southwest toward the Tyler Basin in Smith County.

The altitude of the top of the Carrizo-Wilcox aquifer (Figure 4) ranges from about 300 feet above sea level (near the outcrop areas) in the northwestern corner of Upshur County and in the southeastern corner of Gregg County, to nearly 500 feet below sea level (900 feet below land surface) in the southwestern corner of Upshur County. The Carrizo-Wilcox in Gregg and Upshur Counties has an average thickness of about 600 feet.

The Queen City Sand, the second most important aquifer, crops out over 90 percent of the area or about 840 square miles. The formation is absent along Little Cypress and Kelsey Creeks, a few miles west of Gilmer, and along the Sabine River south of Longview (Figure 2). The base of the aquifer dips generally toward the trough (the East Texas Embayment) at a rate approximately equal to the dip of the top of the Carrizo-Wilcox aquifer (Figure 5). The thickness of the aquifer, which in most places is about equivalent to the depth to the base of the aquifer shown on Figure 5, ranges from a few feet to about 500 feet.

GROUND-WATER HYDROLOGY

Occurrence and Movement of Ground Water

Ground water in the Carrizo-Wilcox aquifer and the Queen City Sand occurs under artesian and water-table conditions in Gregg and Upshur Counties. Under water-table conditions, the water is unconfined and when tapped by wells, the water does not rise in the wells above the zone of saturation in the aquifer. Under artesian conditions, the water is confined and when tapped by wells, the water rises in the wells under hydrostatic pressure to a level above the top of the aquifer. If the pressure head is large enough to cause the water in the well to rise to an altitude greater than that of the land surface, the well will flow. The level to which water will rise in artesian wells is called the piezometric surface.

The Carrizo-Wilcox aquifer yields water under artesian conditions in Gregg and Upshur Counties, except in the outcrop area of the Carrizo where the water is unconfined. Water in the Queen City is unconfined except in the southwestern and northeastern parts of Upshur County where the overlying Weches Greensand effectively confines the water.

Ground water moves slowly (tens to hundreds of feet per year) from areas of recharge to areas of discharge. The direction of movement of the water in the Carrizo-Wilcox aquifer is shown in Figure 6. The contours show that the ground water moves generally toward the center of the trough where, coincidentally, large or concentrated withdrawals have formed general cones of depression in the piezometric surface. The slope of the piezometric surface across the 250 foot contour line (Figure 6) averages about 8 feet per mile.

The movement of water in the Queen City Sand, as indicated by the water-table map (Figure 7), generally is toward the larger streams. Because of the low hydraulic gradient (8 feet per mile), the rate of movement is slow, perhaps only a few hundred feet per year.

Recharge and Discharge

Ground water in the Carrizo-Wilcox aquifer and the Queen City Sand is derived from the infiltration of precipitation on the outcrop areas, from runoff en route to a watercourse, and from the infiltration of water from streams and lakes. The recharge areas of the Carrizo-Wilcox lie mostly in adjacent counties to the northwest and southeast. Those of the Queen City are in Gregg and Upshur Counties and in adjacent counties to the north and west.

A number of factors govern the rate of natural recharge, the most important of which are: (1) the type of soil in the outcrop areas; (2) the duration and intensity of rainfall; (3) the slope of the land surface; (4) the presence of vegetational cover; and (5) the depth of the water table.

Recharge to the Carrizo-Wilcox aquifer could not be determined from the available data. However, an estimate of the minimum amount of recharge to the Queen City Sand can be made on the basis of the quantity of water that is being transmitted downdip under a hydraulic gradient (8 feet per mile) that has not been significantly affected by pumping. Thus, recharge is equal to at least 2.4 mgd (million gallons per day) or 2,700 acre-feet of water per year. An additional but undetermined quantity enters the aquifer and moves to the streams where it is discharged as seep and spring flow. The streamflow records of Little Cypress Creek near Ore City, which drains an area of 383 square miles, are insufficient to determine the low flow of the stream, which is sustained by ground water discharged largely from the Queen City Sand.

The water in the two aquifers is discharged both naturally and artificially. The natural discharge is the flow of springs and seeps, evaporation from the water table, and transpiration by trees and plants whose roots reach the water table. The quantity of water discharged by each method is difficult to determine, but it is at least several times the amount discharged by wells. Little water is discharged naturally from the Carrizo-Wilcox aquifer. An unknown, but probably large quantity of water is discharged from the Queen City through springs and seeps and by evapotranspiration. The artificial discharge by wells was 3.02 mgd (about 3,400 acre-feet) from both aquifers in 1966, of which 2.84 mgd was from wells in the Carrizo-Wilcox aquifer.

Hydraulic Properties of the Aquifers

The hydraulic properties of an aquifer that determine its capacity to transmit and store water are expressed as the coefficient of transmissibility and the coefficient of storage. (See definition of terms.)

Pumping tests were made in seven wells tapping the Carrizo-Wilcox aquifer. The results of these tests are shown in Table 3. The coefficients of transmissibility determined from these tests ranged from 3,100 to 11,000 gpd (gallons per day) per foot; discharge rates ranged from 100 to over 800 gpm; and specific capacities ranged from 2.8 to 15.5 gpm per foot of drawdown (Table 3). The range in transmissibility is due to variations in the permeability and thickness of the aquifer sands. None of the wells fully penetrated the aquifer; consequently, the results of the tests generally gave values that are less than those that would have been obtained from wells penetrating the entire aquifer. The coefficients of permeability, which were estimated from the total amount of sand believed to be contributing to the well (in most of the wells it was the equivalent of the amount of screen or perforation in the well), ranged from 41 to 128 gpd per square foot for an average of nearly 80 gpd per square foot. This value is considerably higher than the 50 gpd per square foot determined for the same unit in Wood County (Broom, 1968, p. 14). Thus, where as much as 400 feet of sand is available to the aquifer, the coefficient of transmissibility might be as much as 32,000 gpd per foot. The coefficient of storage obtained from one test was 0.00006. This value is within the range generally attributable to artesian conditions.

Table 3.—Results of Aquifer Tests in Gregg and Upshur Counties

WELL	SCREENED INTERVAL (FT)	AVERAGE DISCHARGE DURING TEST (GPM)	COEFFICIENT OF TRANS-MISSIBILITY (GPD/FT)	SPECIFIC CAPACITY (GPM/FT)	COEFFICIENT OF STORAGE	REMARKS
			Carrizo-Wilcox Aquifer			
YK-35-17-204	417-524	810	6,800	15.5	-----------	Drawdown of pumped well.
YK-35-17-205	510-530 540-560 570-600	598	9,000	3.6	-----------	Drawdown of pumped well. Recovery of pumped well. Data collected by Layne Texas Co.
YK-35-17-801	435-500	------	4,200	-------	-----------	Recovery of pumped well. Data collected by Texas Water Wells.
YK-35-18-702	475-495 529-600	490	11,000	6.0	-----------	Drawdown of pumped well.
KU-35-26-705	370-434	------	5,500	-------	0.00006	Drawdown of observation well.
KU-35-26-706	270-316 321-335 375-420	300	4,500	2.8	-----------	Drawdown of pumped well.
KU-35-26-708	298-328 483-528	100	3,100	-------	-----------	Recovery in well after pumping 5 months at an average discharge of 100 gpm.
			Queen City Aquifer			
YK-34-32-402	284-409	------	4,900	-------	.0003	Recovery of observation well. Data collected by Texas Water Development Board.
YK-34-32-403	352-420 470-505	------	3,200	-------	-----------	Recovery of pumped well. Data collected by Texas Water Development Board.

Pumping test data are insufficient for evaluating the hydraulic characteristics of the Queen City Sand. On the basis of two closely spaced tests (Table 3), the average coefficient of transmissibility was approximately 4,000 gpd per foot, and the average coefficient of permeability was 35 gpd per square foot. The wells are screened only in the basal sands of the Queen City; where wells also tap the overlying sands, the transmissibility probably is at least 5,000 gpd per foot. Although the storage coefficient of 0.0003 obtained from the test is characteristic of an artesian aquifer, the water in the Queen City generally occurs under water-table conditions, so a storage coefficient of about 0.10 probably would be more typical for the aquifer.

The coefficients of transmissibility and storage may be used to predict future drawdowns of water levels by pumping. Figure 8 shows the relation of drawdown to distance and time as a result of pumping from a water-table aquifer of infinite areal extent. If the coefficients of transmissibility and storage are 5,000 gpd per foot and 0.10, respectively, which probably are representative of the Queen City Sand, the decline in water level would be 1 foot at a distance of 1,000 feet from a well pumping 300 gpm for 30 days, about 12 feet after one year, and about 27 feet after 10 years. If the coefficient of transmissibility was smaller than that assumed, the drawdown would be greater. Figure 9 shows a similar relation as a result of pumping from an artesian aquifer of infinite areal extent with a coefficient of transmissibility of 20,000 gpd per foot and a coefficient of storage of 0.0001, which probably are representative of the Carrizo-Wilcox aquifer where all the sands are screened in the well. The decline in water level would be 22 feet at a distance of 1,000 feet after 30 days pumping at 500 gpm, about 29 feet after one year, and about 35 feet after 10 years.

Pumping from wells too closely spaced may cause intersecting cones of depression, which will cause additional lowering of the water levels and serious declines in the yields of the wells. Figures 8 and 9 should serve as a

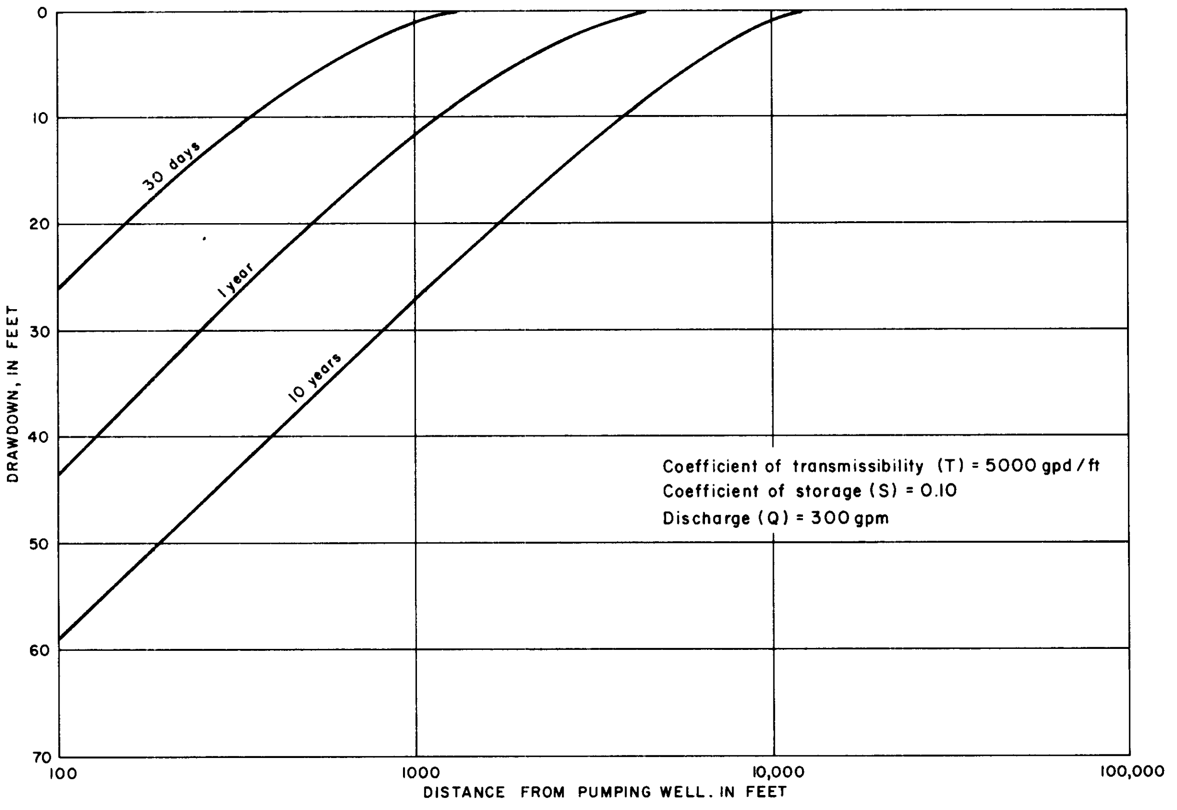

Figure 8.—Relation of Drawdown to Distance and Time, Water-Table Conditions

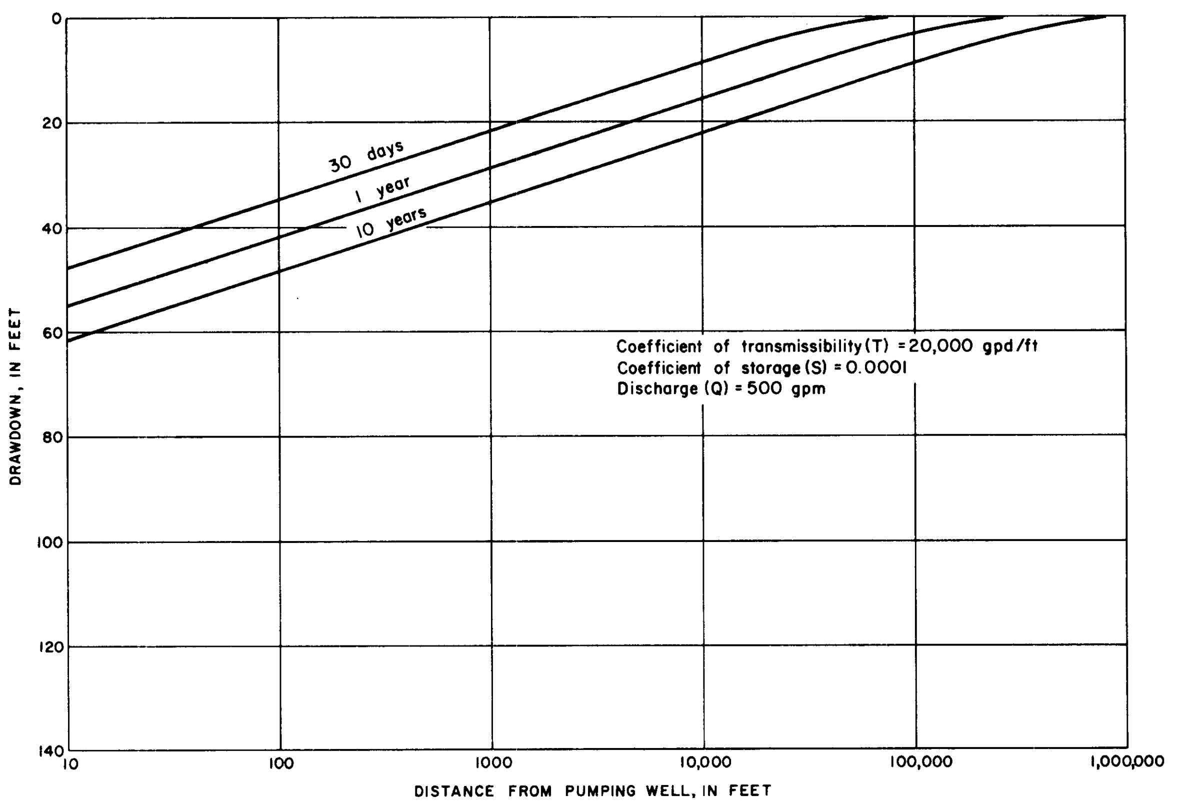

Figure 9.—Relation of Drawdown to Distance and Time, Artesian Conditions

general guide for spacing of wells that tap the Carrizo-Wilcox aquifer and Queen City Sand in Gregg and Upshur Counties.

DEVELOPMENT AND USE OF GROUND WATER

History of Water Development

Prior to 1910, nearly all the water used in Gregg and Upshur Counties was from shallow dug wells in the Queen City Sand. The water needs of the city of Longview were supplied by three shallow wells with a combined yield of 52 gpm (Deussen, 1914, p. 177). In an effort to meet increased water needs in 1910, Longview drilled two wells 400 to 600 feet deep to the Carrizo-Wilcox aquifer. The water from the drilled wells was marginal in chemical quality and the wells were abandoned in 1914, at which time the city of Longview began using water from the Sabine River, a few miles south of the city. Elsewhere in Gregg and Upshur Counties, there was little additional water development for nearly 20 years.

The discovery of the East Texas oil field in 1930-31 created an immediate demand for water for industrial uses and for oil well drilling and processing operations. Concurrently, the populations of Longview, Kilgore, and Gladewater more than tripled and created a comparable need for additional municipal supplies. The oil industry met its water needs with wells that tapped the Carrizo-Wilcox aquifer. Following the lead of the oil industry, the cities of Kilgore and Gladewater also tapped the Carrizo-Wilcox aquifer for their increased water needs. At that time, Longview's Sabine River source was sufficient to meet its increased water needs. However, by 1934, excessive concentrations of oil field brines and other wastes in the Sabine River during periods of low flow caused Longview to look for another source of water supply. From 1936 to 1950, Longview diverted water from Big Sandy Creek at a point near the city of Big Sandy. Since then, the city has obtained its water supply from Lake Cherokee on the Gregg-Rusk county line.

The need for larger supplies of better quality water caused the cities of Gladewater and Kilgore to obtain new sources of water in 1953. Gladewater abandoned its wells and began using the newly developed Lake Gladewater; Kilgore placed its old wells on a standby basis and began using water from a newly developed Carrizo-Wilcox well field in Smith County.

Present Use of Ground Water

Pumpage and use of ground water in Gregg and Upshur Counties in 1966 are summarized in Table 4. Approximately 3.0 mgd or 3,400 acre-feet was pumped from the Carrizo-Wilcox aquifer and the Queen City Sand. The 1,500 acre-feet in Upshur County (Table 4) represents practically all water used for municipal, industrial, and rural domestic purposes in the county. Poultry and dairy cattle are the principal livestock users of well water; generally, spring-fed creeks and numerous livestock ponds supply the water needs of beef cattle. There was practically no ground water used for crop irrigation in 1966, although a few small-capacity wells have been developed for the supplemental irrigation of peach orchards and truck crops during extended dry periods.

The 1,900 acre-feet of ground water used in Gregg County (Table 4) included only about 14 percent of the total water used for municipal and industrial purposes in the county; the other 86 percent was from two surface-water supplies and from wells outside the report area. Lake Cherokee (several miles south of the city) supplied 7.3 mgd or 8,192 acre-feet of water in 1966 for the municipal needs of Longview and 1.1 mgd or 1,233 acre-feet for the industrial needs. Lake Gladewater (a few miles north of the city) furnished 0.7 mgd or 760 acre-feet in 1966 to the city of Gladewater. The water needs of Kilgore are supplied from eight wells in the Carrizo-Wilcox aquifer in Smith County, about 15 miles southwest of the city. Kilgore pumped 1.4 mgd or 1,591 acre-feet of water in 1966.

Municipal Use

Ground-water pumpage for municipal purposes in Gregg and Upshur Counties in 1966 was about 1.1 mgd or 1,200 acre-feet (Table 4), of which all but 90 acre-feet was from the Carrizo-Wilcox aquifer. Municipal pumpage included Gilmer (0.51 mgd or 572 acre-feet), Big Sandy (0.06 mgd or 67 acre-feet), and Ore City (0.05 mgd or 56 acre-feet). Municipal pumpage also includes that of institutions, smaller towns and communities, and some suburban areas of Gilmer, Gladewater, Kilgore, and Longview. Some of the well systems for the latter users are privately owned and others are cooperatively owned.

Industrial Use

Industrial ground-water pumpage in Gregg and Upshur Counties in 1966 was about 1.6 mgd or 1,800 acre-feet (Table 4), of which practically all was from the Carrizo-Wilcox aquifer. Industrial pumpage in Gregg County (1.22 mgd or 1,368 acre-feet) was used mostly by oil and gas plants for cooling and process operations. Industrial pumpage in Upshur County (0.40 mgd or 448 acre-feet) was limited chiefly to use in the production of steel conduits at Gilmer. No fresh ground water was reported as being used for oil-field repressurization in Gregg and Upshur Counties.

Table 4.—Pumpage and Use of Ground Water in Gregg and Upshur Counties, 1966

COUNTY	AQUIFER	PUBLIC SUPPLY		INDUSTRIAL		RURAL DOMESTIC AND LIVESTOCK		TOTALS	
		MGD	ACRE-FEET PER YEAR	MGD	ACRE-FEET PER YEAR	MGD	ACRE-FEET PER YEAR	MGD	ACRE-FEET PER YEAR
Gregg	Carrizo-Wilcox	0.44	493	1.22	1,368	0.02	22	1.68	1,883
	Queen City	-------	---------	-------	---------	-------	------	-------	---------
Upshur	Carrizo-Wilcox	.56	628	.40	448	.20	224	1.16	1,300
	Queen City	.08	90	-------	---------	.10	112	.18	202
Totals	Carrizo-Wilcox and Queen City	1.08	1,211	1.62	1,816	0.32	358	3.02	3,385

Rural Domestic and Livestock Uses

Ground-water pumpage for rural domestic and livestock uses in Gregg and Upshur Counties was 0.32 mgd or 360 acre-feet in 1966 (Table 4). In Gregg County, this use amounted to only 0.02 mgd or 22 acre-feet and practically all was withdrawn from the Carrizo-Wilcox. In Upshur County, domestic and livestock use amounted to 0.30 mgd or 336 acre-feet, two-thirds of which was from the Carrizo-Wilcox and one-third from the Queen City.

CHANGES IN WATER LEVELS

Records of water levels in wells tapping the Carrizo-Wilcox aquifer and the Queen City Sand are included in Table 7. In general, the water levels have been measured too infrequently to determine a long-term trend. On the basis of available data, the water levels in the Carrizo-Wilcox aquifer have declined in areas where the aquifer is heavily pumped, as at Gilmer and Glenwood, and have risen substantially in those areas where pumping, principally for municipal supply, has been reduced or discontinued, as at Kilgore and Gladewater (Table 5). Elsewhere in the two counties, water levels have changed only slightly.

Available records indicate no significant change in water levels in the Queen City Sand. However, some owners of shallow wells report a seasonal fluctuation in the water table, with summer levels often 10 feet or more below winter levels. Although declines in the water tables in the Queen City have not been general, many of the old shallow domestic wells have had to be deepened or new wells drilled in recent years to sustain a sufficient home supply. This is largely the result of greater drawdowns in the wells caused by greater demands for water in modern homes. The typical domestic well prior to the 1940's was equipped with hand-lift facilities suitable for supplying 100 gpd. Recently drilled, domestic wells are equipped with an electric pump which is capable of yielding at least 400 gpd.

WELL CONSTRUCTION

The yields from wells tapping the Carrizo-Wilcox and Queen City aquifers in Gregg and Upshur Counties depend on the well location, well spacing, and the method and type of well construction. Improperly spaced wells will cause unnecessary water lifts and pumping costs. Because of the nonuniform water-bearing character of the aquifers, it is advisable where large yields are needed to choose a well site based on sand sampling, electric logging, and pumping tests of one or more test holes.

The construction of well YK-35-17-205 (Table 7) is typical of the municipal and industrial wells in Gregg and Upshur Counties. Briefly, the construction details of the well are as follows: (1) the well was drilled to 505 feet and 16-inch surface casing was set and cement was pumped between the wall of the well and surface casing, providing a seal against vertical leakage of water along the casing to the producing zone and providing a deterrent to corrosion of the outer surface of the surface casing; (2) the well was then deepened to 610 feet, penetrating about 100 feet of the Carrizo-Wilcox aquifer; (3) the hole below the surface casing was underreamed to a diameter of 36 inches; (4) a total length of 610 feet of 10¾-inch blank steel liner and screen, with set nipple and back pressure valve on the bottom, was lowered into the well—the screen as positioned on the material string to be opposite the water-bearing sands when the set nipple reached the bottom of the well; (5) using the space between the surface casing and the 10¾-inch liner as a conduit, small-size gravel was poured into the well so that the space between the underreamed wall of the well and the screen was filled with gravel,

Table 5.--Changes in Water Levels in Selcted Wells Tapping the Carrizo-Wilcox Aquifer in Gregg and Upshur Counties

WELL	OWNER	DEPTH (FT)	YIELD (GPM)	YEAR MEASURED	WATER LEVEL (FEET BELOW LAND SURFACE)	RISE (+) OR DECLINE (-) OF WATER LEVEL SINCE PRECEDING MEASUREMENT
YK-35-11-402	City of Ore City	411	Unused since 1952	1961	110	------
				1966	113	- 3
YK-35-17-202	City of Gilmer	457	480	1937	96	year drilled
				1961	131	- 35
				1966	183	- 52
YK-35-18-702	East Texas Water Co. (near Glenwood)	610	490	1962	202	year drilled
				1967	257	- 55
KU-35-25-802	City of Gladewater	390	Unused since 1953	1943	182	year drilled
				1961	132	+50
				1966	123	+ 9
KU-35-26-709	White Oak School (at White Oak)	470	Unused since about 1960	1941	172	------
				1961	178	- 6
				1966	181	- 3
KU-35-33-901	City of Kilgore	875	Unused since 1953	1931	87	year drilled
				1939	155	- 68
				1940	157	- 2
				1941	162	- 5
				1966	133	+29
KU-35-35-701	Gregg County Airport (South of Longview)	464	200	1941	94	year drilled
				1966	101	- 7

forming what is termed a "gravel-pack" (the gravel tends to reduce the velocity of water entering the well and thereby reduces the amount of fine sand that otherwise would be pumped); and (6) drilling mud was washed from the well and the well was tested for production. Equipped with a 75-horsepower motor and a vertical turbine pump, the well discharged 510 gpm with a drawdown of 147 feet for a specific capacity of nearly 3.5 gpm per foot of drawdown.

Most of the rural domestic and livestock wells in the report area are less than 50 feet in depth and tap the Queen City Sand only a few feet below the water table. Nearly all the shallow wells completed before 1940 were dug by hand and lined with brick or native rock; the diameter of these wells generally ranges from 3 to 4 feet. Most of the older wells were originally equipped with hand-lift pumps which have since been replaced by water-jet, cylinder, or centrifugal pumps powered by 1/4 to 3/4-horsepower electrical motors. Recently completed shallow wells are bored by bucket-type power augers whose operating depths generally are limited to about. 50 feet. The bored wells generally are lined with 30-inch diameter tiles of 3-foot lengths. Lift facilities are about the same as the other shallow wells.

An increasing number of rural domestic and livestock wells today are being drilled and constructed by methods similar to those used for municipal and industrial wells. These wells have a cemented steel surface casing, usually 4 inches in diameter, set at the top of the water-bearing sand, and a 2- to 3-inch screen or perforated liner is set opposite the water sand. A gravel- or sand-pack is somtimes employed. The drilled rural domestic and livestock wells are usually equipped with water-jet or submergible turbine pumps, powered by electric motors of about 1 horsepower.

CHEMICAL QUALITY OF GROUND WATER

The major factors that determine the suitability of a water supply are the limitations imposed by the contemplated use of the water. Among the various criteria established for water quality are: bacterial content; physical characteristics such as temperature, odor, color, and turbidity; and chemical constituents. Usually, the bacterial content and the undesirable physical properties can be alleviated economically, but the removal of undesirable chemical constituents can be difficult and expensive. The source and significance of dissolved-mineral constituents (adapted from Doll and others, 1963) are summarized in Table 6. Chemical analyses of water from 79 wells tapping the Carrizo-Wilcox aquifer, 19 wells and 1 spring tapping the Queen City aquifer, and 2 wells tapping both aquifers are shown in Table 9. The chloride and dissolved-solids concentrations of water from the Carrizo-Wilcox aquifer are shown on Figure 10.

The U.S. Public Health Service (1962) has established and periodically revises standards of drinking water to be used on common carriers engaged in interstate commerce. The standards are designed to protect the traveling public and may be used to evaluate domestic and public water supplies. According to the standards, chemical constituents should not be present in a public water supply in excess of the listed concentrations of common constituents shown in the following table, except where other more suitable supplies are not available. Below is a partial list of the standards adopted by the U.S. Public Health Service (1962, p. 7-B); these constituents are included in the table of chemical analyses (Table 9).

SUBSTANCE	CONCENTRATION (MG/L)
Chloride (Cl)	250
Fluoride (F)	.8*
Iron (Fe)	.3
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

* According to the Public Health Service (1962, p. 8, 41), the optimum fluoride level for a given community depends on climatic conditions because the amount of water (and consequently the amount of fluoride) ingested is influenced primarily by air temperature. The optimum value of 0.8 mg/l (milligrams per liter) in Gregg and Upshur Counties is based on the annual average of maximum daily air temperature of 24°C (75.7° F) at Longview. The presence of fluoride in average concentrations greater than twice this value, or 1.6 mg/l, would constitute grounds for rejection of the supply.

Of the samples from 69 wells in the Carrizo-Wilcox aquifer analyzed for fluoride, 63 contained less than 0.9 mg/l (milligrams per liter); only one contained more than 1.6 mg/l. Of 18 samples from the Queen City Sand, 17 contained less than 0.5 mg/l; and one contained 1.2 mg/l. Water containing optimum fluoride content reduces tooth decay, especially when the water is used by children during the period of enamel calcification. In excessive concentration, fluoride may cause mottling of the teeth, depending on the age of the child, the amount of water consumed, and the susceptibility of the individual (Maier, 1950, p. 1120-l 132).

Water with chloride in excess of 250 mg/l in combination with sodium has a salty taste and will tend to be corrosive. Chloride in 96 samples from the Carrizo-Wilcox ranged from 7.4 to 1,100 mg/l with 29 of the samples (30 percent) containing chloride in excess of 250 mg/l. Chloride in 22 samples from Queen City ranged from 2.8 to 80 mg/l, but only 2 of the samples contained chloride in excess of 50 mg/l. On the basis of the sampling, chloride is no problem in the Queen City, but it can be a serious problem in the Carrizo-Wilcox. Generally, the highest concentrations of chloride in the Carrizo-Wilcox were found in Gregg County. Except in

Table 6.—Source and Significance of Dissolved-Mineral Constituents and Properties of Water

(From Doll and others, 1963, p. 39-43)

CONSTITUENT OR PROPERTY	SOURCE OR CAUSE	SIGNIFICANCE
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stain laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. U.S. Public Health Service (1962) drinking water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in oil-field brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation
Bicarbonate (HCO_3) and Carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. U.S. Public Health Service (1962) drinking water standards recommend that the sulfate content should not exceed 250 mg/l.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in oil-field brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. U.S. Public Health Service (1962) drinking water standards recommend that the chloride content should not exceed 250 mg/l.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual (Maier, 1950, p. 1120-1132).
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. U.S. Public Health Service (1962) drinking water standards suggest a limit of 45 mg/l. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding (Maxcy, 1950, p. 271). Nitrate shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.

(Continued on next page)

Table 6.—Source and Significance of Dissolved-Mineral Constituents and Properties of Water—Continued

CONSTITUENT OR PROPERTY	SOURCE OR CAUSE	SIGNIFICANCE
Boron (B)	A minor constituent of rocks and of natural waters.	An excessive boron content will make water unsuitable for irrigation. Wilcox (1955, p. 11) indicated that a boron concentration of as much as 1.0 mg/l is permissible for irrigating sensitive crops; as much as 2.0 mg/l for semitolerant crops; and as much as 3.0 mg/l for tolerant crops. Crops sensitive to boron include most deciduous fruit and nut trees and navy beans; semitolerant crops include most small grains, potatoes and some other vegetables, and cotton; and tolerant crops include alfalfa, most root vegetables, and the date palm.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	U.S. Public Health Service (1962) drinking water standards recommend that waters containing more than 500 mg/l dissolved solids not be used if other less mineralized supplies are available. For many purposes the dissolved-solids content is a major limitation on the use of water. A general calssification of water based on dissolved-solids content, in mg/l, is as follows (Winslow and Kister, 1956, p. 5): Waters containing less than 1,000 mg/l of dissolved solids are considered fresh; 1,000 to 3,000 mg/l, slightly saline; 3,000 to 10,000 mg/l, moderately saline; 10,000 to 35,000 mg/l, very saline; and more than 35,000 mg/l, brine.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness up to 60 mg/l are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; more than 180 mg/l, very hard.
Sodium-adsorption ratio (SAR)	Sodium in water.	A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil (U.S. Salinity Laboratory Staff, 1954, p. 72, 156). Defined by the following equation: $$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}},$$ where Na^+, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (me/l) of the respective ions.
Residual sodium carbonate (RSC)	Sodium and carbonate or bicarbonate in water.	As calcium and magnesium precipitate as carbonates in the soil, the relative proportion of sodium in the water is increased (Eaton, 1950, p. 123-133). Defined by the following equation: $$RSC = (CO_3^{--} + HCO_3^-) - (Ca^{++} + Mg^{++})$$ where CO_3^{--}, HCO_3^-, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (me/l) of the respective ions.
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.

the vicinities of Big Sandy and Gladewater, excessive concentrations of chloride in the Carrizo-Wilcox were rarely found in Upshur County. Figure 10 shows concentrations of chloride, depth of well, and the dissolved solids in the Carrizo-Wilcox aquifer in Gregg and Upshur Counties.

Iron in concentrations of more than 0.3 mg/l will cause unsightly reddish-brown stain on clothes and porcelain fixtures and incrustations or scale in pipes or other conduits and containers. Iron in 63 samples from the Carrizo-Wilcox aquifer ranged from 0.00 to 0.82 mg/l, but only 10 of the samples contained iron in excess of 0.30 mg/l. Iron in 13 samples from the Queen City Sand ranged from 0.02 to 48 mg/l with 5 of the samples containing iron in excess of 1.0 mg/l. On the basis of the sampling, iron is a serious problem in the Queen City, but it is not much of a problem in the Carrizo-Wilcox if the wells are properly constructed to draw water only from the Carrizo-Wilcox. The largest concentrations of iron from Queen City wells came from those completed at depths from about 100 to 200 feet. Where water high in iron is used, the iron can be reduced substantially by proper treatment.

Nitrate in excess of 45 mg/l may be pathologically harmful to humans. Where excessive concentrations of nitrate occur locally, it may be from fertilizer or the result of organic pollution from sewage facilities. In 83 samples from the Carrizo-Wilcox nitrate ranged from 0.0 to 14 mg/l; in 17 samples from the Queen City it ranged from 0.0 to 30 mg/l. On the basis of the sampling, nitrate does not appear to be a problem in either aquifer; however, it is reasonable to expect some excessive concentrations could exist at shallow depths in the vicinity of septic tanks and other waste-disposal facilities.

Sulfate in excess of 250 mg/l may produce a laxative effect. In 91 samples from the Carrizo-Wilcox, sulfate ranged from 0.0 to 150 mg/l, but only 4 of the samples contained in excess of 50 mg/l. Sulfate in 19 samples from the Queen City ranged from 0.0 to 784 mg/l, but only the sample with the highest concentration (784 mg/l) exceeded 50 mg/l. On the basis of the sampling, sulfate is no problem in the Carrizo-Wilcox, but it can be a local problem in the Queen City Sand.

Dissolved solids is a measure of the total mineral constituents in water, and water containing more than 500 mg/l is not recommended for a drinking-water supply if less mineralized waters are available. Water containing more than 1,000 mg/l dissolved solids is unsuitable for many purposes. Dissolved solids in 92 samples from the Carrizo-Wilcox ranged from 217 to 2,260 mg/l with 63 of the samples (68 percent) containing more than 500 mg/l; 22 of the samples (24 percent) contained dissolved solids in excess of 1,000 mg/l. Dissolved solids in 21 samples from the Queen City ranged from 31 to 953 mg/l, but only two samples exceeded 500 mg/l dissolved solids. On the basis of the sampling, dissolved solids can be a serious problem in the Carrizo-Wilcox; but in the Queen City, dissolved solids are a local problem. As in the case of chlorides, the highest concentrations of dissolved solids in the Carrizo-Wilcox generally occur in the deeper wells in Gregg County. Excessive concentrations are rare in the Carrizo-Wilcox in Upshur County except in the vicinities of Big Sandy and Gladewater (Figure 10).

Calcium and magnesium are the principal constituents in water that cause hardness. Excessive hardness causes increased consumption of soap and induces the formation of scale in hot water heaters and water pipes.

HARDNESS RANGE (MG/L)	CLASSIFICATION
60 or less	Soft
61 to 120	Moderately hard
121 to 180	Hard
More than 180	Very hard

Hardness in 97 samples from the Carrizo-Wilcox ranged from 1 to 127 mg/l, but only 4 of the samples showed hardness of more than 60 mg/l. Hardness in 23 samples from the Queen City ranged from 6 to 113 mg/l, but only 3 of the samples showed a hardness of more than 60 mg/l. On the basis of the sampling, water from both aquifers is generally soft; locally, it may be moderately hard to hard.

The quality of water for industry does not necessarily depend on potability-it may or may not be acceptable for human consumption. Suggested water-quality tolerances for a number of industries have been summarized by Hem (1959, p. 250-254) and Moore (1940). Water used by industry is commonly classified by uses as cooling, process, and boiler waters. For cooling uses the natural temperature may be significant. Temperatures of water from the Carrizo-Wilcox (Table 7) range from 21°C (69°F) to 27°C (80°F), generally increasing with depth. Temperature of water from the Queen City ranges from 18°C (65°F) to 22OC (72°F), also generally increasing with depth. Any constituent of the water that may adversely affect the heat-exchange surfaces is undesirable for cooling uses. Calcium, magnesium, aluminum, iron, and silica may cause scale or incrustations in both cooling and boiler facilities. Of these constituents, the relatively high concentrations of iron in the Queen City Sand may be of particular concern and the concentrations of silica in both aquifers may be of importance. The scale-forming tendency of silica in boiler water generally varies directly with applied pressures. The maximum suggested concentrations of silica in boiler water (Moore, 1940), for various ranges of boiler pressure, are shown on the following page.

CONCENTRATION OF SILICA (MG/L)	BOILER PRESSURE (PSI)
40	Less than 150
20	150 to 250
5	251 to 400
1	More than 400

Silica in 66 samples from the Carrizo-Wilcox ranged from 10 to 46 mg/l, but only 3 of the samples contained silica in excess of 20 mg/l. Silica in 11 samples from the Queen City ranged from 9.9 to 79 mg/l with 4 of the samples containing silica in excess of 20 mg/l. On the basis of the sampling, water from the Carrizo-Wilcox would be more suitable for boiler water than that from the Queen City.

Process water, the water incorporated into or used in contact with manufactured products, is subject to a wide range of quality requirements. The quality requirements for this use may include physical and biological factors in addition to chemical factors. Many process waters must be low in dissolved solids and free of iron and manganese. Iron would be the principal objection to process water from the Queen City, and dissolved solids would be the principal objection to process water from the Carrizo-Wilcox. Manganese in 20 samples from the Carrizo-Wilcox ranged from 0.00 to 0.09 mg/l with only 2 of the samples containing manganese in excess of 0.05 mg/l. Manganese in 2 samples from the Queen City was 0.09 and 0.10 mg/l. Unlike cooling and boiler water, much of the process water is consumed or undergoes a change during the manufacturing process and subsequently is either not available or not suitable for reuse.

Corrosiveness is an objectionable property in water for nearly every use. The hydrogen ion concentration (pH) is an important controlling factor, and generally, corrosiveness of water increases as the pH decreases. (See significance of pH in Table 6.) A pH of 7.0 indicates neutrality of a solution between acid and basic. The pH values of 72 samples from the Carrizo-Wilcox ranged from 6.9 to 8.7 with only one sample (6.9) showing a value less than 7.1. The pH values of 16 samples from the Queen City ranged from 3.0 to 8.1. Generally, water from wells tapping the Queen City at depths of more than 200 feet have pH values higher than 7.0 and water from depths of less than 200 feet tends to be more corrosive than water from the Carrizo-Wilcox.

The suitability of water for irrigation generally cannot be evaluated on chemical content alone, but must be evaluated along with type of soil, adequacy of drainage, tolerance of crops, and frequency of rainfall. Dissolved constituents (salinity) of the applied irrigation waters are significant, but permissible limits will vary with local conditions controlling the rate of accumulation of the constituents in the soil from the applied waters. With a rainfall of 46 inches and a sandy, well-drained soil in Gregg and Upshur Counties, permissible limits for salinity probably would be sufficiently high to allow supplemental irrigation with water from both the Carrizo-Wilcox and Queen City aquifers.

DISPOSAL OF OIL-FIELD BRINES

Considerable quantities of brine are produced along with the oil from the East Texas oil field in Gregg and Upshur Counties. According to reports of the Railroad Commission of Texas and the East Texas Salt Water Disposal Company (Texas Water Commission and Texas Water Pollution Control Board, 1963), total brine production in 1961 was 92,450,000 barrels (about 12,000 acre-feet). This, incidentally, amounts to nearly four times the total amount of fresh ground water produced in the report area. Without adequate disposal methods, brine may contaminate the fresh-water supplies in the report area.

Methods of brine disposal are regulated by the Railroad Commission of Texas. Rules require that oil-field brine be disposed of in such a way that surface- or ground-water sources are not contaminated. Brine is disposed of in the report area mostly by injection wells; a comparatively minor amount (about 1 percent) is disposed of by the open pit method. Effective January 1, 1969, the Railroad Commission of Texas prohibits the use of pits for storage and evaporation of oil-field brine and other mineralized waters (by Special Order No. 20-56, 841) .

Another potential source of contamination of ground-water supplies is the upward movement of brine from deep strata through inadequately cased or improperly plugged oil and gas tests and wells. This contamination hazard has been minimized in many oil and gas fields by the regulations of the Railroad Commission, which specify in field rules the casing and plugging requirements. As additional data become available in some areas, it is apparent that the requirements do not always adequately protect the fresh to slightly saline waters. For example, the field rules for the East Texas oil field specify a minimum of 100 feet of surface casing for oil wells. Data collected during the investigation show that fresh to slightly saline water extends down to the top of the Midway Group, well below the specified surface casing depth. However, no cases have been reported in which contamination has resulted from inadequate surface casing in Gregg and Upshur Counties. Holloway (1964) investigated a case of alleged contamination of the water supply in Kilgore, but the results of the investigation were inconclusive. Also, a comparison of samples from water wells dating back to early oil-field development with later samples from the same wells (Table 9) does not show deterioration of ground-water quality in the East Texas oil field.

AVAILABILITY OF GROUND WATER FOR FUTURE DEVELOPMENT

The availability of ground water for future development from the aquifers in Gregg and Upshur Counties depends principally on the capacity of the aquifers to transmit and store water and the rate of recharge to the aquifers. Another factor is the chemical quality of the water, which in some parts of the area may be a deterrent to development of the ground-water supplies, particularly for municipal and domestic uses.

The capacity of an aquifer to transmit water under a hydraulic gradient that has not been significantly affected by pumping is an index of the minimum quantity of water that perennially would be available for development. On the basis of the present hydraulic gradient of 8 feet per mile and an average permeability of 80 gpd per square foot, about 12,000 acre-feet a year (10.9 mgd) passes through a vertical section of the Carrizo-Wilcox aquifer 68 miles long and coincident with the 250-foot contour (Figure 6). Whether this amount is perennially available for development is not definitely known because the 8-foot per mile gradient used in the computations apparently has been affected by pumping from the aquifer, at least to a small extent. In Wood County, where development of the Carrizo-Wilcox aquifer has been similar to that in the report area, and where there also is practically no discharge to streams, the average hydraulic gradient was 5 feet per mile, which closely approximates the gradient undisturbed by pumping. If this gradient is applied to the aquifer in Gregg and Upshur Counties, about 8,000 acre-feet per year would be transmitted through the aquifer or more than 2 times the quantity pumped in 1966.

The Queen City Sand transmits considerably less water than does the Carrito-Wilcox under the same hydraulic gradient. Assuming a permeability of 35 gpd per square foot and a gradient of 8 feet per mile, 2,700 acre-feet per year (2.4 mgd) is moving across the 300-foot contour shown on Figure 7. This compares to only 200 acre-feet pumped from the aquifer in 1966. An amount several times greater than that transmitted through the aquifer is being discharged to the streams at the outcrop. Perhaps a large part of this discharge could be salvaged by the use of a large number of closely spaced shallow wells throughout the recharge area, which is nearly the entire report area. Although complete salvage in this manner would not be practicable, the present rate of pumping (about 200 acre-feet per year) could be increased at least several times.

The quantity of ground water that may be perennially available for development is small compared to the quantity of water that is in transient storage. Computations based on the saturated sand thickness and a porosity of 30 percent indicate that 70 million acre-feet of water is in storage, of which 45 million acre-feet is in the Carrizo-Wilcox aquifer and 25 million acre-feet is in the Queen City Sand. Much of the water in the Carrizo-Wilcox, however, lies at a depth of more than 400 feet, the depth that may be considered as the present economic limit for development. Of the 25 million acre-feet of water in the Queen City, only about 8 million acre-feet theoretically would be available from storage, assuming a specific yield of only 10 percent. To develop even half of this amount would be difficult because the very low average transmissibility of the aquifer (about 5,000 gpd per foot) would require many small-capacity wells.

The chemical quality of the water, particularly the chloride content, may limit development of the ground-water supplies in the Carrizo-Wilcox aquifer in a large part of Gregg County and in a few localized areas in Upshur County. In these areas, the chloride concentration commonly is too high for municipal or domestic purposes.

The maps (Figures 11 and 12) that show the thickness of sand containing fresh water are useful in locating areas favorable for the development of ground water from the two aquifers. The thickness of the sand in the Carrizo-Wilcox ranges from 200 feet in the southeastern part of Gregg County to slightly more than 400 feet near Diana in the east-central part of Upshur County (Figure 11). The most favorable areas for development are those where the saturated sands are more than 300 feet thick. In these areas, properly constructed and adequately spaced wells probably would be capable of yielding at least 500 gpm. Yields of this magnitude are obtained from wells in the vicinity of Kilgore, Gilmer, and Glenwood. The thickness of saturated sand in the Queen City ranges from less than 100 feet in most of Gregg County to 400 feet in the southwestern part of Upshur County (Figure 12). The most favorable areas for wells capable of yielding as much as 200 gpm are those where the thickness is at least 200 feet. A well at Big Sandy currently yields 272 gpm; similar yields probably could be obtained in the vicinity of West Mountain, Glenwood, and Diana.

DEFINITION OF TERMS

Many of the following definitions have been taken or adapted from Meinzer (1923), American Geological Institute (1960), Langbein and Iseri (1960), and Ferris and others (1962).

Acre-foot (ac-ft).-The volume of water required to cover one acre to a depth of 1 foot; 43,560 cubic feet, or 325,851 gallons.

Aquiclude. -A formation, group of formations, or part of a formation that is non-water bearing, or is sufficiently impermeable to severely restrict the transmission of water.

Aquifer.-A formation, group of formations, or part of a formation that is water bearing, or is sufficiently permeable to allow transmission of considerable quantities of water.

Aquifer test.-A pumping test from which the essential hydrologic properties of an aquifer may be determined, such as the coefficients of permeability, transmissibility, and storage.

Artesian aquifer.-An aquifer that is confined both above and below by a relatively impermeable formation (aquiclude), and in which water is under pressure greater than atmospheric pressure. Consequently, the water rises in artesian wells to levels above the top of the aquifer and sometimes rises to levels above land surface (flows).

Cone of depression.-Depression of the water table or piezometric surface caused by a discharging well; more or less the shape of an inverted cone.

Drawdown. -The difference between the static water level and the pumping water level in a well.

Evapotranspiration. -A combined term for evaporation and transpiration; the amount of water withdrawn from surface and ground storage by evaporation and plants.

Fresh water and saline water.-The terms as applied in the report are taken from a general classification based on dissolved-solids content by Winslow and Kister (1956); fresh, 0 to 1,000 mg/l (milligrams per liter); slightly saline, 1,000 to 3,000 mg/l; moderately saline, 3,000 to 10,000 mg/l; very saline, 10,000 to 35,000 mg/l; and brine, more than 35,000 mg/l.

Hydraulic gradient. -The slope of the water table or piezometric surface, usually expressed in feet per mile.

Milliequivalents per liter (me/l).-The concentration of chemical substances in terms of the reacting values of electrically charged particles or ions in solution.

Milligrams per liter (mg/l). -One milligram per liter represents 1 milligram of solute in 1 kilogram of solution. As commonly measured and used, milligrams of a substance per liter of water is numerically equivalent to parts per million, in concentrations less than about 7,000 parts per million.

Permeability, coefficient of.-A measure of the capacity of an aquifer to transmit water. The rate of flow in gallons per day through a cross section of 1 square foot under a hydraulic gradient of 1 foot per foot and at a temperature of 16°C (6O°F).

Piezometric surface.-An imaginary surface that everywhere coincides with the static level of the water in an aquifer. The surface to which the water from a given aquifer will rise under its hydrostatic pressure or head.

Specific capacity.-The rate of yield of a well per unit of drawdown, usually expressed as gallons per minute per foot of drawdown.

Storage, coefficient of.-The volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Transmissibility, field coefficient of. -The rate of flow of ground water in gallons per day through a vertical strip of the aquifer 1 foot wide extending through the vertical thickness of the aquifer at a hydraulic gradient of 1 foot per foot and at the prevailing temperature of the water.

Transmission capacity of an aquifer. -The quantity of water that can be transmitted through a given width of an aquifer at a given hydraulic gradient, usually expressed in acre-feet per year or million gallons per day.

Water-table aquifer.-An aquifer that is unconfined; the upper surface of the zone of saturation is under atmospheric pressure only and the water is free to rise or fall in response to the changes in the volume of water in storage. The depth to the static water level in a water-table well coincides with the depth to the water table.

Water tab/e.-The upper surface of the zone of saturation.

Yield of a well.-The rate of discharge, usually expressed in gallons per minute (gpm). In this report, yields are classified as small, less than 50 gpm; moderate, 50 to 500 gpm; and large, more than 500 gpm.

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Table 8.—Drillers' Logs of Wells in Gregg and Upshur Counties

Gregg County

Well KU-35-26-706

Owner: City of White Oak.
Driller: Layne-Texas Co.

	THICKNESS (IN.)	DEPTH (FT)
Topsoil	1	1
Clay, yellow	13	14
Clay, sandy	16	30
Shale, brown	6	36
Shale, sandy	8	44
Shale, gray and brown	96	140
Rock	3	143
Shale and sandy shale	61	204
Shale, sandy	19	223
Shale and lignite	41	264
Shale, sandy	39	303
Shale	19	322
Sand	14	336
Shale and sand	3	339
Sand and shale layers	10	349
Shale and hard layers	2	351
Sand, thin layers	17	368
Shale and sand layers	4	372
Sand and shale layers	49	421
Shale and thin layers of sand	59	480
Shale	22	502

Well KU-35-27-401

Owner: Tryon Road Water Supply Corp.
Driller: Layne-Texas Co.

	THICKNESS (IN.)	DEPTH (FT)
Surface	6	6
Clay, sandy, and sand	39	45
Clay, blue and streaks of sand	95	140
Sand, black (broken—cut good)	20	160
Shale	37	197
Rock	1	198
Shale	6	204
Shale and streaks of sand	32	236
Sand and hard streaks	21	257
Clay, sandy and streaks of sand	24	281
Sand, cut good	11	292
Clay, sandy	9	301
Lignite	9	310
Sand and lignite	27	337
Sand, real fine	49	386
Shale, hard	10	396
Sand, sandy shale and streaks of lignite	33	420
Shale and sandy shale	24	453
Shale, sandy and sand	16	469
Sand, good	27	496
Shale, sandy	14	510
Sand, broken	11	521
Shale	8	529
Lignite	4	533
Shale	2	535
Shale and streaks of sand	19	554
Sandrock	10	564
Shale, sandy	65	629
Sand and gravel	5	634
Shale	14	648
Sand and clay streaks	25	673
Clay, sandy and streaks of sand	55	728
Shale	33	761
Sand, fine, gray	43	804
Sand and streaks of shale	55	859
Shale	5	864

Upshur County

Well YK-35-17-205

Owner: Pittsburg Standard Conduit Co.
Driller: Layne-Texas Co.

	THICKNESS (IN.)	DEPTH (FT)
Surface	4	4
Clay, sandy	8	12
Sand	4	16
Clay	17	33

Table 8.—Drillers' Logs of Wells in Gregg and Upshur Counties—Continued

	THICKNESS (IN.)	DEPTH (FT)
Well YK-35-17-205—Continued		
Sand	12	45
Shale, dark gray, sandy and shale	32	77
Sand, gray	45	122
Shale, gray, and sandy shale	37	159
Sand and shale breaks	19	178
Shale, sandy, and sand layers	52	230
Shale, sandy, and lignite streaks	29	259
Shale, gray, and lignite streaks	44	303
Sand, gray, and shale layers	13	316
Shale, gray, and lignite	30	346
Shale, gray, and layers of sand	20	366
Sand and shale breaks	4	370
Shale and sand streaks	6	376
Sand and hard streaks	4	380
Sand and sandy shale	18	398
Shale and sand streaks	12	410
Shale, sand streaks, and lignite	24	434
Sand and sandy shale	37	471
Shale, sandy, and layers of lignite	31	502
Shale, gray and white	8	510
Sand and shale layers	22	532
Sand, few shale layers (cut good)	31	563
Shale, sandy	8	571
Sand, few shale layers (cut good)	22	593
Sand and lignite	7	600
Shale, brown, and lignite	12	612

	THICKNESS (IN.)	DEPTH (FT)
Well YK-35-18-702		
Owner: East Texas Water Co. Driller: Layne-Texas Co.		
Surface	2	2
Clay, sandy	68	70
Sand, fine	10	80
Sand, gray, coarse, and rock layers	51	131
Shale	21	152
Sand, fine, gray, and streaks of shale	39	191
Shale	14	205
Sand, fine, gray	24	229
Shale	12	241
Sand, fine, gray	29	270
Shale	13	283
Sand, coarse, white	30	313
Shale and sandy shale, and lignite	73	386
Sand, fine, white	8	394
Shale and lignite	8	402
Sand, fine, and lignite	14	416
Shale, and sandy shale	49	465
Sand, fine, white	29	494
Lignite and shale	12	506
Sand	6	512
Shale	15	527
Sand, fine	83	610
Lignite and sand	10	620
Sand, fine	18	638
Shale and streaks of sand	12	650