Report 270

GROUND-WATER RESOURCES OF COLORADO, LAVACA, AND WHARTON COUNTIES, TEXAS

TEXAS DEPARTMENT OF WATER RESOURCES

July 1982

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GROUND-WATER RESOURCES OF COLORADO, LAVACA, AND WHARTON COUNTIES, TEXAS

By

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GROUND-WATER RESOURCES OF COLORADO, LAVACA, AND WHARTON COUNTIES, TEXAS

ABSTRACT

The main sources of fresh water for all uses in Colorado, Lavaca, and Wharton Counties are the Chicot and Evangeline aquifers. The Jackson Group, Catahoula Sandstone, and Jasper aquifer are minor sources of water and are largely undeveloped in the area. The Chicot aquifer, which consists of discontinuous layers of sand and clay of about equal aggregate thickness, ranges in total thickness from 0 in the outcrop area to about 1,200 feet (366 m) in southern Wharton County. The Evangeline aquifer, which also consists of discontinuous sand and clay layers, ranges in total thickness from 0 at the outcrop to about 1,500 feet (457 m) in Wharton County. The combined thicknesses of the fresh-water sands in the Chicot and Evangeline aquifers range from 0 at the outcrop to more than 850 feet (259 m) in Wharton County.

Average daily withdrawals of ground water for all uses in 1974 were 252 million gal/d (954,000 m^3/d), most of which was used for rice irrigation; smaller amounts of water were pumped for municipal supply and industrial use. Estimates of the additional amounts of fresh and slightly saline water in available storage are based on the assumptions of average sand thicknesses of 250 feet (76 m) and 200 feet (61 m) in the Chicot and Evangeline aquifers, respectively, and a specific yield of 0.2. Sands of the Chicot aquifer contain about 72.0 million acre-feet (88,776 hm^3) of fresh water in available storage, and sands of the Evangeline aquifer contain about 71.7 million acre-feet (88,406 hm^3) of fresh water and about 9.0 million acre-feet (1 1,097 hm^3) of slightly saline water in available storage. Additional amounts of water, probably 20 to 25 percent of the amount available from the sands; would be available from the clays.

Additional development of the ground-water resources is possible throughout most of Colorado, Lavaca, and Wharton Counties, but the consequences of more land subsidence and declining water levels should be carefully considered. The most favorable areas are in central Wharton County. Additional potential for development exist in most other areas where as much as 50 feet (15 m) of sand occurs in the Chicot aquifer.

Considerable amounts of brine are produced in Colorado, Lavaca, and Wharton Counties in conjunction with the production of oil and gas. To prevent possible contamination of “the fresh water", the Railroad Commission of Texas requires that oil and gas wells must have cemented casings from the land surface to the base of the slightly saline water. The elimination of brine-disposal pits has minimized contamination by this method of salt-water disposal, but contamination may still occur through improperly cased wells, abandoned injection wells, and abandoned brine-disposal pits.

The vast amounts of water in storage cannot be recovered fully without depleting the supply and incurring other serious consequences. More judicious approaches to determining the quantities of water available for development were based on theoretical lines of recharge and discharge with drawdowns of 200 feet (61 m) at the lines of discharge. On the basis of theoretical lines of recharge and discharge with drawdowns of 200 feet (61 m), about 50,000 acre-feet (62 hm^3) and 20,000 acre-feet (25 hm^3) could be produced from the Chicot and Evangeline aquifers, respectively, with only moderate pumping lifts without depleting the supply. These amounts of water are less than the potential amounts of natural recharge that are available to the aquifers. The potential recharge is estimated to be 78,000 acre-feet (96 hm^3) per year for the Chicot aquifer and 38,000 acre-feet (47 hm^3) per year for the Evangeline aquifer. These recharge estimates are about the maximum amount perennially available without depleting the large quantities of ground water in storage.

Present (1974) pumpage from the Chicot and Evangeline aquifers exceeds those estimated amounts of recharge. Consequently, some water-level decline and land-surface subsidence may be expected to continue.

Land-surface subsidence as a result of ground-water withdrawal is not a problem at this time. However, more data are needed to determine the extent of subsidence and the relationship between the amount of ground-water withdrawals and the amount of subsidence. The available data indicate that maximum subsidence within the three counties is less than 1 foot (0.3 m), and in most places is less than 0.5 foot (0.15 m).

GROUND-WATER RESOURCES OF COLORADO, LAVACA, AND WHARTON COUNTIES, TEXAS

INTRODUCTION

Colorado, Lavaca, and Wharton Counties, which include an area of about 3,000 square miles (7,770 km^2) on the Gulf Coastal Plain of southeastern Texas, are about midway between Houston and San Antonio and from 35 to 100 miles (56 to 161 km) inland from the Gulf of Mexico (Figure 1). Agriculture, mainly rice farming and livestock production, form the economic base for a population of about 75,000 in the three-county area. The production of oil, gas, sulfur, and gravel are additional and important sources of income in some local areas.

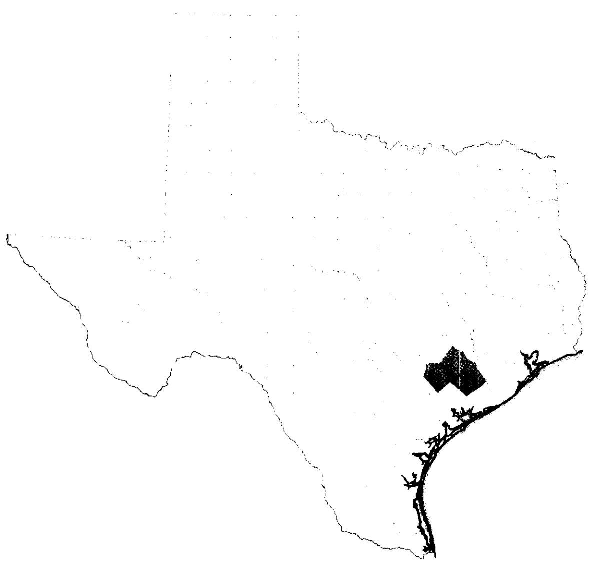

Figure 1.—Location of Colorado, Lavaca, and Wharton Counties

The climate of the area is humid subtropical, and annual rainfall is abundant. The average annual precipitation for 1912-73 was 37.07 inches (940 mm) at Hallettsville in Lavaca County and 41.02 inches (1,040 mm) at Columbus in Colorado County. For 1905-73, the average annual precipitation at Pierce in Wharton County was 41.11 inches (1,040 mm). Rainfall is fairly well distributed throughout the year, with the maximum amount usually occurring in May or September and the minimum amount usually occurring in March (Figure 2). The average monthly temperatures at Pierce and Hallettsville for 1932-63 are also shown on Figure 2. The average annual gross lake-surface evaporation for the three-county area was about 54 inches (1,370 mm) during 1940-65 (Figure 3). Evaporation is not a problem in the area except during exceptionally dry years when the potential evaporation rate, which exceeds the average annual precipitation, increases the severity of drought conditions.

Purpose and Scope of the Investigation

The investigation of the ground-water resources of Colorado, Lavaca, and Wharton Counties began in 1973 as a cooperative project of the U.S. Geological Survey and the Texas Water Development Board (now the Texas Department of Water Resources). The purpose of the investigation was to determine the occurrence, availability, dependability, quantity, and quality of the ground-water resources of the area. Special emphasis was placed upon estimating the quantities of ground water available for development and on determining the areas most favorable for additional development.

The scope of the investigation included the collection, compilation, and analyses of data on the location and extent of the water-bearing formations, the chemical quality of the water in the aquifers, the quantity of water being pumped for all uses, the effects of ground-water pumping on water levels in wells, the hydraulic characteristics of the principal water-bearing formations, estimates of the quantities of ground water available for development, and the effects of ground-water withdrawals on land-surface subsidence. An inventory was made of all industrial, municipal, and irrigation wells, and of selected rural-domestic wells, livestock wells, and test holes in Colorado, Lavaca, and Wharton Counties (Table 4); records of selected wells were compiled for adjacent counties (Table 5). The locations of the wells and test holes are shown on Figures 30-32.

In addition to the inventory of wells and test holes, the following items of work were included in the investigation:

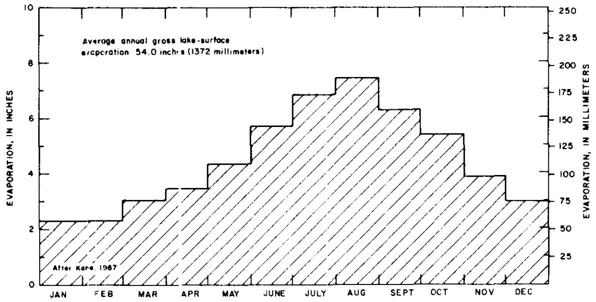

Figure 3.—Average Monthly Gross Lake-Surface Evaporation in Colorado, Lavaca, and Wharton Counties, 1940-65

1. Electrical logs of water wells and oil tests were analyzed to construct geohydrologic sections, to construct maps showing the thicknesses of sands in the principal aquifers, to determine the altitudes of the base of fresh and slightly saline water, and to determine the altitudes of the base of the Chicot and Evangeline aquifers.

2. An inventory was made of the withdrawals of ground water for public supply, industrial use, and irrigation.

3. Drillers' logs of wells were collected and analyzed (Table 6).

4. Forty-three aquifer tests were made in wells in the Chicot, Evangeline, and Jasper aquifers. The information obtained from these tests provided data for the computations of transmissivities, storage coefficients, and hydraulic conductivities.

5. Climatological records were collected and compiled.

6. Water levels in wells were measured, and historical records of water levels were analyzed to determine the long-term hydrologic effects of ground-water pumping (Table 7).

7. Data on land-surface subsidence were collected and analyzed.

8. Water samples were collected and analyzed to determine the chemical quality of the water in the principal aquifers (Table 8).

Previous Investigations

Taylor (1902, 1907), in generalized hydrologic studies of the Gulf Coastal Plain, furnished the earliest information available on ground water in Colorado, Lavaca, and Wharton Counties. His work is the source of the water-level data used to determine the original (predevelopment) altitudes of the potentiometric surfaces in the aquifers.

George (1936) compiled information on wells and test holes, water quality, and drillers' logs in Lavaca County. May (1938) inventoried wells in Colorado County and assembled drillers' logs and chemical analyses of ground-water samples. Bridges (1935) compiled well records, drillers' logs, and chemical analyses of water samples for Wharton County; and Cromack (1940) provided additional well records, drillers' logs, and water analyses for Wharton County. Barnes (1948) presented a detailed discussion of the water resources of Wharton County, including well records, drillers' logs, and chemical analyses.

Water levels in a few selected wells in Colorado, Lavaca, and Wharton Counties have been measured annually by either the U.S. Geological Survey or the Texas Department of Water Resources since 1934, and in other wells since 1956. Historical water-level measurements in Jackson, Matagorda, and Wharton Counties were reported by Rayner (1958). Wood (1956) reported on ground-water availability on the Texas Gulf Coast, including Colorado, Lavaca, and Wharton Counties. Wood, Gabrysch, and Marvin (1963) collected field data and prepared a report on the water-bearing potential of the principal aquifers in the Gulf Coast region, including the area of Colorado, Lavaca, and Wharton Counties.

Mount and others (1967) made a reconnaissance of the Colorado River basin that included parts of Colorado and Wharton Counties. Because the ground-water hydrology of Wharton County and the southern parts of Colorado and Lavaca Counties is similar to the hydrology of other areas in which investigations have been completed, the following reports were useful in analyzing the hydrologic data obtained for this report:

County	Author and date[1]
Jackson	Baker (1965)
Matagorda	Hammond (1969)

[1] See references cited

County	Author and date[1]
Brazoria	Sandeen and Wesselman (1973)
Fort Bend	Wesselman (1972)
Austin and Waller	Wilson (1967)
Fayette	Rogers (1967)
Gonzales	Shafer (1965)
DeWitt	Follett and Gabrysch (1965)
Victoria and Calhoun	Marvin and others (1962)

[1] See references cited

Well-Numbering System

The well-numbering system used in this report is the system adopted by the Texas Department of Water Resources for use throughout the State. Under this system, each one-degree quadrangle in the State is given a number consisting of two digits. These are the first two digits in the well number. Each one-degree quadrangle is divided into 7 1/2-minute quadrangles that are given two-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 given single-digit numbers from 1 to 9. This is the fifth digit of the well number. Each well within a 2 1/2-minute quadrangle is given a two-digit number in the order in which it was inventoried. These are the last two digits of the well number.

Only the last three digits of the well number are shown adjacent to the well locations on the maps (Figures 30-32). The second two digits are shown in the northwest corner of each 7 1/2-minute quadrangle, and the firts two digits are shown by the large double-line numbers.

In addition to the seven-digit well number, a two-letter prefix is used to identify the county. The prefixes for Colorado, Lavaca, Wharton, and adjacent counties are as follows:

County	Prefix	County	Prefix
Austin	AP	Gonzales	KR
Brazoria	BH	Jackson	PP
Colorado	DW	Lavaca	RY
DeWitt	HX	Matagorda	TA
Fayette	JT	Victoria	YT
Fort Bend	JY	Warton	ZA

For example, well ZA-66-54-603 (which supplies water for the city of El Campo) is in Wharton County (ZA) in the 1-degree quadrangle (66), in the 7 1/2-minute quadrangle (54), in the 2 1/2-minute quadrangle (6), and was the third well (03) inventoried in that 2 1/2-minute quadrangle.

Metric Conversions, Abbreviations, and Use of Quantitative Terms

For readers interested in using the metric system, metric equivalents of English units of measurements are given in parentheses in the text of this report. The English units may be converted to metric units by the following conversion factors:

From	Multiply by	To obtain
acre-foot	0.001233	cubic hectometer (hm^3)
barrel	.1590	cubic meter (m^3)
foot	.3048	meter (m)
foot per day (ft/d)	.3048	meter per day (m/d)
foot per mile (ft/mi)	.189	meter per kilometer (m/km)
foot squared per day (ft^2/d)	.0929	meter squared per day (m^2/d)
inch	25.4	millimeter (mm)
inch	2.54	centimeter (cm)
mile	1.609	kilometer (km)
million gallons per day (million gal/d)	.04381	cubic meter per second (m^3/s)
million gallons per day (million gal/d)	3,785	cubic meter per day (m^3/d)
square mile	2.590	square kilometer (km^2)

Quantitative terminology used in this report with regard to yields of wells and water quality are defined as follows:

Yields of wells (in gallons per minute)	Water quality[1] (dissolved-solids concentration in milligrams per liter)
small—less than 100	fresh—less than 1,000
moderate—100 to 1,000	slightly saline—1,000 to 3,000
large—more than 1,000	moderately saline—3,000 to 10,000
	very saline—10,000 to 35,000
	brine—more than 35,000

The general term "salt water" is used here to describe water in which the salinity varies or is unknown.

[1] Modified from Winslow and Kister (1956).

Acknowledgments

The authors express their appreciation to the many land owners, well owners, and industrial and municipal officials for their cooperation in allowing access to their land and wells, for assisting in the collection of well data, and for permitting aquifer tests to be conducted in appropriate wells.

Particular appreciation is expressed to Mr. Harold Mickelson, to the Crowell Drilling Company, to the Katy Drilling Company for their exceptional help during this investigation, to Jack Waldron with Layne Texas Company, and to Marvin Lang of L&N Drilling Company.

GEOLOGIC AND HYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

The geologic units containing fresh and slightly saline water in Colorado, Lavaca, and Wharton Counties are the Jackson Group of Eocene age; the Catahoula Sandstone of Oligocene and Miocene age; the Oakville Sandstone and Fleming Formation of Miocene age; the Goliad Sand of Pliocene age; the Willis Sand, Lissie Formation (correlative with the Bentley and Montgomery Formations), and Beaumont Clay of Pleistocene age; and the alluvium of Quaternary age (Figure 4). The hydrologic units are identified as the Catahoula Sanastone, the Jasper aquifer, the Burkeville confining layer, the Evangeline aquifer, and the Chicot aquifer. The correlation of the hydrologic and geologic units is given in Table 1.

With exception of the Quaternary alluvium, the geologic formations crop out in belts that are nearly parallel to the shoreline of the Gulf of Mexico. The younger formations crop out nearer the Gulf and the older formations crop out farther inland (Figure 4). All formations thicken downdip so that the older units dip more steeply than the younger ones. Faults are common in the area, and some of them displace the older Tertiary formations by several hundred feet. The south flank of Boling Dome, for example, is associated with one of the largest known thrust faults on the Texas Gulf Coast (Halbouty and Hardin, 1954, p. 1725-1740). The fault displacements tend to decrease upward so that in many places the faulting may not be apparent at the surface. Generally, the geologic units containing freshwater are not displaced enough to disrupt regional hydraulic continuity; therefore the faults have not been shown on the geologic map and geohydrologic sections.

Jackson Group

The Jackson Group of Eocene age underlies the Catahoula Sandstone. The Whitsett Formation, the uppermost formation of the Jackson Group, crops out in the extreme northwestern part of Lavaca County (Figure 4). The older formations of the Jackson Group are present in the subsurface but are not differentiated in this report.

The Jackson Group is composed of a series of predominantly terrestrial shales with some sand units that are capable of yielding small to moderate amounts of fresh to slightly saline water in the outcrop area and in areas a short distance downdip from the outcrop. Geologic and hydrologic data for the Jackson Group are meager, and because of its minor importance as a water-bearing unit in the three-county area, the Jackson Group is not discussed in detail in this report.

Catahoula Sandstone

The Catahoula Sandstone of Oligocene and Miocene age, which consists of alternating beds of clay, tuff, and sandstone, crops out in the northwestern part of Lavaca County (Figure 4). Near the outcrop, the Catahoula is sandy, but it generally becomes tuffaceous downdip. The sandy units of the Catahoula are probably in hydraulic continuity with the overlying sands of the Jasper aquifer. In and near the outcrop area, the Catahoula supplies small to moderate quantities of fresh to slightly saline water to wells in the northwestern part of Lavaca County and in the extreme northwestern part of Colorado County. Downdip from the outcrop area, the Catahoula contains a greater percentage of fine-grained material and functions as a confining layer.

Jasper Aquifer

The Jasper aquifer consists mainly of the Oakville Sandstone, which crops out in the northwestern part of Lavaca County (Figure 4), but may in places include the upper part of the Catahoula Sandstone (Table 1). The Oakville, which unconformably overlies the Catahoula Sandstone, consists of laterally discontinuous sand and gravel lenses interbedded with shale and clay. Massive crossbedded-sandstone beds at the base of the formation grade upward into more thinly bedded units that contain greater amounts of shale and clay. The Jasper aquifer ranges in thickness from about 200 feet (61 m) near the outcrop to about 2,500 feet (760 m) downdip in

Table 1.--Correlation of geologic and hydrologic units

Geologic classification: System	Series	Stratigraphic unit	Colorado, Lavaca, and Wharton Counties	Houston district (Wood and Gabrysch, 1965)	Houston district (Jorgensen, 1975)	Brazoria County (Sandeen and Wesselman, 1973)	Austin and Waller Counties (Wilson, 1967)	Galveston County (Petitt and Winslow, 1957)	Houston district (Lang, Winslow, and White, 1950)	Fort Bend County (Wesselman, 1972)
QUATERNARY	Pleistocene and Holocene	Quaternary alluvium	Chicot aquifer	"Confining" layer and Alta Loma Sand of Rose (1943)	Chicot aquifer: Upper unit	Chicot aquifer: Upper unit	Alluvium of the Brazos River	Beach and dune sand	Alluvial deposits	Chicot aquifer: Upper unit
		Beaumont Clay	Chicot aquifer	Heavily pumped layer	Chicot aquifer: Upper unit	Chicot aquifer: Upper unit	Evangeline aquifer (May contain unidentifiable parts of basal Chicot aquifer along the edges of Brazos River flood plain or along southern part of both counties)	Beaumont Clay	Beaumont Clay	Chicot aquifer: Upper unit
		Lissie Formation: Montgomery Formation	Chicot aquifer	Heavily pumped layer	Chicot aquifer: Lower unit	Chicot aquifer: Lower unit	Evangeline aquifer	"Alta Loma Sand"	"Alta Loma Sand"	Chicot aquifer: Lower unit
		Lissie Formation: Bentley Formation	Chicot aquifer	Heavily pumped layer	Chicot aquifer: Lower unit	Chicot aquifer: Lower unit	Evangeline aquifer	"Alta Loma Sand"	"Alta Loma Sand"	Chicot aquifer: Lower unit
		Willis Sand	Chicot aquifer	Heavily pumped layer	Chicot aquifer: Lower unit	Chicot aquifer: Lower unit	Evangeline aquifer	Lissie Formation	Zone 7 Zone 6	Chicot aquifer: Lower unit
TERTIARY	Pliocene	Goliad Sand	Evangeline aquifer	Heavily pumped layer	Evangeline aquifer	Evangeline aquifer	Evangeline aquifer		Zone 5 Zone 4 Zone 3	Evangeline aquifer
	Miocene	Fleming Formation	Burkeville confining layer	Zone 2	Burkeville confining layer		Burkeville aquiclude		Zone 2	Burkeville aquiclude
		Oakville Sandstone	Jasper aquifer		Jasper aquifer: Upper unit Lower unit		Jasper aquifer		Zone 1	Jasper aquifer
		Catahoula Sandstone (Tuff): Upper Catahoula	Catahoula Sandstone (designated as Tuff west of Colorado County)							
	?—?—?	Catahoula Sandstone (Tuff): "Anahuac" Formation	Catahoula Sandstone (designated as Tuff west of Colorado County)							
	Oligocene	Catahoula Sandstone (Tuff): "Frio" Formation	Catahoula Sandstone (designated as Tuff west of Colorado County)							
	Eocene	Jackson Group: Whitsett Formation	Jackson Group							

Wharton County. The average range in thickness within the zones of fresh to slightly saline water is about 200 to 800 feet (61 to 240 m).

The transmissivity values for the Jasper aquifer (Table 2), which were calculated by using the Theis equation (Wenzel, 1942, p. 94-97) and measurements of the recovery of water levels in four pumped wells in Lavaca County (Table 2), ranged from 500 to 1,250 ft^2/d (45 to I I5 m^2/d). The storage-coefficient values were not determined. In parts of the geohydrologic sections (Figures 5-8), the Jasper aquifer and the overlying Burkeville confining layer were combined because delineation of the units would be highly arbitrary.

The Jasper aquifer, which is a minor source of water in the three-county area, supplies small to moderate quantities of water to municipal supply, irrigation, rural-domestic and livestock wells. Because both the Jasper and the Eurkeville contain slightly saline to moderately saline water in most areas, and because they occur at depths of more than 2,500 feet (760 m) in southern Wharton County, they are not likely to be developed as major sources of ground-water supply in most of the three-county area.

Burkeville Confining Layer

The Burkeville confining layer is composed mostly of clay but contains some layers of sand. In the subsurface, identification of the Burkeville is based on the sequences of clay layers, as determined from electrical logs, that act as regional impediments to the vertical flow of water. The thickness of the Burkeville confining layer (Figures 5-8) generally ranges from about 300 to 500 feet (90 to 150 m). Although the Burkeville is a confining layer downdip from the outcrop, parts of the unit in the outcrop area and in the shallow subsurface contain sufficient amounts of saturated sand to supply small quantities of fresh to slightly saline water to rural-domestic and livestock wells.

Evangeline Aquifer

The Evangeline aquifer consists of sand and clay layers in the Goliad Sand and in the upper part of the Fleming Formation (Figure 4 and Table I). The altitude of the base of the Evangeline (Figure 9) was determined by interpretations of electrical logs, which indicate that the aquifer ranges in depth from the land surface at the outcrop to more than 2,300 feet (700 m) below NGVD (National Geodetic Vertical Datum or mean sea level) in southern Wharton County. The Evangeline aquifer is present in the subsurface throughout most of Colorado, Lavaca, and Wharton Counties. It crops out in central Lavaca County and subcrops (overlapped by the Willis Formation) in central and northern Colorado County (Figure 4), but is absent in northwestern Lavaca County in the outcrop area of the Burkeville confining layer.

Within the three-county area, the Evangeline generally contains more sand than clay, and although some sands and clays are continuous throughout much of the area, the unit varies in total thickness from 0 in the outcrop area to about 1,500 feet (45 7m) in the south-central part of Wharton County. The thicknesses of individual sand beds range from a few feet to about 100 feet (30 m) in the sequences that contain fresh and slightly saline water, and the aggregate thickness of the sand units is as much as 470 feet (I43 m). The maximum thickness of the fresh-water section in the Evangeline is about 1,380 feet (420 m) in southeastern Wharton County. Fresh water occurs at depths of as much as 2,000 feet (610 m) in east-central Wharton County.

The hydraulic characteristics of the Evangeline aquifer in Colorado and Lavaca Counties were determined from aquifer-test data. Table 2 shows the transmissivities and hydraulic conductivities of the aquifer and the specific capacities of several wells. Storage coefficients were not determined. The transmissivities, as analyzed from aquifer tests by using the Theis equation, ranged from 480 to 3,400 ft^2/d (45 to 320 m^2/d). Hydraulic conductivities ranged from 5.5 ft/d (I.7 m/d) to about 24 ft/d (7.3 m/d) and averaged about I2 ft/d (3.7 m/d) in wells screened only in the Evangeline.

Twelve of the aquifer tests were made in wells that were screened in more than one aquifer. Nine of the tests were made in wells in which most of the screened sections were in the Evangeline aquifer, with lesser amounts of the screened sections in the Chicot aquifer. The transmissivities of the Evangeline and Chicot combined ranged from 3,800 to 9,900 ft^2/d (353 to 920 m^2/d). A test in one well (DW-66-20-903) screened in the Evangeline, Burkeville, and Chicot indicated a transmissivity of only 1,000 ft^2/d (93 m^2/d). Two other aquifer tests were made in wells screened mostly in the Chicot aquifer and partially screened in the Evangeline. The transmissivities determined in these tests averaged about 3,000 ft^2/d (280 m^2/d).

Chicot Aquifer

The Chicot aquifer, which consists mainly of discontinuous layers of sand and clay of about equal

Table 2.--Summary of aquifer tests in Colorado, Lavaca, and Wharton Counties

Water-bearing units: B--Burkeville confining layer, C--Chicot aquifer, E--Evangeline aquifer, J--Jasper aquifer.

Well	Date	Water-bearing unit	Intervals screened (feet below land surface)	Sand thickness (feet)	Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Average pumping rate (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Remarks
					COLORADO COUNTY					
DW-66-20-505	11-17-72	E	65 feet slotted between 162-222 and 253-258 feet; gravel packed.	65	670	10	457	167	2.7 (7 hours)	30-minute recovery after pumping 10 hours.
602	2-21-68	E	79 feet slotted between 195-234 and 255-295 feet; gravel packed.	79	780	10	519	140	3.7 (1 hour)	30-minute recovery after pumping 4 hours.
903	8-10-55	E-B-C	788 feet of casing slotted between 115-903 feet; gravel packed.	180±	1,000	6	1,050	--	--	60-minute recovery after pumping 100 minutes.
21-301	6-28-75	E	400 feet of casing slotted between 400-800 feet; gravel packed.	--	3,400	--	530	12.4	42.7 (1 hour)	93-minute recovery after pumping 2 hours.
601	7-21-75	E-C	Casing slotted from 200-915 feet; gravel packed.	300±	7,380	25	2,000	--	--	60-minute recovery after pumping 2 days.
28-303	3-22-65	E	291 feet of casing slotted between 276-854 feet; gravel packed.	291	3,130	11	1,210	--	--	30-minute recovery after pumping 8 hours.
901	7-15-55	C-E	350 feet of casing slotted between 105-601 feet; gravel packed.	250±	3,050	12	1,200	--	--	60-minute recovery after pumping 2 hours.
30-101	12-28-55	E-C	110 feet of screen between 360-385, 405-420, 440-460, 470-485, and 490-525 feet; gravel packed.	135	4,000	30	625	--	10.6 (5 hours)	80-minute recovery after pumping 4 2/3 hours.
102	do.	E-C	115 feet of screen between 351-362, 365-407, 441-481, and 489-511 feet; gravel packed.	125	6,380	51	--	--	--	Interference test; 60-minute recovery after pumping well DW-66-30-101 for 4 2/3 hours.
203	6-19-75	E-C	Casing slotted between 340-806 feet; gravel packed.	220	9,860	45	2,642	109	26.4 (1 hour)	8 1/2-hour drawdown test.
35-304	9-28-65	E	97 feet of casing slotted between 695-722, 726-736, 756-796, and 800-820 feet; underreamed and gravel packed.	90	1,400	16	412	1/ 72.5	5.7 (1 hour)	30-minute recovery after pumping 8 hours.
37-204	10-27-70	E-C	370 feet of casing slotted between 350-1010 feet; gravel packed.	370	3,780	10	3,002	167	18.0 (1 hour)	30-minute recovery after pumping 8 hours.
					LAVACA COUNTY					
RY-66-33-507	6- 5-64	J	155 feet slotted between 290-620 feet; underreamed and gravel packed.	--	760	5	508	110	4.6 (1 hour)	30-minute recovery after pumping 12 hours.
35-902	7-20-55	C-E	387 feet slotted between 172-559 feet; gravel packed.	173	2,940	17	950	--	--	1-hour recovery after pumping 12 hours.
42-502	6-20-64	E	64 feet slotted between 747-757 and 791-845 feet; underreamed and gravel packed.	64	480	8	376	--	--	30-minute recovery after pumping 4 hours.
903	6-18-75	E	Casing slotted opposite sands between 290-737 feet; gravel packed.	320±	1,750	6	1,203	1/ 103	11.7 (1 hour)	90-minute recovery after pumping well 4 days.

1/ 1-hour recovery.

Table 7.--Summary of aquifer tests in Colorado, Lavaca, and Wharton Counties--Continued

Well	Date	Water-bearing unit	Intervals screened (feet below land surface)	Sand thickness (feet)	Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Average pumping rate (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Remarks
					LAVACA COUNTY--Continued					
RY-66-43-203	4-23-54	C	69 feet slotted between 250-273, 320-343, and 395-415; underreamed and gravel packed.	69	2,000	29	577	--	--	30-minute recovery after pumping 12 hours.
50-401	1- 5-51	E-C	512 feet slotted opposite sands between 187-880 feet; gravel packed.	280±	4,970	18	2,650	106	25 (1 hour)	15-minute recovery after pumping 6 hours.
502	11-21-50	E-C	299 feet slotted between 153-641 feet; gravel packed.	299	4,290	14	2,435	100	19.6 (1 hour)	20-minute recovery after pumping 8 hours (average discharge after 1 hour, 1955 gal/min--used for 1 hour specific capacity).
57-201	6-12-64	E-C	Casing slotted between 234-584 feet; gravel packed.	350	6,020	17	1,020	28	36.3 (1 hour)	102-minute recovery after pumping 60 hours.
67-31-606	10-14-71	J	90 feet screened between 180-200, 245-275, and 285-325 feet; gravel packed.	90	500	6	210	53	4.0 (1 hour)	30-minute recovery after pumping 8 hours.
39-509	9-27-72	J	Nine sections of screen between 610-935; underreamed and gravel packed.	150	1,250	8	500	117	4.3 (1 hour)	30-minute recovery after pumping 8 hours.
510	6-16-63	J	Seven sections of slotted casing between 754-975 feet; underreamed and gravel packed.	121	500	4	351	62	5.7 (1 hour)	30-minute recovery after pumping 8 hours.
48-703	5- 7-69	E	Casing slotted between 320-430 feet; gravel packed.	93	2,220	24	456	--	--	2-hour recovery after pumping 2 hours.
					WHARTON COUNTY					
ZA-66-31-901	6-20-75	C	35 feet of casing slotted between 100-135 feet; gravel packed.	65	13,800	212	223	--	--	3-hour recovery after pumping 4 days.
902	7-26-55	C	12 feet of casing slotted between 40-52 feet.	--	25,500-46,400	--	420	1/17.9	23.4 (1 hour)	1-hour recovery after pumping 26 hours.
903	do.	C	315 feet of casing slotted between 40-50 and 100-405 feet.	300±	9,040	30	1,370	--	--	1-hour recovery after pumping 14 days.
906	10-19-55	E	87 feet of casing slotted between 860-897, 935-970, and 975-990 feet.	100	1,130	11	146	--	--	Recovery of pumped well.
38-303	6-24-75	C	432 feet of casing slotted between 223-655 feet; gravel packed.	225	45,630	203	2,650	--	--	7-hour, 50-minute recovery, first reading taken 4 hours after pumping stopped.
45-201	7-21-55	C	Slotted 0-257 feet; gravel packed.	235	27,000-	115	1,650	--	--	1-hour recovery after pumping 24 hours.
804	7-11-55	C	278 feet of casing slotted between 110-388 feet; gravel packed.	278	16,440	59	1,675	1/36.1	46.5 (4 days)	1-hour recovery after pumping 4 days.

1/ 1-hour recovery.

Table 2.--Summary of aquifer tests in Colorado, Lavaca, and Wharton Counties--Continued

Well	Date	Water-bearing unit	Intervals screened (feet below land surface)	Sand thickness (feet)	Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Average pumping rate (gal/min)	Drawdown (feet)	Specific capacity [(gal/min)/ft]	Remarks
				WHARTON COUNTY--Continued						
ZA-66-46-402	7-12-55	C	266 feet of casing slotted between 100-366 feet; gravel packed.	250±	32,100	128	3,100	1/ 20.8	149.0 (1 hour)	1-hour recovery after pumping 3 weeks.
48-904	7-26-55	C	275 feet of casing slotted between 95-370 feet; gravel packed.	204	17,900	88	1,710	31.1	55.0 (60 days)	1-hour recovery after pumping 3 weeks.
54-601	10-19-55	E-C	165 feet of screen between 690-725, 755-775, 842-855, 880-925, 970-1002, and 1065-1085; gravel packed.	171	4,800	28	1,090	--	9.0 (1 hour)	Recovery of pumped well.
603	10-21-55	E	285 feet of screen between 790-1265 feet; gravel packed.	297	2,860	10	625	--	7.9 (2 hours)	Recovery of pumped well.
55-103	6- 5-55	C	240 feet of casing slotted between 260-500 feet; gravel packed.	180±	10,600	59	1,150	35.5	32.4 (1 hour)	2-hour, 59-minute recovery test after 4-hour, 56-minute pump test.
61-302	6-17-75	C	65 feet of screen between 400-440 and 503-528 feet; gravel packed.	75	3,880-8,640	52-115	--	12.6	--	Interference test; 150-minute recovery test after pumping well ZA-66-61-309 for 70 minutes. The storage coefficient is 0.0018.
305	7-14-55	C	369 feet of casing slotted between 134-599 feet; gravel packed.	230	15,100	66	2,100	25.3	83.0 (2 days)	63-minute recovery after pumping 48 hours.
309	6-17-75	C	100 feet of screen between 95-110, 175-195, 245-260, 280-315, and 335-350 feet; gravel packed.	120	3,000-7,420	25-62	820	52.8	15.5 (1 hour)	150-minute recovery after pumping 70 minutes.
62-709	6-25-75	C	585 feet of casing slotted between 200-785 feet; gravel packed.	251	16,070	64	2,276	--	--	2 1/2-hour recovery test after pumping 24 hours.
713	do.	C	Casing slotted from about 200-690 feet.	211±	19,080	90	--	--	--	Interference test; 2 1/2-hour recovery test after pumping well ZA-66-62-709 for 24 hours. (Bottom part of well may be collapsed.)
904	7-18-55	C	307 feet of casing slotted between 162-289, 352-452, 467-527, and 553-573 feet; gravel packed.	278	13,400	48	1,430	21.0	68.1 (14 days)	1-hour recovery test after pumping 2 weeks.
63-201	7-14-55	C	Slotted at all sand intervals between 116-594 feet; gravel packed.	361	19,100	53	1,760	23.3	75.5 (1 hour)	1-hour recovery test after pumping 75 hours.

1/ 1-hour recovery.

thickness, is ths main source of ground water in the three-county area. The Chicot aquifer overlies the Evangeline aquifer and is composed of water-bearing units in the Willis Sand, Lissie Formation, Beaumont Clay, and Quaternary alluvium (Figure 4 and Table 1). The Chicot includes all deposits from the land surface to the top of the Evangeline aquifer (Figures 5-8), and all of the deposits contain fresh water in Colorado, Lavaca, and Wharton Counties. The base of the Chicot aquifer, as determined from interpretations of electrical logs, ranges in altitude from the land surface at the outcrop to more than 1,100 feet (335 m) below NGVD in southern Wharton County (Figure 10).

On the basis of interpretations of electrical logs, the Chicot ranges in thickness from 0 in the outcrop areas to more than 1,000 feet (305 m) in southern Wharton County. The thicknesses of individual sand units in the aquifer range from a few feet to about 500 feet (152 m).

The Chicot and Evangeline aquifers generally are in hydraulic continuity, and it is difficult to differentiate the two units. Delineation of the Chicot in the subsurface is based in part on a higher sand-clay ratio in the Chicot than in the underlying Evangeline and in part on the differences in hydraulic conductivity because the Chicot generally has higher values of hydraulic conductivity than the Evangeline.

The combined thicknesses of the fresh-water sands in the Chicot and Evangeline aquifers range from 0 at the outcrop to more than 850 feet (259 m) in Wharton County. The average sand thickness is about 250 feet (76 m) in the Chicot aquifer and about 200 feet (61 m) in the Evangeline aquifer.

The hydraulic characteristics of the Chicot aquifer in parts of the three-county area were determined from aquifer-test data. Table 2 shows the transmissivities and hydraulic conductivities of the aquifer and the specific capacities of selected wells. The transmissivities range from 2,000 ft^2/d) (185 m^2 /d) to more than 46,000 ft^2/d (4,300 m^2 /d). Hydraulic conductivities range from 29.0 ft/d (8.8 m/d) to more than 200 ft/d (61 m/d), and average about 80 ft/d (24.4 m/d).

RECHARGE, MOVEMENT, AND DISCHARGE OF GROUND WATER

Recharge to Aquifers

The principal source of recharge to the aquifers in Colorado, Lavaca, and Wharton Counties is the infiltration of rainfall in the outcrop areas. The sand units composing the Chicot aquifer (excluding those in the Beaumont Clay) crop out and are recharged within an area of about 1,100 aquare miles (2,850 km^2) in northern Wharton County, in the eastern and southern parts of Lavaca County, and in most of Colorado County. Approximately 4 inches (102 mm) of rainfall infiltration would be required to replace the ground-water withdrawals from the Chicot aquifer in 1974 of 207 million gal/d (780,000 m^3/d). The Evangeline aquifer is recharged by the infiltration of rainfall in an outcrop area of about 600 square miles (1,550 km^2) in central Lavaca County, and in an undetermined area in Colorado County where the aquifer is overlapped by younger formations. About 1 inch (25 mm) or less of infiltration would be required to equal the 43 million gal/d (163,000 m^3/d) of water pumped from the Evangeline aquifer in 1974. A fraction of an inch of infiltration would be required to equal about 2 million gal/d (7,500 m^3/d) that was withdrawn from the other aquifers in 1974.

The quantities of water that are available as natural recharge to the Chicot and Evangeline aquifers in the three-county area have been approximated to be about 78,000 acre-feet (96 hm^3) per year for the Chicot and 38,000 acre-feet (47 hm^3) per year for the Evangeline. Inherent in these approximations of potential recharge are increments of water that originally moved as recharge through the aquifers prior to development by wells and water that entered the outcrops of the aquifers as recharge but was discharged to streams. The derivations of the quantities of potential recharge and the significance of these quantities are given in the section of this report on “Fresh water available for development.”

Ground-Water Movement

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. Before development of the aquifers in Colorado, Lavaca, and Wharton Counties began, the general direction of water movement was down gradient from the outcrop areas toward the Gulf of Mexico and toward areas of discharge along the major drainage systems such as the Colorado River. In some places ground-water pumping for municipal supply, industrial use, and irrigation has created cones of depression in the potentiometric surface; and in these areas, ground water moves from all directions toward the center of the cones of depression.

The rate of movement of ground water depends upon the effective porosity and hydraulic conductivity of the aquifer and the hydraulic gradient. In Colorado, Lavaca, and Wharton Counties, the rate of movement of ground water ranges from tens of feet to hundreds of feet per year. The average rate of ground-water movement in the Chicot aquifer is approximately 75 feet (23 m) per year. This value is based on calculations using an average hydraulic gradient of 4 ft/mi (0.8 m/km), a porosity of 30 percent, and an average hydraulic conductivity of 81 ft/d (25 m/d), as determined from aquifer-test data.

An average rate of ground-water movement of 37 feet (11 m) per year for all aquifers was calculated by using an average hydraulic conductivity of about 40 ft/d (12 m/d). The rates of movement near pumping wells are much greater than the calculated averages because the hydraulic gradients near the wells are much steeper than the regional hydraulic gradients.

Discharge from Aquifers

Ground water is discharged naturally through seeps and springs and by evaporation and transpiration from the water table part of the aquifers. Evaporation is more significant during summer months when the rice fields are flooded with water pumped from the aquifers. Ground water is discharged artificially by wells, drainage ditches, gravel pits, and other manmade structures that intersect the water table. In 1974, the total amount of water pumped by wells was about 280,000 acre-feet (345 hm^3), or about 252 million gal/d (954,000 m^3/d).

Until ground-water pumping lowered the original water levels in the aquifers, the perennial streams in the area received significant amounts of ground water that was discharged near the outcrops of the aquifers. Ground water was discharged because the water table was above the level of the streambeds and the recharge rate exceeded the capacity of the sands to transmit the water into the artesian parts of the aquifers. Presently, the streams in some areas are receiving considerably less water than originally.

GROUND-WATER USE AND EFFECTS OF PUMPING

Although little is known about ground-water usage in Colorado, Lavaca, and Wharton Counties prior to 1900, some aspects of development may be inferred from the history of the area. Taylor (1907) reported several flowing wells in the three-county area; and George (I936), May (1938), and Cromack (1940), confirmed the occurrence of flowing wells. Water flowing from wells in Lavaca County originated from the Jasper aquifer, while water from most flowing wells in Colorado County and from two flowing wells in Wharton County originated from the Evangeline aquifer. Water from one flowing well in Wharton County originated from the Chicot aquifer. Most wells ceased flowing by the mid-1940's after ground-water pumping had lowered the artesian pressures.

Most of the ground water pumped in the three-county area is used for rice irrigation, but minor amounts are used for irrigation of cotton and maize. A total of about 260,000 acre-feet (320 hm^3) was pumped for irrigation in 1974, and approximately two-thirds of this amount was used in Wharton County. The second largest use of ground water is for sulfur production at the Boling Salt Dome in Wharton County. Industrial use of ground water in Lavaca and Colorado Counties is insignificant because in 1974, only 13,000 acre-feet (16 hm^3) of water was pumped for industrial use in the three counties.

Ground water is the only source of water for municipal supply in the three-county area, and the total amount pumped for this purpose in 1974 was 6,400 acre-feet (7.9 hm^3). There was no significant pumping of ground water for municipal supply in Colorado County before about 1938 or before about 1910 in Wharton County. Pumping for municipal supply has increased only slightly in Lavaca County since 1948, which is the earliest date of available data.

Ground-water pumping for all uses has increased significantly since the 1940's, and in the early to mid-l 950's ground-water pumping sharply increased with the introduction of the two-crop rice season. The daily withdrawals of ground water for all uses in 1974 were about 252 million gal/d (954,000 m^3/d), and the total withdrawals in 1974 were about 280,000 acre-feet (345 hm^3).

The net annual depletion of water from the aquifers in the three-county area is equal to the pumpage minus the amount of natural recharge and return flow from irrigation. In a study of return flow from rice irrigation in Colorado County, Tuck (1974) estimated that about 30 percent of the water used for rice irrigation returns as surface flow to the drainage system and is available for downstream reuse and recharge. An undetermined amount of water infiltrates to the aquifers directly from the flooded rice fields.

Figures 11-13 show the approximate withdrawals of ground water from the Chicot and Evangeline aquifers in each of the three counties, and show that most of the ground water is pumped from the Chicot aquifer. Of the total of about 280,000 acre-feet (345 hm^3) of ground water used in 1974, approximately 82 percent was withdrawn from the Chicot aquifer, 17 percent from the aquifers. Three of the hydrographs that contain data dating back to 1934 indicate little change in the water levels until about 1947, which may reflect the above-normal rainfall from 1940 to 1946 and the consequent decrease in pumping for irrigation. After 1947, the hydrographs indicate a steady rate of water-level decline.

The greatest amount of water-level decline in the Evangeline aquifer for the period of record is shown by the hydrograph of well ZA-66-54-604. In this public-supply well for El Campo in Wharton County, water levels declined about 65 feet (20 ml) during the 42 years of record. Water levels in other wells in the Evangeline have declined at a faster rate. For example, the water level in well RY-66-42-902, near the edge of a large rice-growing area, declined 20 feet (6 m) during a 10-year period. Many water-level fluctuations are shown on the hydrogtaphs of wells in the Evangeline aquifer, but some of the fluctuations, such as those shown on the hydrograph of well DW-66-28-902 (Figure 18), may result from measurements being made in the spring after the beginning of the pumping season. Normally, water levels recover cluring the winter and are measured early in the spring when they reflect a higher potentiometric surface.

Figure 16 shows the approximate altitude of water levels measured during 1959-60 in wells screened in the Chicot aquifer. This map can be compared with Figure 15 which shows the altitudes of water levels in the Evangeline and Chicot aquifers in 1947, because the majority of the water-level measurements in 1947 were in wells in the Chicot aquifer. The water levels in the Chicot aquifer in 1959-60 show a general decline in the southeastern part of Lavaca County, in the southeastern part of Colorado County, and in most of Wharton County since 1947.

In one area of concentrated pumping for rice irrigation in the southern part of Colorado County and extending into Lavaca and Wharton Counties, a small cone of depression occurs within a larger area of general decline in the altitude of the potentiornetric surface. Figure 16 also shows the altitudes of water levels in selected wells in the Chicot aquifer that were measured during a 2-week period in March 1975, before the beginning of pumping for rice irrigation. From 1959-60 to 1975, water levels in the Chicot aquifer declined more than 20 feet (6 m) in some areas, but the overall water-level decline averaged about 10 feet (3 m) or less.

During 1950-56, the average annual rainfall was about 9 inches (229 mm) below normal; consequently, water levels generally declined as a result of increased pumping for irrigation. In addition, the introduction of the two-crop rice season about 1954 resulted in additional increases in pumping for irrigation and greater water-level declines. An example of rapid decline is shown by the hydrograph of irrigation well ZA-66-45-802 (Figure 18), in which the water level declined 19 feet (6 m) during the 16 years of record. Figure 19 shows the approximate decline of water levels in wells in the Chicot aquifer between 1947 and 1975. The map indicates little or no decline in areas of limited irrigation, but indicates declines of about 40 feet (12 m) in areas of extensive irrigation.

Water-level declines that will result from pumping can be estimated if the aquifer characteristics are known. The theoretical relationship between drawdown and distance from the center of pumping for different transmissivities is shown on Figure 20. For example, if the transmissivity and storage coefficient are 6,000 ft^2/d (557 m^2/d) and 0.001, respectively, the drawdown would be 9 feet (2.7 m) at a distance of 1 mile (1.6 km) from a well or group of wells discharging 1 million gal/d (3,785 m^3/d) for 1 year. If the transmissivity and storage coefficient are 1,000 ft^2/d (93m^2/d) and 0.0001, respectively, pumping at the same rate and for the same time would result in a decline of 61 feet (19 m) at the same distance.

Figure 21 shows the relationship of drawdown to distance and time as a result of pumping from water-table and artesian aquifers. These graphs show that the rate of drawdown decreases with time. For example, if the drawdown at a distance of 100 feet (30 m) from a well in a water-table aquifer is about 14 feet (4.3 m) after 1 million gal/d (3,785 m^3/d) has been pumped for 1 year, the drawdown would be about 19 feet (5.8 m) after 1 million gal/d (3,785 m^3/d) had been pumped for 100 years. The drawdown in a water-table aquifer is less than in an artesian aquifer because under water-table conditions, the coefficient of storage is much larger.

CHEMICAL QUALITY OF GROUND WATER

The factors that determine the suitability of water for a particular use are the quality of the water and the limitations imposed by the contemplated use. Some of the properties or constituents that affect the utility of the water supply include the concentrations of chemical constituents, suspended-sediment content, bacterial content, temperature, hardness, color, taste, and odor. For most purposes, the dissolved-solids concentration is a major limitation on the use of water. Chemical analyses of water from wells in Colorado, Lavaca, and Wharton Counties are given in Table 8. This table includes the results of analyses by the U.S. Geological

Survey, by other government agencies, and by commercial laboratories. The concentrations of the chemical constituents are reported in mg/l (milligrams per liter) or $\mu g/l$ (micrograms per liter).

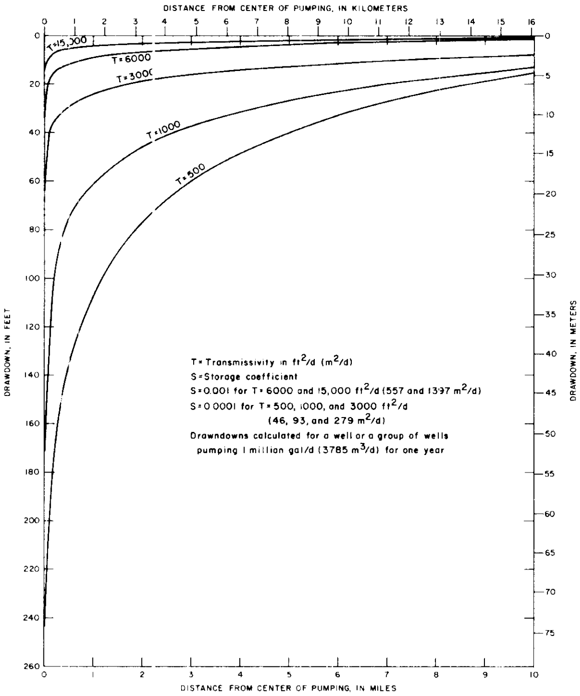

Figure 20.—Relationship of Drawdown to Transmissivity and Distance

The chemical composition of ground water depends upon the source of the water; the rate of movement of the water; and most importantly, the minerals contained in the rocks and soils through which the water moves. Differences in the chemical quality of ground water generally reflect differences in the chemical composition of the sediments of the water-bearing formations, and the generally slow rate of ground-water movement inhibits the mixing of waters of different chemical compositions. Relatively impermeable beds of clay may form local barriers to ground-water movement and tend to stratify the water by limiting vertical movement.

The data in Table 8 show that the chemical quality of the ground water varies considerably throughout Colorado, Lavaca, and Wharton Counties at different places and different depths in the aquifers. The factors causing these differences include composition of the aquifers, hydraulic continuity or lack of continuity, and contamination from oil-field operations.

The Federal Water Pollution Control Act Amendments of 1972 required that the U.S. Environmental Protection Agency (EPA) publish water-quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that may be expected from the presence of pollutants in any body of water, including ground water. In 1973, EPA published the criteria for water quality for the protection of human health and for the protection and propagation of desired species of aquatic biota (National Academy of Sciences, 1973). The latest revision of these criteria was published by EPA in 1976 (U.S. Environmental Protection Agency, 1976). This publication addresses the effects of the basic water constituents and pollutants that are considered most significant in the aquatic environment in the context of present knowledge and experience.

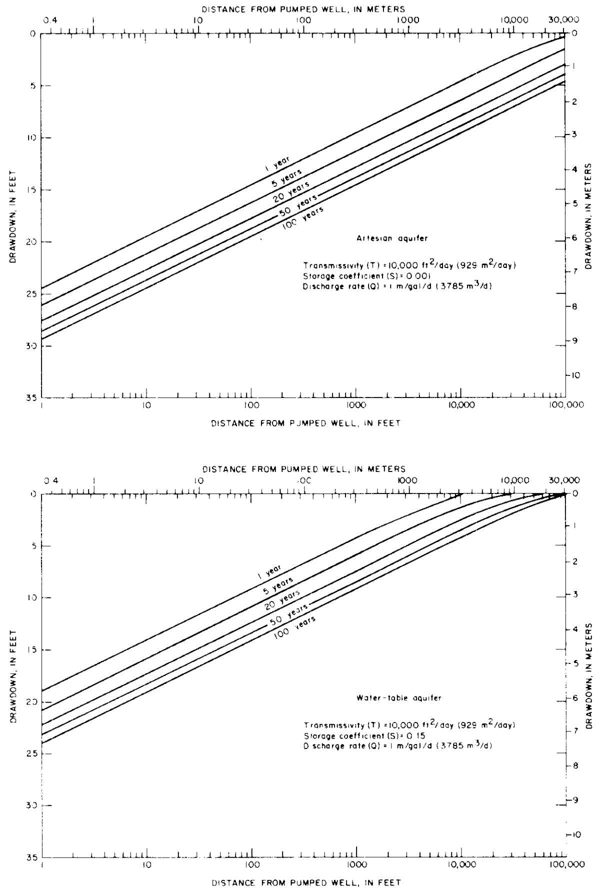

Figure 21.—Relationship of Drawdown to Time and Distance as a Result of Pumping Under Artesian and Water-Table Conditions

According to EPA, "The word criterion represents a constituent concentration or level associated with a degree of environmental effect upon which scientific judgement may be based. As it is currently associated with the water environment it has come to mean a designated concentration of a constituent that when not exceeded, will protect an organism, an organism community, or a prescribed water use or quality with an adequate degree of safety" (U.S. Environmental Protection Agency, 1976, p. 4).

EPA's "Quality Criteria for Water" (National Academy of Sciences, 1973) includes a concise statement of the dominant criterion or criteria for a particular constituent followed by a narrative introduction, a rationale that includes justification for the designated criterion or criteria, and a listing of the references cited within the rationale.

The criteria for some of the properties or constituents of domestic water supplies are included in the following tabulation. For a discussion of the supporting scientific rationale, the reader is referred to the report by EPA (National Academy of Sciences, 1973, p. 25-401).

Property or constituent	Recommended criteria (mg/l)
Chloride (Cl)	250
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (N)	10
Sulfate (SO_4)	250

Recommended criteria for fluoride were not included in the 1976 "Quality Criteria for Water." However, the earlier 1973 report recommended that the maximum levels shown in the following table not be exceeded in public-water supply sources.

Annual average of maximum daily air temperatures		Fluoride maximum (mg/l)
80-91	26.3-32.5	1.4
72-79	21.5-26.2	1.6
65-71	17.7-21.4	1.8
59-64	14.7-17.6	2.0
55-58	12.1-14.6	2.2
50-54	10.0-12.0	2.4

Although these criteria are based upon current knowledge of the effects on health and welfare, it must be emphasized that many other factors should be considered in making decisions relative to establishing particular standards and control measures. These criteria are quoted as a basis for comparison.

Water containing concentrations of chloride exceeding 250 mg/l in combination with sodium may have a salty taste. Fluoride in drinking water reduces tooth decay, especially in young children; however, concentrations greater than the recommended criteria may cause mottling of the teeth. Excessive iron and manganese in the water supply tends to stain utensils and to discolor laundry and plumbing fixtures. Water having a nitrate (N) concentration greater than 10 mg/l is potentially dangerous for infant feeding because it has been related to infant cyanosis or "blue baby" disease. Large concentrations of nitrate may also indicate pollution by sewage or organic material. Excessive sulfate concentrations in drinking water often produce a laxative effect.

The hardness of water, caused mainly by calcium and magnesium, is important in a domestic water supply although no limits of hardness have been established. Excessive hardness causes an increase in the consumption of soap and induces the formation of scale in hot-water heaters and water pipes. A commonly used classification of water hardness is given in the following table:

Hardness range (mg/l)	Classification
60 or less	soft
61 to 120	moderately hard
121 to 180	hard
more than 180	very hard

The suitability of water for irrigation depends partly upon the chemicals in the water and the effect of these chemicals on plants and soils. The suitability is also affected by the type of crop, the soil structure and composition, the irrigation and drainage facilities, the amount of water used, and the climate. Some of the more important chemical characteristics that are considered in the evaluation of water for irrigation are: (1) The relative proportion of sodium to other cations, which is an index of the sodium or alkali hazard; (2) the concentrations of soluble salts, an index of the salinity hazard; (3) the amount of residual carbonate; and (4) the concentration of boron.

The water-quality requirements for rice irrigation have been studied extensively because of its importance to the economy of many parts of the country, including Colorado, Lavaca, and Wharton Counties. Young rice is particularly sensitive to a high sodium chloride concentration in the water, but develops a resistance to this constituent as the plant matures. According to Shutts (1953, p. 871-884), the commonly accepted tolerances of rice are as follows:

Concentration of salts as sodium chloride (mg/l)	Tolerance
600	Tolerant at all stages.
1,300	Rarely harmful and only to seedlings in dry, hard soil.
1,700	Harmful before tillering; tolerable from jointing to heading.
3,400	Harmful before booting; tolerable from booting to heading.
5,100	Harmful at all stages.

Chemical analyses of about 460 water samples collected in the three-county area over the past 40 years are listed in Table 8. The chemical quality of ground water from selected wells in the various aquifers is shown on Figure 22.

Chloride concentrations of more than 250 mg/l were exceeded in approximately 7 percent of the samples analyzed. Dissolved-solids concentrations of 500 mg/l were exceeded in about 40 percent of the samples analyzed. The greatest number of analyses showing dissolved-solids concentrations of more than 500 mg/l were from samples collected in Lavaca County. Less than 3 percent of all samples analyzed were classified as slightly to moderately saline.

About 425 water samples were analyzed for hardness as $CaCO_3$. Water from more than two-thirds of these samples was very hard, and water from less than 5 percent of the samples was soft. The maximum hardness determined was 2,400 mg/l for a sample collected from well RY-67-48-301 in Lavaca County.

Iron determinations were made in about 110 samples. Only six analyses, five of which were from Lavaca County, showed iron in excess of 0.3 mg/l (300 μg/l).

About 215 samples were analyzed for fluoride, but none of the analyses showed concentrations in excess of the recommended limits of 1.4 mg/l. The maximum value of fluoride concentration was 1.2 mg/l in a sample from well ZA-66-61-309 in Wharton County.

Of about 275 samples analyzed for nitrate, only 2 of the samples contained nitrate in excess of the Environmental Protection Agency criterion. Water from well DW-66-20-409 contained 17.2 mg/l and well RY-67-32-702, which is unused, contained 22 mg/l nitrate.

The concentration of sulfate exceeded the limit of 250 mg/l in 1 sample of a total of about 400 samples that were analyzed. The highest value was 540 mg/l in water from well RY-67-48-301 in Lavaca County. Only seven analyses showed concentrations greater than 100 mg/l.

Chemical Quality of Water in the Aquifers

Catahoula Sandstone

Water in the Catahoula Sandstone is generally of poorer quality than the water in the overlying Jasper aquifer. Samples of water from two wells penetrating the Catahoula (DW-66-11-602 and DW-66-18-605) were analyzed (Table 8). The only well for which a complete chemical analysis is available yielded a sodium bicarbonate type water.

Jasper Aquifer

The Jasper aquifer contains fresh water in the northern parts of Lavaca and Colorado Counties. The water quality, however, varies widely. Hardness ranges from very hard in water from most of the wells less than 300 feet (91 m) deep to soft in water from two wells about 1,000 feet (305 m) deep. A sodium calcium bicarbonate or calcium bicarbonate type water is produced from the shallow wells. The dissolved-solids concentration ranged from 366 mg/l in well RY-67-39-504, which is 288 feet (88 m) deep, to 1,179 mg/l in well RY-67-39-510, which is 980 feet (299 m) deep. Electrical logs indicate that the salinity of water in the Jasper aquifer increases downdip.

Evangeline Aquifer

Fresh water occurs in the Evangeline aquifer throughout most of Colorado, Lavaca, and Wharton Counties. Wells drilled into the deeper sands yield a sodium bicarbonate type water as shown by well ZA-66-54-604, which is 1,060 feet (323 m) deep. The shallower sands tend to contain calcium bicarbonate type water as shown by well RY-66-49-401, which is 230 feet (70 m) deep.

About one-half of the water samples collected from the Evangeline aquifer were analyzed for the concentrations of dissolved solids and about one-half of the samples analyzed contained 500 mg/l or more dissolved solids. The dissolved-solids concentration in most of the water samples obtained from wells producing from both the Evangeline and Chicot aquifers ranged from about 200 to 500 mg/l. In the southern part of Wharton County, both slightly saline and moderately saline water occur in the Evangeline aquifer.

Chicot Aquifer

Fresh water occurs in the Chicot aquifer throughout the entire three-county area except in local areas of contamination from oilfield operations. Water in the Chicot aquifer is, for the most part, a calcium bicarbonate type; but water from about 20 percent of the samples analyzed was a sodium bicarbonate type. Water from well ZA-66-47-101, which is representative of the Chicot aquifer, is a calcium bicarbonate type water. The Chicot aquifer contains hard to very hard water, but the concentrations of dissolved solids vary greatly. Contamination from oil-field operations probably contributed to the higher concentrations of dissolved solids in many of the samples analyzed.

Changes in Water Quality

Several wells in the three-county area have been sampled two or three times for water-quality analyses. Water from two wells in the Jasper aquifer in Colorado County showed increasing mineralization during a 28.year period of record. The dissolved-solids concentration in waler from well DW-66-18-601 increased from 219 to 610 mg/l and from 557 to 612 mg/l in water from well DW-66-18-602. Water-quality changes with time were noted in two wells screened in the Evangeline aquifer in Wharton County. The dissolved-solids concentration in water from well ZA-66-31-906 decreased from 314 to 298 mg/l during a 16-year period and increased from 365 to 379 mg/l in water from well ZA-66-E4-604 during a 35-year period. Water from wells screened in a depth interval between 100 feet (30 m) and 370 feet (l13 m) showed the greatest increase in the concentrations of dissolved solids-from 617 to 867 mg/l in water from well DW-66-37-703 during a 15-year period, and water from well ZA-66-48-904 showed the greatest decrease, from 614 to 362 mg/l, during a14-year period.

The greatest change in the concentration of dissolved solids in a deeper well (RY-66-43-203) screened from 244 to 44.4 feet (74 to 135 m) occurred in Lavaca County, in which the dissolved-solids concentration decreased from 338 to 274 mg/l over a 20-year period. Water from most wells in the Chicot and Evangeline aquifers that were sampled over a period of time showed little change in water quality or only a slight increase in mineralization. Water from shallow wells or from wells located near oil or gas fields usually showed the greatest changes in mineralization.

Relationship of Fresh Water to Saline Water

The approximate altitude of the base of freshwater is shown on Figure 23; the approximate altitude of the base of slightly saline water is shown on Figure 24. The interface between fresh and saline water in Colorado, Lavaca, and Wharton Counties is very irregular, and the geohydrologic cross sections (Figures 5-8) show vertical layering of fresh and slightly saline water in some areas. The electrical log of well DW-66-30-207 indicates that a zone of fresh water occurs in sand units between depths of 2,800 and 2,950 feet (850 and 900 m). Slightly saline water occurs above this zone, and moderately saline water occurs below this zone. This stratification may be due in part to differences in hydraulic conductivity within parts of the aquifers.

The altitude of the base of fresh water varies considerably throughout the three-county area. In two areas (Figure 23), fresh water extends to considerable depths. The greatest depth of occurrence, about 2,100 feet (640 m) below NGVD, is in the southeastern part of Wharton County (south of Wharton) where the thickest sands occur in the Evangeline aquifer. In an extensive area of southeastern Colorado County, fresh water occurs at depths greater than 1,800 feet (550 m) below NGVD. In this area, fresh water occurs in the Jasper aquifer and may occur in the Catahoula Sandstone.

In the area of the Boling Salt Dome in eastern Wharton County, a distinct anomaly occurs in the altitude of the base of fresh water. At this location, the base of fresh water rises to less than 750 feet (230 m) below NGVD. Within central Lavaca County, the base of fresh water rises to less than 400 feet (120 m) below NGVD and extends as a narrow band from Fayette County in the northeast to Dewitt County in the southwest. In the vicinity of Yoakum, the base of fresh water is less than 300 feet (90 m) below NGVD. In the northwestern corner of Lavaca County, the base of fresh water rises to about 260 feet (80 m) below NGVD (Figure 23).

The highest altitude of the base of slightly saline water is in northwestern Lavaca County, where slightly saline water occurs at a depth of approximately 480 feet (145 m) below NGVD (Figure 24). In southeastern Wharton County, the base of slightly saline water rises to less than 1,200 feet (365 m) below NGVD, as indicated by the electrical log of well ZA-65-41-932. This relatively shallow depth of occurrence of slightly saline water may result from ground-water circulation around the Boling Salt Dome. The greatest depth at which slightly saline water occurs is almost 2,900 feet (885 m) below NGVD in northern Wharton County.

CONTAMINATION OF GROUND WATER IN OILFIELD OPERATIONS

Disposal of Salt Water

Considerable amounts of brine are produced in Colorado, Lavaca, and Wharton Counties in conjunction with the production of oil and gas. According to a salt water disposal inventory made by the Texas Water Development Board, Texas Water Pollution Control Board, and Railroad Commission of Texas for 1967, 27,338,522 barrels (4.3 million m^3) or about 3,500 acre-feet) of salt water was produced in 1967 in the three counties. The method of disposal, the number of well fields, and the quantity of salt water disposed by each method are given in Table 3. The locations of the oil and gas fields are shown on Figure 25.

Since 1967, when these data were compiled, the danger of contamination has been minimized by State regulations that eliminate the use of unlined surface pits for the disposal of oil-field brines (Railroad Commission of Texas, 1973). Although unlined surface pits are no longer used, the effects of such disposal practices in the past will continue for many years because of the slow rates of infiltration, dispersion, and ground-water movement. Some previously open pits in the Pickett Ridge, Magnet-Withers, Withers North, Bernard Prairie, Boling, and Niels Carlsen fields (Figure 25) may already have contaminated the shallow fresh water bearing sands in some places. Contamination in the area of these fields is suggested by chemical analyses of water samples that show a generally higher than normal mineralization of the water in the aquifers (Table 8).

Improperly Cased Wells

Salt water contamination also occurs through improperly cased oil and gas wells, which normally penetrate aquifers containing both fresh water and saline water before reaching the oil- or gas-producing horizons. If the wells or tests are improperly cased or plugged, brines can move upward from the higher-pressured formations into zones of fresh and slightly saline water. To prevent this type of contamination, the Railroad Commission of Texas (1973) requires that the fresh and slightly saline water be protected by cementing surface casing to the appropriate depths.

The depths of the sands containing fresh to slightly saline water in oil fields for which field rules have been issued and the amount of cemented casing required are shown on Figure 26. These data show that in most fields, the fresh water is adequately protected by the surface-casing rules.

FRESH WATER AVAILABLE FOR DEVELOPMENT

Various methods of estimating the availability of ground water have been used in the coastal region of Texas, and each method has been useful in its own way in providing indices of water availability.

One method that has been widely employed in both regional and county-wide studies in Texas uses theoretical lines of recharge and discharge with preselected pumping lifts along the line of discharge. The theoretical nature of this method is necessarily predicated upon several assumptions, which may be difficult to meet in actual practice. However, the quantitative values obtained by using this method may be useful as guides to water availability.

Another widely-used method of estimating ground-water availability is that of relating availability to potential recharge. This method is also useful as a guide to determining how much water is available perennially without depleting the ground water in storage.

The estimates of availability of ground water in the Chicot and Evangeline aquifers in Colorado, Lavaca, and Wharton Counties were based on these two methods.

Chicot Aquifer

The following assumptions were used in calculating the amount of fresh water available from the Chicot aquifer:

1. Water levels will be lowered 200 feet (61 m) by development along a line of discharge 35 miles (56 km) in length, approximately parallel to the coast and to the trend of the outcrop of the aquifer. This area of development (line of discharge) is assumed to be in Wharton County in an area of occurrence of thick sections of sand containing fresh water. The distance

Table 3.—Methods of disposal and quantity of salt water disposed in 1967 in Colorado, Lavaca, and Wharton Counties

Method of disposal	Number of oil or gas fields	Quantity disposed		
		Barrels	Acre-feet	Percent
COLORADO COUNTY				
Disposal wells	14	2,022,571	260.7	89.0
Open surface pits	24	250,299	32.3	11.0
Miscellaneous methods	1	871	.1	0
TOTAL		2,273,741	293.1	100.0
LAVACA COUNTY				
Disposal wells	4	442,389	57	52.3
Open surface pits	10	402,850	51.9	47.7
Miscellaneous methods	1	125	0	.0
TOTAL		845,364	108.9	100.0
WHARTON COUNTY				
Disposal wells	37	27,254,514	3,512.9	99.7
Open surface pits	10	32,727	4.2	.1
Miscellaneous methods	6	51,281	6.6	.2
TOTAL		27,338,522	3,523.7	100.0

NOTE: Totals may not agree with individual figures due to rounding.

areas as base flow. The average precipitation in Colorado, Lavaca, and Wharton Counties is about 40 inches (1,016 mm). One inch (25 mm) of water applied to the 1,100 square miles (2,850 km^2) of the recharge area of the Chicot aquifer is equivalent to 58,000 acre-feet (72 hm^3) of potential recharge. This increment of potential recharge, plus about 20,000 acre-feet (25 hm^3) of ground water moving through the aquifer equals 78,000 acre-feet (96 hm^3) of water that is estimated to be about the maximum amount perennially available for development from the Chicot without depleting the large quantity of ground water in storage.

The ground water in storage in the Chicot aquifer underlies approximately 75 percent or about 2,250 square miles (5,830 km^2) of the three-county area. Within this area, the total thickness of the fresh-water sands ranges from 0 at the inland extent of the outcrop in Colorado and Lavaca Counties to more than 450 feet (137 m) in southern Wharton County (Figure 27); the average thickness is about 250 feet (76 m). On the basis of an average sand thickness of 250 feet (76 m) and a specific yield of 0.2, approximately 72.0 million acre-feet (88,776 hm^3) of fresh water is theoretically available from storage in the sands of the Chicot aquifer in Colorado, Lavaca, and Wharton Counties. About two-thirds of this total amount is in Wharton County. In addition to the amount theoretically available from the sands, a significant amount of water, probably 20-25 percent of the amount available from the sands, would be available from the clays due to compaction.

Estimates of such large amounts of water theoretically available from storage can be misleading, however, because the total amount cannot be recovered without serious consequences, such as land-surface subsidence. In addition, the depths from which it is economically feasible to pump water would be a constraint on development.

A part of this large amount of ground water in storage is presently (1974) being produced from the Chicot aquifer in excess of the estimated annual recharge rate. Water levels may be expected to continue to decline together with some subsidence of the land surface. The wide spacing of wells in the Chicot throughout the three-county area, however, provides a favorable well-distribution pattern that should minimize these problems.

Evangeline Aquifer

In calculating the amounts of water available for development in the Evangeline aquifer, the assumptions were similar to those used in calculating the amounts available from the Chicot. However, because of the geographic configuration of the three-county area with respect to the outcrop of the Evangeline aquifer, separate calculations of availability were made for Lavaca County.

1. The area of development (line of discharge) is assumed to be in southern Lavaca County in an area of occurrence of thick sands containing fresh water. The line of discharge is 30 miles (48 km) in length, parallel to the coast and to the trend of the outcrop of the Evangeline aquifer. The average distance between the line of recharge and the line of discharge is about 14 miles (22 km).

2. The hydraulic gradient is constant at 17 ft/mi (3.2 m/km) after a drawdown of 200 feet (60 m) at the line of discharge. The 1975 gradient was about 9 ft/mi (1.7 m/km).

3. The average transmissivity of the Evangeline aquifer is 2,400 ft^2 /d (223 m^2 /d).

On the basis of these assumptions, the Evangeline aquifer will ultimately transmit slightly more than 10,000 acre-feet (12 hm^3) of water annually to the line of discharge in Lavaca County.

In estimating the amount of water available from the Evangeline aquifer in Colorado and Wharton Counties, the 35-mile (56-km) line of discharge was assumed to be in southern Wharton County, where the thick fresh-water sands occur. The distance between the recharge area and the line of discharge is about 50 miles (80 km), and the hydraulic gradient is 13 ft/mi (2.5 m/km) after a drawdown of 200 feet (61 m) at the line of discharge. On the basis of these assumptions, the Evengeline will ultimately transmit approximately 9,200 acre-feet (11 hm^3) of water annually to the line of discharge in Wharton County.

In the three-county area, therefore, the Evangeline aquifer will transmit annually about 20,000 acre-feet (25 hm^3) of water to the 200-foot (61-m) lines of discharge. This amount of water, which is less than the recharge rate, is considered to be a quantity that could be produced annually with only moderate pumping lifts without depleting the ground water in storage.

The amount of recharge that is available to the Evangeline aquifer may be considered as the sum of two quantities. This recharge may be estimated by considering the amount of water that moved through the aquifer under predevelopment conditions and the amount of ground water that was discharged by the aquifer to streams in the outcrop area.

Applying the equation:

$$Q=TIL$$

where T (transmissivity) is 2,400 ft2/d (223 m^2/d), I (original hydraulic gradient) is approximately 5 ft/mi (0.9 m/km), and L (length of the aquifer across which the water move;) is 30 miles (48 km) and 35 miles (56 km) for Lavaca County and the Colorado-Wharton County area, respectively, a total of about 6,500 acre-feet (8 hm^3) of water originally moved as an increment of recharge through the Evangeline in the three-county area.

The amount of ground water that the aquifer discharged to the streams may be estimated by assuming that 1 inch (25 mm) of water is discharged by the aquifer at the outcrop. This 1 inch (25 mm) of water applied to the approximately 600 square miles (1,550 km^2) of the outcrop of the Evangeline aquifer is equivalent to about 32,000 acre-feet (39 hm^3) of available recharge. This quantity plus the 6,500 acre-feet (8 hm^3) that originally moved through the aquifer equals about 38,000 acre-feet (47 hm^3) of water that may be considered the maximum amount perennially available for development from the Evangeline without depleting the large amount of ground water in storage.

The ground water in storage in the Evangeline aquifer underlies an area of approximately 2,800 square miles (7,250 km^2), or more than 90 percent of the three-county area. The total thickness of the fresh-water sands ranges from 0 at the outcrop in northwestern Lavaca County to about 470 feet (143 m) in central Wharton County (Figure 28); the average thickness is about 200 feet (61 m). Most of the sands in the Evangeline aquifer contain fresh water, but slightly saline water occurs in some of the deeper sand layers in parts of Colorado and Lavaca Counties and in most of Wharton County.

On the basis of an average thickness of 200 feet (61 m) and a specific yield of 0.2 for the fresh-water sands, about 71.7 million acre-feet (88,400 hm^3) of fresh water is theoretically available from storage in the sands of the Evangeline aquifer in Colorado, Lavaca, and Wharton Counties. Additionally, from 20 to 25 percent of this amount would also be available from the clays due to compaction as water levels are lowered.

The sand units in the Evangeline aquifer that contain slightly saline water underlie an area of approximately 1,400 square miles (3,600 km^2). On the basis of an average sand thickness of about 50 feet (15 m) and a specific yield of 0.2, about 9.0 rnillion acre-feet (11,097 hm^3) of slightly saline water is theoretically available from storage in the Evangeline aquifer in Colorado, Lavaca, and Wharton Counties.

These large amounts of water theoretically available from storage in the Evangeline can be misleading because most of this water cannot be pumped without serious consequences, such as land-surface subsidence and excessive pumping lifts.

Nevertheless, a part of these reserves can be developed and are being developed. In 1974, pumpage from the Evangeline exceeded by 10,000 acre-feet (12 hm^3) the estimated 38,000 acre-feet (47 hm^3) of recharge that is about the maximum amount perennially available. Consequently, water levels may be expected to continue to decline together with some subsidence of the land surface. Proper well spacing, such as the wide well-distribution pattern that is common to rice-irrigation practices in the three-county area, is an effective way of dealing with these problems.

Jackson Group, Catahoula Sandstone, and Jasper Aquifer

The Jackson Group in northern Lavaca County is the oldest geologic unit containing fresh water in the three-county area, and the Catahoula Sandstone, which overlies the Jackson Group, contains a small amount of fresh water. Because of the relative insignificance of these units as sources of water, no data have been collected on their potential for additional development. The Jasper aquifer contains fresh water only in northern Lavaca County and in northern and central Colorado County. The Jasper is not a major aquifer in the three-county area because the sands containing fresh and slightly saline water are very thin in comparison to those in the overlying Chicot and Evangeline aquifers.

The fresh-water sands in the aquifers below the Evangeline aquifer underlie an area of approximately 1,200 square miles (3,100 km^2) and average about 75 feet (23 m) in thickness. The amount of fresh water in storage is about 11.5 million acre-feet (14,180 hm^3), but only a very small amount of this water can be economically recovered because of the great depths (as much as l,000-2,000 feet or 305-610 m) at which most of it occurs. The sands containing slightly saline water in the aquifers below the Evangeline aquifer underlie an area of approximately 2,500 square miles (6,500 km^2) throughout Colorado and Lavaca Counties and in most of Wharton County. On the basis of an estimated average sand thickness of 60 feet (18 m), about 19.2 million acre-feet (23,674 hm^3) of slightly saline water is in storage below the Evangeline aquifer.

Areas Most Favorable for Ground-Water Development

The areas in Colorado, Lavaca, and Wharton Counties that are the most favorable for future development of fresh ground-water supplies are indicated by the values of transmissivity shown on Figure 29. This rnap was constructed by multiplying the average hydraulic conductivity of the Chicot and Evangeline aquiiers by their respective thickness of fresh-water sand;. The average hydraulic conductivity was determined from aquifer tests that were selected to determine the transmissivities of the aquifer.

The areas of highest transmissivity are in Wharton County. Because of the high transmissivities of the Chicot aquifer, about two-thirds of the three-county area is suitable for additional ground-water development where at least 50 feet (15 m) of sand occurs in the aquifers. The areas least favorable for future development are the areas in northwestern Colorado County and all the southern part of Lavaca County, where transmissivities are less than 5,000 ft^2/d (460 m^2/d).

WELL CONSTRUCTION

The method of well construction in Colorado, Lavaca, and Wharton Counties depends upon the desired capacity of the well, the intended use of the water, the allowable cost of construction, and the preferences of individual drillers. Most of the recently constructed small-capacity wells, such as those used for rural-domestic and livestock needs, were drilled by hydraulic-rotary equipment. These wells range from 3 to 6 inches (8 to 15 cm) in diameter and commonly use 2- to 4-inch (5- to l0-cm) casing and screens. Each well is usually completed by screening a single interval of 4 to 20 feet (1.2 to 6.1 m) in the water-bearing zone. Most of the wells are equipped with jet or submergible pumps powered by electrical motors.

Large-capacity wells, such as those used for irrigation, industry, or public supply are also drilled by hydraulic-rotary methods. First, a test hole about 6 inches (15 cm) in diameter is drilled and logged to determine the depths and thicknesses of the sand intervals. The test hole may also be used to determine the aquifer characteristics and water quality. If the test-hole log and other data indicate that suitable water-bearing sands are present, the test hole is then reamed to complete the well. The wells are usually fitted with deep-well turbine pumps powered by internal-combustion engines or electric motors.

The upper part of a test hole for a municipal-supply or industrial well is usually reamed 14 to 30 inches (36 to 76 cm) in diameter. A slightly smaller surface casing is set and cemented in place to form the pump pit. The remaining part of the test hole is then reamed to a diameter less than that of the surface casing. The interval to be screened is then underreamed to about 30 inches (76 cm) in diameter, and 8- to 12-inch (20- to 30-cm) diameter wire-wrapped screens and blank casing are installed. The annular space between the screen or casing and the wall of the hole is filled with gravel. This "gravel pack" stabilizes the hole, increases the effective diameter of the well, and provides a transfer medium for the water moving from the sand into the well.

The construction of rice-irrigation wells usually differs from the construction of municipal-supply and industrial wells, which are usually screened in selected sand units. The test hole for an irrigation well is usually reamed throughout the entire depth of the well, and a string of slotted casing, extending from near the surface or from a few hundred feet below the surface is installed through the remaining depth of the well. The space between the casing and the wall of the hole is filled with gravel from the bottom of the well to the land surface. This type of well construction, rather than selective screening, does not always produce water of the best quality available; but if the water is suitable for irrigation, this method of construction is highly effective.

LAND-SURFACE SUBSIDENCE

The major cause of land-surface subsidence in Colorado, Lavaca, and Wharton Counties is the withdrawal of water from the artesian aquifers. According to Meinzer and Wenzel (1942, p. 458), the water pressure in an artesian aquifer provides a buoyant effect that helps support the aquifer. When the water pressure is reduced, the buoyant effect is reduced and an additional load is transferred to the skeleton of the aquifer. A pressure difference between the sands and clays causes water to move from the clays to the sands. This causes compaction of the clays, which in turn results in subsidence of the land surface.

The amount of land-surface subsidence that has occurred may be determined by comparing the altitudes of bench marks over a period of time. The National Geodetic Survey determined and redetermined the altitudes of a line of bench marks in Colorado, Lavaca, and Wharton Counties between 1933 and 1973, but the extent of land-surface subsidence is generally unknown in most of the three-county area because the altitudes in approximately one-half of the area, including most of Wharton County, have not been redetermined since the original surveys in the early 1940's. Another large part of the three-county area was originally surveyed in the early 1930's and surveyed again in the early 1940's. The northern part of Wharton County was surveyed in 1957, but most of the county has not been surveyed since the 1940's.

In the area in which the bench-mark altitudes were redetermined in 1973, the amount of land-surface subsidence can be determined. At Hallettsville, for example, 0.256 foot (0.078 m) of subsidence occurred between 1933 and 1973, while only 0.043 foot (0.013 m) of subsidence occurred before 1943. In Jackson County, near the Wharton County line, the land surface subsided 0.571 foot (0.174 m) between 1943 and 1973. The greatest amount of land-surface subsidence measured in the three-county area is in southeastern Lavaca County, where 0.702 foot (0.214 m) of subsidence occurred between 1935 and 1973.

Because of a lack of subsidence data in Colorado, Lavaca, and Wharton Counties, especially in Wharton County, data from surrounding counties were used to estimate the amount of subsidence within these three counties. Most lines of bench marks, for which altitudes were redetermined in the early 1970's, as in Matagorda County, show less than 1 foot (0.3 m) of subsidence; and only a few bench marks in eastern Jackson County have subsided more than 1 foot (0.3 m). At Francitas in Jackson County, the data indicate subsidence of about 2 feet (0.6 m) betwsen 1918 and 1973, with approximately 1.7 feet (0.5 m) of the subsidence occurring between 1952 and 1973. The increase in the rate of subsidence in this area coincides with the introduction of the two-crop rice season and the increased withdrawals of ground water in the early 1950's.

NEEDS FOR ADDITIONAL STUDIES

The program of measuring water levels in observation wells should be continued in Colorado, Lavaca, and Wharton Counties; and the program should be expanded to include measurements in wells in areas of recent ground-water development. In addition, an expanded program of aquifer tests would be helpful in defining more accurately the hydraulic characteristics of the aquifers. A program to collect water-quality data on a continuing basis should be initiated to monitor the possible encroachment of salt water. A program for measuring subsidence is needed in the three-county area, especially in areas of large ground-water pumping for rice irrigation. This program should be coordinated with the program of collecting water-level and pumping data so that correlations can be made between subsidence and ground-water withdrawals.

SUMMARY

The Chicot and Evangeline aquifers, which are recharged by the infiltration of rainfall in the outcrop areas, are the main sources of fresh water for all uses in Colorado, Lavaca, and Wharton Counties; and most of the water is obtained from the Chicot aquifer, which overlies the Evangeline aquifer. The Jackson Group, Catahoula Sandstone, and Jasper aquifer are minor sources of water and are largely undeveloped in the area.

The Chicot aquifer, which consists of discontinuous layers of sand and clay of about equal aggregate thickness, ranges in total thickness from 0 in the outcrop area to more than 1,000 feet (305 m) in southern Wharton County. In places, the sand units containing fresh water are as much as 500 feet (152 m) thick. The Evangeline aquifer, which also consists of discontinuous sand and clay layers, ranges in total thickness from 0 at the outcrop to about 1,500 feet (457 m) in Wharton County. The aggregate thickness of the sand units containing fresh and slightly saline water is as much as 470 feet (143 m). The combined thicknesses of the fresh-water sands in the Chicot and Evangeline aquifers range from 0 at the outcrop to more than 850 feet (259 m) in Wharton County. The average sand thickness is about 250 feet (76 m) in the Chicot aquifer and about 200 feet (61 m) in the Evangeline aquifer.

The interface between the fresh and slightly saline water is irregular, and in some areas, the fresh, slightly saline, and moderately saline waters occur in vertical layers. Where the sand units are thick, as in south-central Wharton County, fresh water is available at depths of almost 2,200 feet (670 m). In Colorado and Lavaca Counties, where the aquifers are not as thick as in Wharton County, fresh water occurs in the Jasper aquifer and Catahoula Sandstone below the base of the Evangeline aquifer. The shallowest depth at which slightly saline water is encountered is about 800 feet (244 m) in the northwestern part of Lavaca County.

Daily withdrawal of ground water for all uses in 1974 was 252 million gal/d (954,000 m^3/d), most of which was used for rice irrigation. Smaller amounts of water were pumped for municipal supply and industrial use. Estimates of the amounts of fresh and slightly saline water theoretically available from storage in the sands were based on average sand thicknesses of 250 feet (76 m) and 200 feet (61 m) in the Chicot and Evangeline aquifers, respectively, and a specific yield of 0.2. The Chicot aquifer contains about 72.0 million acre-feet (88,776 hm^3) of fresh water available from storage, and the Evangeline aquifer contains about 71.7 million acre-feet (88,406 hm^3) of fresh water and about 9.0 million acre-feet (11,097 hm^3) of slightly saline water available from storage. The Jackson Group, Catahoula Sandstone, and Jasper aquifer together contain about 11.5 million acre-feet (14,180 hm^3) of fresh water and about 19.2 million acre-feet (23,674 hm^3) of slightly saline water in available storage. Additional amounts of water, probably 20-25 percent of the amounts available from the sands, would be available in the clays.

Estimates of such vast amounts of water theoretically available from storage can be misleading, because it is probable that these amounts cannot be recovered without serious consequences. More practical guides to a judicious development of the water supply were based on theoretical lines of recharge and discharge with drawdowns of 200 feet (61 m) at the lines of discharge and also were based on potential recharge. On the basis of theoretical lines of recharge and discharge and drawdowns of 200 feet (61 m), about 50,000 acre-feet (62 hm^3) and 20,000 acre feet (25 hm^3) could be produced from the Chicot and Evangeline aquifers, respectively, with only moderate pumping lifts without depleting the vast amount of ground water in storage. These indices of availability are less than the estimated potential amounts of recharge that are available to the aquifers. Estimates of the potential recharge are 78,000 acre-feet (96 hm^3) per year for the Chicot and 38,000 acre-feet (47 hm^3) per year for the Evangeline. These recharge estimates may be viewed as about the maximum amount perennially available without depleting the large quantities of ground water in storage.

Present (1974) pumpage from the Chicot and Evangeline aquifers exceeds the estimated recharge rates. For this reason, water levels may be expected to continue to decline, along with some land-surface subsidence.

Additional development of the ground-water resources is possible throughout most of Colorado, Lavaca, and Wharton Counties; but the attendant consequences of more land-surface subsidence and declining water levels should be considered. The most favorable areas for additional development are in central Wharton County. Additional potential for development exists in most other areas where as much as 50 feet (15 m) of sand occurs in the Chicot aquifer.

Considerable amounts of brine are produced in Colorado, Lavaca, and Wharton Counties in conjunction with the production of oil and gas. In 1967, about 3,500 acre-feet (4.3 hm^3) of brine was produced. To prevent possible contamination of the fresh water, the Railroad Commission of Texas requires that oil and gas wells must have cemented casings from the land surface to the base of the slightly saline water. Presently (1977), the fresh water is adequately protected in most of the oil fields by the rules for the required amount of cemented casing. The elimination of brine-disposal pits has minimized contamination by this method of salt-water disposal, but contamination may still occur through improperly cased wells, abandoned injection wells, and abandoned brine-disposal pits. Some previously open pits in the Pickett Ridge, Magnet-Withers, Withers North, Bernard Prairie, Boling, and Niels Carlsen fields may already have contaminated the shallow fresh water in the vicinity of these fields.

Land-surface subsidence is not a problem at this time. However, more data are needed to determine the extent of subsidence and the relationship between the amount of ground-water withdrawals and the amount of subsidence. The available data indicate that maximum subsidence within the three counties is less than 1 foot (0.3 m), and in most places is less than 0.5 foot (0.15 m).

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Table 5.--Records of wells and test holes in Matagorda, Jackson, Fayette, DeWitt, Austin, Fort Bend, Victoria, and Gonzales Counties

Water-bearing unit: C--Chicot aquifer, J--Jasper aquifer.
Method of lift: E--electric; G--gasoline, butane, or diesel engine; N--none; S--submergible; T--turbine. Number indicates horsepower.
Use of water: D--domestic, Irr--irrigation, N--none, S--stock.

No.	Owner	Driller	Date completed	Depth of well (ft.)	Casing: Diameter (in.)	Casing: Depth (ft.)	Water-bearing unit	Altitude of land surface (ft.)	Water level: Above (+) below land surface datum (ft.)	Water level: Date of measurement	Method of lift	Use of water	Remarks
MATAGORDA COUNTY													
TA-65-57-103	Pierce Est. #1	Stanolind Oil & Gas Co.	1951	8607	--	--	--	68	--	--	--	N	Oil test, used in cross section.
80-07-308	Kountz #12	Magnolia Petroleum Co.	1954	5007	--	--	--	50	--	--	--	N	Oil test, used in cross section.
JACKSON COUNTY													
PP-66-52-401	Morton Bros.	Henry Cleveland	1954	680	20 12	-- 680	C	116	71.1 86.4	10-22-59 5-21-74	N	N	
61-103	Sam B. Heard	Crowell Drilling Co.	1970	426	16	426	C	81	--	--	T,G,70	Irr	Casing slotted 101-426 feet.
407	M. W. Mauritz, et al. #1	Sam G. Harrison	1954	6416	--	--	--	67	--	--	--	N	Oil test, used in cross section.
FAYETTE COUNTY													
JT-66-03-801	Burnsides #1	Hamman Oil & Refining Co.	1954	2858	--	--	--	420	--	--	--	N	Oil test, used in cross section.
17-101	Harry Vogelsang #1	Gulf Coast Leaseholds, Inc. and J. D. Watzlavick	1961	4326	--	--	--	370	--	--	--	N	Oil test, used in cross section.
DEWITT COUNTY													
HX-67-56-802	Mrs. M. A. Plaacke #1	Harkins & Co.	1957	5516	--	--	--	199	--	--	--	N	Oil test, used in cross section.
AUSTIN COUNTY													
AP-66-15-802	D. C. Hillboldt #1	Shell Oil Co.	1958	10884	--	--	--	200	--	--	--	N	Oil test, used in cross section.
FORT BEND COUNTY													
JY-65-43-103	Mabel Allen #1	Kennon & Cantrell	1951	5420	--	--	--	80	--	--	--	N	Oil test, used in cross section.
VICTORIA COUNTY													
YT-66-57-502	T. W. Nickel	--	--	500+	2	500	E?	172	1+	3-14-74	N	S	Measured flow 0.25 gal/min 3-14-74; produces some gas.
67-31-201	F. E. Carter	Leroy Richter Water Well Drilling	1970	248	4 2	--	J	360	105	12-31-70	S,E	D,S	Casing slotted.
GONZALES COUNTY													
KR-67-31-201	do.	do.	1970	248	4	248	C2	360	a/ 105	do.	S,E	D,S	Pump set at 222 feet; casing slotted 238-248 feet.

a/ Reported.

Table 6.--Drillers' logs of wells in Colorado, Lavaca, and Wharton Counties

COLORADO COUNTY

	Thickness (feet)	Depth (feet)
WELL DW-66-04-503		
Owner: Stratford Hog Farm		
Driller: Pomykal Drilling Co.		
Clay	18	18
Rock and shale	7	25
Shale	87	112
Sand	13	125
Shale	8	133
Rock	1	134
Shale	53	187
Sand	28	215
Shale	55	270
Sand	5	275
Shale, sandy	5	280
Sand	29	309
Shale	4	313
Rock	20	333
Shale	7	340
Rock	70	410
Shale	14	424
WELL DW-66-18-601		
Owner: City of Weimer #1		
Driller: Layne-Texas Co.		
Clay	6	6
Sand and layers of clay	56	62
Rock	2	64
Clay, sandy	13	77
Sand, muddy	59	136
Sand and layers of rock	7	143
Clay, sandy	70	213
Rock	4	217
Soapstone	10	227
Rock	6	233
Sand, hard packed	8	241
Rock	2	243
Sand	32	275
Shale and clay	206	481
Rock	2	483
Soapstone	27	510
Sandstone, soft	23	533
Sand, hard packed	23	556
Shale, hard	13	569
Rock	2	571
WELL DW-66-18-601--Continued		
Sand	8	579
Rock	2	581
Gumbo	31	612
Sand	7	619
WELL DW-66-18-602		
Owner: City of Weimar #2		
Driller: A. E. Fawcett, Jr.		
Surface material	10	10
Sand and rock	41	51
Rock	1	52
Clay, sandy	5	57
Sand and rock	15	72
Rock	1	73
Sand and clay	9	82
Sand and rock	5	87
Clay	23	110
Clay and rock	25	135
Clay	5	140
Soapstone	7	147
Sand and lime	1	148
Sand and rock	5	153
Clay	37	190
Sand and clay	10	200
Gumbo	21	221
Sand and rock	24	245
Soapstone	8	253
Sand and rock	21	274
Clay	4	278
Shale and clay	41	319
Sand and rock	10	329
Gumbo	30	359
Shale, hard	63	422
Sand and shale	20	442
Lime and gumbo	61	503
Shale, hard	18	521
Sand and boulders	71	592
Gumbo	13	605

WELL DW-66-20-502

Owner: A. J. Wray
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Surface soil	6	6
Sand and gravel, coarse	42	48
Clay, sandy	24	72
Sand and shale, sandy	40	112
Shale, sandy	12	124
Sand and shale	57	181
Sand and gravel	39	220
Shale, sandy	6	226
Shale	31	257
Hard rock	1	258
Shale	20	278
Sand	34	312
Sandstone	1	313
Shale and sand	16	329
Sandstone	2	331
Shale, sticky	32	363
Shale, sandy	41	404
Shale	20	424
Sand, hard	18	442
Shale	5	447
Sand and shale	93	540
Shale, hard	45	585
Shale, sandy	55	640
Sand and shale	38	678
Shale	10	688
Sand	12	700
Shale	33	733
Shale, sandy	21	754
Sand	12	766
Shale and sand	28	794
Shale, sticky	3	797
Shale, with sand breaks	37	834
Shale, sandy	9	843
Lime, sandy and shale	23	866
Shale, hard with lime	14	880
Shale, sandy	9	889
Shale, hard	6	895
Shale, sticky	8	903

WELL DW-66-20-802

Owner: E. M. Conner
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Top soil	8	8
Sand	37	45
Clay	50	95
Sand	96	191
Clay	13	204
Rock and sand	16	220
Clay	15	235
Rock and sand	31	266
Clay	23	289
Rock and sand	54	343
Clay	35	378
Sand	17	395
Clay	1	396

WELL DW-66-20-902

Owner: R. J. Kleinman
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Soil	4	4
Gravel and clay	55	59
Clay and gravel	24	83
Sandy clay	36	119
Clay	163	282
Sand, hard, broken	28	310
Shale	30	340
Sand, broken	60	400
Sand	52	452
Shale and boulders	48	500
Shale and sandy shale	48	548
Shale	9	557
Sand and shale breaks	28	585
Shale	24	609
Shale and sand	9	618
Shale	16	634
Shale, sandy	9	643
Shale	42	685
Sand and shale breaks	40	725
Shale	24	749
Shale and sand breaks	12	761
Sand	5	766
Shale	14	780

WELL DW-66-21-201

Owner: Oscar Class
Driller: L&N Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Clay, red and iron ore	15	17
Clay, yellow	9	26
Sand	39	65
Clay, yellow	6	71
Sand	13	84
Clay, yellow	5	89
Sand	46	135
Sand, rock	5	140
Sand	4	144
Clay, red	50	194
Sand and rock	14	208
Clay, red	38	246
Sand and rock	57	303
Clay, red	8	311

WELL DW-66-21-602

Owner: G. E. Thomas, Jr.
Driller: American Water Co.

	Thickness (feet)	Depth (feet)
Surface	10	10
Sand	20	30
Rock	15	45
Sand	25	70
Shale	15	85
Sand	100	185
Shale	15	200
Sand	35	235
Shale	15	250
Sand	25	275
Shale	15	290
Sand	25	315
Shale	10	325
Sand	30	355
Shale	35	390
Sand	14	504

WELL DW-66-21-603

Owner: Jimmy Adkins
Driller: American Water Co.

	Thickness (feet)	Depth (feet)
Surface	15	15
Sand	5	20
Clay	15	35

WELL DW-66-21-603--Continued

	Thickness (feet)	Depth (feet)
Sand	60	95
Shale, sticky	30	125
Sand	25	150
Shale	10	160
Sand	65	235
Shale	35	270
Sand	15	285
Shale	20	305
Sand	15	320
Shale	55	375
Sand	20	395
Shale, sticky	35	430
Sand	45	475
Shale	10	485
Sand	47	532
Shale, sticky	18	555
Sand	67	622
Shale	158	770
Sand	35	805
Shale	7	812

WELL DW-66-21-901

Owner: Superior Oil Co.
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Clay and gravel	38	38
Clay	20	58
Rock	2	60
Clay and gravel	9	69
Sand	29	98
Sand, hard	48	146
Clay and boulders	38	184
Sand, broken	28	212
Clay and boulders	31	243
Sand	46	289
Clay	15	304

WELL DW-66-21-903

Owner: G. Goeckler
Driller: American Water Co.

	Thickness (feet)	Depth (feet)
Surface soil	30	30
Sand and gravel	45	75
Clay, white	115	190
Sand, medium	20	210
Shale, hard, and rock	45	255

WELL DW-66-21-903--Continued

	Thickness (feet)	Depth (feet)
Sand	10	265
Shale, sticky	33	298
Sand	15	313
Shale, blue	27	340
Sand	18	358
Shale and rock	23	381
Sand	6	387
Shale, sticky	103	490
Sand	14	504

WELL DW-66-28-701

Owner: George Burke, Jr.
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil	50	50
Rock	8	58
Clay, rocky	7	65
Rock	2	67
Clay, rocky	7	74
Sand, rocky	4	78
Clay strips	42	120
Rock and sand	15	135
Clay	57	192
Sand, rocky	36	228
Clay and small sand strips	19	247
Sand, rocky	17	264
Clay	13	277
Rock and sand	4	281
Clay	43	324
Sand, rocky	25	349
Clay	64	413
Sand	69	482
Clay	21	503
Sand and rock	20	523
Clay	25	548
Sand	35	583
Rock	27	610
Clay	40	650
Sand and rock	26	676
Clay	39	715
Shale	97	812
No record	36	848

WELL DW-66-28-802

Owner: Clipson Bros.
Driller: American Water Co.

	Thickness (feet)	Depth (feet)
Surface	5	5
Clay	25	30
Sand and rock	50	80
Rock	8	88
Sand	26	114
Shale	12	126
Sand	14	140
Shale	45	185
Sand	35	230
Shale	24	254
Sand and rock	4	258
Shale	50	308
Sand and rock	94	402
Shale	32	434
Rock	2	436
Sandrock	36	472
Shale, sticky	38	510
Sand	59	569

WELL DW-66-28-903

Owner: R. E. Smith
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil	12	12
Sand	41	53
Clay	45	98
Rock	6	104
Sand and rock	24	128
Rock	4	132
Sand and rock	6	138
Rock	4	142
Sand and rock	18	160
Clay	68	228
Sand and rock	42	270
Clay	18	288
Sand	11	299
Clay	13	312
Sand	103	415
Clay	30	445
Sand	23	468
Clay	70	538
Sand	42	580
Clay	22	602

WELL DW-66-28-903--Continued

	Thickness (feet)	Depth (feet)
Sand	38	640
Clay	20	660
Sand	35	695
Bottom clay	--	695

WELL DW-66-28-905

Owner: R. E. Smith #6
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil	26	26
Sand	19	45
Clay	21	66
Sand	20	86
Clay	14	100
Rock	2	102
Sand, rocky	4	106
Rock	2	108
Clay	63	171
Sand, rocky	44	215
Clay	45	260
Sand, rocky	40	300
Clay	37	337
Sand	17	354
Clay	40	394
Rock	3	397
Sand	28	425
Clay	65	490
Sand	16	506
Rock	3	509
Sand	81	590
Sand, rocky	64	654
Bottom clay	--	654

WELL DW-66-30-102

Owner: City of Eagle Lake #5
Driller: Big State Water Wells, Inc.

	Thickness (feet)	Depth (feet)
Surface soil	4	4
Clay	13	17
Sand and gravel	39	56
Clay, hard	8	64
Clay	14	78
Rock	10	88
Rock, sand, gravel, and clay	25	113
Sand	10	123
Rock and gravel	5	128
Rock, sand, and clay	7	135
Sand and gravel	14	149
Clay and sand breaks	39	188
Sand	11	199
Shale, hard	13	212
Sand	17	229
Shale, sandy	5	234
Shale and sandy shale	44	278
Sand and layers of shale	45	323
Shale and boulders	35	358
Sand	25	383
Shale, sandy and hard layers	20	403
Sand	10	413
Shale	10	423
Shale and sandy shale	20	443
Sand and layers of hard shale	70	513
Sand	15	528
Shale, sandy and layers of sand	42	570
Sand, gravel and shale breaks	33	605
Shale	2	607

WELL DW-66-30-103

Owner: Ralph Thomas
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil and clay	10	10
Quicksand	5	15
Sand and gravel	25	40
Clay and lime rock	30	70
Rock, hard	10	80
Rock and short sand strips	45	125
Clay	13	138
Lime rock and clay	31	169
Sand and clay strips	22	191
Sand	16	207
Clay	3	210
Clay and small sand strips	92	302
Sand and rock	33	335
Clay	10	345
Sand with clay strips	2	347
Sand and rock	23	370
Sand, rocky	120	490
Bottom clay	--	490

WELL DW-66-30-201

Owner: Payne Brothers
Driller: L&N Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Clay, yellow	11	13
Clay, red	9	22
Sand	13	35
Sand and gravel	17	52
Clay, red and yellow	33	85
Rock	16	101
Clay, red and yellow	17	118
Rock	5	123
Lime rock and clay	3	126
Sand	6	132
Rock	4	136
Sand	18	154
Clay, yellow	8	162

WELL DW-66-30-401

Owner: Wharton Turf Grass
Driller: L&N Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil	5	5
Clay, yellow	4	9
Clay, red	21	30
Sand	11	41
Gravel	19	60
Clay, yellow	27	87
Lime rock	3	90
Sand and lime rock	3	93
Lime rock	15	108
Sand	7	115
Sand and rock	3	118
Rock and yellow clay	4	122
Sand	2	124
Rock and sand	3	127
Sand	4	131
Rock and sand	9	140
Sand	15	155
Rock	1	156
Sand	9	165
Clay, yellow	1	166

WELL DW-66-35-303

Owner: John J. Williams
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil and clay	39	39
Sand	16	55
Rock	3	58
Lime rock and sand	14	72
Clay	30	102
Sand	28	130
Clay	35	165
Rock limestone	6	171
Clay and sand strips	39	210
Clay	63	273
Sand and rock	31	314
Clay	11	325
Sand	12	337
Clay	45	382
Sand	17	399
Clay	16	415
Sand and rock	35	450
Clay	16	466
Rock	10	476
Shale	14	490
Shale, sandy	14	504
Sand and shale strips	80	584
Shale	16	620
Shale, sandy	33	653
Sand	18	671
Shale	24	705
Sand with shale strips	32	737
Shale	23	760
Sand and rock	45	805

WELL DW-66-36-101

Owner: Dale Hunt
Driller: A. H. Justman

	Thickness (feet)	Depth (feet)
Topsoil	34	34
Sand	11	45
Rock	13	58
Clay	24	82
Sand	10	92
Clay	8	100
Sand	17	117
Clay	63	180
Sand	30	210

WELL DW-66-36-101--Continued

	Thickness (feet)	Depth (feet)
Clay	73	283
Rock	2	285
Sand and rock	55	340
Clay	42	382
Sand	11	393
Clay	40	433
Sand	64	497
Clay	63	560
Sand	27	587
Clay	16	603
Rock	1	604
Clay	22	626
Sand	10	636
Clay	7	643
Sand and rock	17	660
Clay	12	672
Sand and rock	11	683
Clay	24	707
Sand and rock	13	720
Clay	8	728
Sand and rock	13	741
Clay	8	749
Sand and rock	35	784
Bottom clay	--	784

WELL DW-66-37-201

Owner: Hlavinka Brothers
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Surface	32	32
Sand and gravel	20	52
Clay	10	62
Sand and gravel	78	140
Rock and sand	60	200
Clay and rock	24	224
Sand and lime rock	40	264
Clay, lime rock, and sand strips	21	285
Clay	51	336
Lime rock, hard, and clay	23	359
Clay and lime rock	121	480
Sand	20	500
Clay	10	510
Sand and rock	60	570
Bottom clay	--	570

WELL DW-66-37-203

Owner: Lester Bunge
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil and clay	32	32
Sand	3	35
Sand and gravel	23	58
Sand	10	68
Clay	7	75
Sand, gravel, and rocks	30	105
Clay	25	130
Sand	7	137
Clay and sand rocks	21	158
Sand	14	172
Clay and sand strips	11	183
Rock and sand strips	5	188
Sand, hard, and hard rock	6	194
Clay	4	198
Sand	12	210
Clay, red	27	237
Sand and rocks	28	265
Sand and clay strips	30	295
Clay	83	378
Sand and rock	13	391
Clay	19	410
Sand and shale strips	51	461

WELL DW-66-37-601

Owner: R. A. Shoop
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Soil, black	3	3
Clay, sandy	17	20
Sand and gravel	17	37
Gravel	71	108
Boulders	21	129
Gravel, broken	71	200

WELL DW-66-37-703

Owner: Engstrom Brothers
Driller: Crowell Brothers

	Thickness (feet)	Depth (feet)
Clay	14	14
Sand	20	34
Clay	14	48
Gravel	28	76
Boulders	21	97
Hard	6	103

WELL DW-66-37-703--Continued

	Thickness (feet)	Depth (feet)
Hard and boulders	16	1 9
Rock	15	134
Clay	12	146
Gravel	16	162
Clay	18	180
Clay	20	200
Sand	4	204
Hard	10	214
Sand and hard streaks	22	236
Sand	50	286
Sand and hard streaks	23	309
Shale	7	316
Sand	44	360
Shale, gray	40	400

WELL DW-66-37-801

Owner: Adolph Korenek
Driller: A. A. Wuensch

	Thickness (feet)	Depth (feet)
Clay	20	20
Limestone, hard	4	24
Gravel and sand	15	39
Clay	3	42
Gravel	17	59
Limestone	5	64
Clay, white and lime	4	68
Boulders	26	94
Limestone, hard, sandy	3	97
Gravel and boulders	4	101
Clay and gravel	2	103
Boulders	10	113
Boulders and limestone	2	115
Flint, hard, and lime	21	136
Clay and gravel streaks	8	144
Gravel and boulders	9	153

WELL DW-66-38-102

Owner: George M. Cason
Driller: Leonard Mickelson

	Thickness (feet)	Depth (feet)
Soil and clay	21	21
Sand	19	40
Clay	8	48
Sand, rocky	25	72
Lime	4	75
Sand, rocky	29	106

WELL DW-66-44-301

Owner: Cole P. Hopkins
Driller: Crowell Brothers

	Thickness (feet)	Depth (feet)
Clay	26	26
Gravel	12	38
Clay	12	50
Gravel and boulders	36	86
Clay	9	95
Boulders	5	100
Gravel	14	114
Rock	6	120
Clay	30	150
Sand, hard	26	176
Shale	14	190
Sand, hard	34	224
Hard	12	236
Sand, fine	52	288
Rock	3	291
Shale	47	338
Sand	8	346
Shale	59	405
Sand, fine	40	445
Shale	14	459

WELL DW-66-44-501

Owner: Texas West Indies #2
Driller: American Water Co.

	Thickness (feet)	Depth (feet)
Surface	10	10
Sand	50	60
Shale	15	75
Sand and rock	65	140
Shale	5	145
Sand	30	175
Shale	10	185
Sand	30	215
Shale	15	230
Sand	15	245
Shale	15	260
Sand	75	335

WELL DW-66-44-601

Owner: Bill Frnka
Driller: Crowell Brothers

	Thickness (feet)	Depth (feet)
Clay	12	12
Sand	6	18
Clay	12	30
Gravel	30	60

Well DW-66-44-601--Continued

	Thickness (feet)	Depth (feet)
Boulders	11	71
Gravel	11	82
Boulders	8	90
Rock	2	92
Sand	4	96

LAVACA COUNTY

WELL RY-66-25-701

Owner: Dr. Harvey Renger
Driller: A.C.C. Vacuum Trucks

	Thickness (feet)	Depth (feet)
Clay	110	110
Sand	70	180
Clay	36	216
Sand	27	243
Clay	51	294
Sand	51	345
Clay	71	416
Sand	36	452

WELL RY-66-33-403

Owner: City of Hallettsville
Driller: Texas Water Wells Inc.

	Thickness (feet)	Depth (feet)
Surface	7	7
Sand, rock	8	15
Clay	5	20
Sand, rock	20	40
Clay	80	120
Sand with hard streaks	48	168
Clay	4	172
Rock	1	173
Sand, rock	7	180
Clay	76	256
Sandy clay	46	302
Clay	21	323
Sand, hard	38	361
Sand and clay streaks	29	390
Clay	29	419
Sand, hard, with clay streaks	77	486
Clay	24	510
Sand, cut good	20	530
Clay	15	545
Sand, clay streaks	25	570

WELL RY-66-33-403--Continued

	Thickness (feet)	Depth (feet)
Shale	66	636
Shale, sandy	14	650
Clay, sandy	30	680
Clay	140	820
Shale, sandy	20	840
Sand	17	857
Shale, sandy	79	936
Sand, hard	21	957
Shale, sandy	17	974

WELL RY-66-33-504

Owner: City of Hallettsville
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Surface soil	2	2
Clay	10	12
Sand	8	20
Clay	41	61
Sand, coarse and clay streaks	29	90
Clay	4	94
Sand and rock streaks	23	117
Clay	153	270
Clay, sandy	35	305
Sand, shale streaks and rock streaks	56	361
Clay and sandy clay	79	440
Clay, sandy and sand streaks	22	462
Sand	30	492
Shale	6	498
Sand	14	512
Clay	41	553
Sand	10	563
Shale	7	570
Shale and sand streaks	8	578
Shale	43	621
Shale, hard	31	662
Shale	114	776

	Thickness (feet)	Depth (feet)
WELL RY-66-33-504--Continued		
Shale, sandy and shale	36	812
Sand, coarse, white	14	826
Shale	44	870
Shale, sandy	58	928
Sand and shale streaks	35	963
Shale	5	968
Shale and sandy shale	91	1,059
Sand	15	1,074
Shale and sandy shale	261	1,335

WELL RY-66-35-901

Owner: Mrs. Vivian Cloninger well 1
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil	15	15
Sand	66	81
Clay	19	100
Sand	36	136
Clay	91	227
Sand	20	247
Clay	39	286
Sand, rocky	38	324
Clay	20	344
Sand	24	368
Clay	40	408
Sand	5	413
Clay	16	429
Sand, rocky	9	438
Clay	32	470
Sand	20	490
Clay	129	619
Sand	11	630
Clay	186	816
Sand, rocky	24	840
Shale, sandy	--	840

WELL RY-66-41-903

Owner: Hermes Brothers
Driller: Schumacher & Sons

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Clay	39	42
Sand, rock	28	70
Sand, clay	20	90
Water, sand	16	106
Clay	44	150
Rock	1	151
Water, sand	19	170
Rock	2	172
Clay, blue	80	252
Rock	5	257
Water, sand	38	295
Clay	13	308
Water, sand	27	335

WELL RY-66-43-301

Owner: Miller Brothers
Driller: A. H. Justman

	Thickness (feet)	Depth (feet)
Surface soil	38	38
Clay	49	87
Sand and clay streaks	35	122
Clay	29	151
Sand	61	212
Clay	63	275
Rock	3	278
Clay	36	314
Sand	26	340
Clay	36	376
Sand	10	386
Clay	64	450
Sand	6	456
Clay	63	519
Sand	10	529
Clay	5	534
Shale, sandy	25	559
Clay	8	567
Shale, sandy	18	585
Clay	13	598
Shale	19	617
Clay	4	621
Sand and rock	21	642
Clay	18	660
Shale, sandy	40	700
Clay	20	720
Sand and rock	53	773
Clay	201	974
Sand and rock	62	1,036

	Thickness (feet)	Depth (feet)
WELL RY-66-43-810		
Owner: Morton Brothers Driller: Katy Drilling Co.		
Surface and clay	66	66
Sand and gravel	15	81
Rock and clay	54	135
Clay	10	145
Sand and rock	30	175
Clay	16	191
Sand	10	201
Clay	17	218
Sand and rock	14	232
Clay	18	250
Sand	19	269
Clay	34	303
Sand	5	308
Clay	16	324
Sand	57	381
Clay	29	410
Sand and rock	40	450
Clay	22	472
Sand and rock	58	530
Clay	23	553
Sand	33	586
Clay	36	622
Sand	17	639
Clay	15	654
Sand	20	674
Clay	44	718
Sand	26	744
Clay	39	757
Sand	11	768
Clay	100	868
WELL RY-66-44-402		
Owner: A. G. Fajkus Driller: Katy Drilling Co.		
Topsoil and clay	35	35
Sand	26	61
Clay	30	91
Sand, rocky	10	101
Clay	6	107
Sand	8	115
Clay	50	165
Sand, rocky	76	241
WELL RY-66-44-402--Continued		
Clay	15	256
Sand, rocky	57	313
Clay	37	350
Sand	39	389
Clay	44	433
Rock and sand strips	21	454
Clay and sand strips	75	529
Sand	35	564
Shale	12	576
Sand and rock	24	600
Shale	17	617
Sand and rock	26	643
Clay and rock with sand strips	27	670
Clay	14	784
Sand and rock	8	792
Clay	17	809
Sand	71	880
WELL RY-66-50-502		
Owner: Henderson Brothers #11 Driller: Layne-Texas Co.		
Surface soil	1	1
Clay	15	16
Sand	10	26
Clay	10	36
Sand	10	46
Rock	4	50
Sand, hard, and lime	10	60
Shale, sandy	34	94
Sand	24	118
Shale, sandy	7	125
Sand	41	166
Shale, sandy	21	187
Shale	42	229
Shale and sand streaks	20	249
Sand	10	259
Shale, sandy, and lime	26	285
Shale	14	299
Shale, sandy	16	315
Sand	17	332
Shale	52	384
Sand	18	402
Shale, sandy	23	425
Sand	23	448

WELL RY-66-50-502--Continued

	Thickness (feet)	Depth (feet)
Shale	36	484
Shale, sandy	36	520
Shale	41	561
Shale, sandy	9	570
Shale	66	636
Shale, sandy	2	638
Shale	73	711
Shale, hard, and lime	36	747
Shale, sandy, and sand streaks	20	767
Shale	12	779
Shale, sandy, and sand streaks	12	791
Shale	50	841
Shale, sandy	12	853
Shale	19	872
Shale, hard, sandy	9	881
Shale	89	970
Shale, sandy	25	995
Shale	77	1,072

WELL RY-67-31-601

Owner: City of Moulton
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Soil and hard caliche	45	45
Shale and clay	125	170
Shale	36	206
Sand	14	220
Shale	79	299
Sand and shale layers	56	355
Shale, soft, and medium hard layers	193	548
Shale, soft	14	562
Shale and hard lime layers	41	603
shale, sticky	12	615
Shale, soft	67	682
Shale and hard lime layers	88	770
Shale, sandy	45	815
Shale and lime	27	842
Shale	18	860
Shale and sand layers	41	901
Shale	39	940
Shale, sandy	35	975
Shale	28	1,003

WELL RY-67-31-602

Owner: City of Moulton
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Caliche	40	43
Clay	207	250
Sand	10	260
Clay, sandy	22	282
Sand and clay breaks	38	320
Shale and sandy shale	29	349

WELL RY-67-32-701

Owner: Frank Petras
Driller: Johnnie Maresh

	Thickness (feet)	Depth (feet)
Topsoil, black	2	2
Clay, tan	26	28
Clay, white	28	56
Clay, pink	16	72
Clay, tan	38	110
Clay, blue	40	150
Rock, sand (little)	50	200
Clay, blue	60	260
Clay, white	80	340
Clay, blue	80	420
Rock	40	460
Clay, blue	60	520
Rock	60	580
Clay, blue	77	657
Rock	3	660
Clay, blue	40	700
Rock	40	740
Water, sand	50	790

WELL RY-67-39-302

Owner: G. G. Nollkamper
Driller: H&S Drilling Co.

	Thickness (feet)	Depth (feet)
Clay	10	10
Sand	7	17
Sand streaks, shale and hard streaks	53	70
Shale and hard streaks	15	85
Sand	10	95
Sand and hard streaks	17	112
Shale	38	250
Lime streaks and shale	65	315
Sand and shale streaks	22	337

	Thickness (feet)	Depth (feet)
WELL RY-67-39-302--Continued		
Shale	28	365
Sand	20	385
Shale	17	402
Sand	28	430
Shale	30	460
Sand	42	502
Shale	5	507
Sand	65	572

WELL RY-67-39-304

Owner: H. R. Seidenburger
Driller: Leroy Richter

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Clay	6	9
Sand, rock/clay streaks	13	22
Blue shale	20	42
Brown-blue-white shale	123	165
Sand	10	175
Brown-blue-white shale	35	210
Sand	10	220
Brown-blue-white shale	160	380
Sand/shale streaks	35	415
Sandy shale	72	487
Hard shale	78	565
Sand, coarse blue	18	583
Shale	24	607
Sand, coarse blue and shale streaks	38	645
Shale	9	654

WELL RY-67-39-402

Owner: Q. B. Schaefer
Driller: O. T. Davis & Sons

	Thickness (feet)	Depth (feet)
Clay and sandrock	40	40
Sand	15	55
Clay	15	70
Sand, coarse	15	85
Shale with hard streaks	95	180
Sand, hard	60	240
Sand, broken	35	275
Sand	58	333

WELL RY-67-39-509

Owner: City of Shiner
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Topsoil	1	1
Clay, yellow, sandy	10	11
Clay, red, sandy	42	53
Sand, rock and clay streaks	38	91
Shale, sand and rock streaks	64	155
Shale, sandy shale streaks	65	220
Sand and rock (cut good)	29	249
Shale, sandy shale	55	304
Shale, sandy and sand streaks	33	337
Sand	5	342
Sand, shale, sand streaks	63	405
Sand, shale streaks	24	429
Shale, sandy and sand streaks	30	459
Sand, shale streaks	46	505
Shale, sandy and sand streaks	37	542
Sand, shale, gravel layers	25	567
Shale, sandy and gravel	43	610
Sand and shale layers	43	653
Shale, sandy and shale	21	674
Shale, sandy shale	34	708
Shale, sand streaks	22	730
Sand, shale layers	12	742
Shale, sandy	13	755
Sand and shale streaks	19	774
Shale, sandy	6	780
Sand and shale layers	11	791
Shale, sandy	6	797
Sand and shale layers	37	834
Shale, sandy and sand	11	845
Sand and shale layers	22	867
Shale, sandy	11	878
Sand and shale layers	18	896
Rock	1	897
Sand (cut good)	7	904
Shale, sandy	3	907
Shale, hard	13	920
Sand and shale streaks	15	935
Shale, hard	20	955
Sand	8	963
Shale and sand layers	30	993
Shale, hard	14	1,007

WELL RY-67-39-510

Owner: City of Shiner
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Soil	4	4
Sand and clay	15	19
Clay	15	34
Clay and rock clusters	123	157
Shale	62	219
Sand and shale streaks	20	239
Shale, rock streaks	10	249
Sand (cut good)	21	270
Shale and sandy shale	115	385
Sand	11	396
Shale	28	424
Sand	18	442
Shale	150	592
Shale and sand layers	15	607
Shale, rock streaks	49	656
Sand	9	665
Shale	11	676
Sand and shale streaks	33	709
Shale	42	751
Sand and shale streaks	11	762
Shale	20	782
Sand and shale streaks	12	794
Shale, sand streaks	21	815
Shale, hard	24	839
Sand and shale layers	34	873
Shale	21	894
Sand	17	911
Shale, sandy shale	79	990

WELL RY-67-40-401

Owner: Charles Chovanetz
Driller: Shellman Drilling Co.

	Thickness (feet)	Depth (feet)
Soil	7	7
Clay	3	10
Sand, yellow	50	60
Sand, gray	13	73
Rock	2	75
Clay, yellow	26	101
Sandrock	19	120
Clay, white and yellow	13	133
Sandrock	22	155
Clay, white and yellow	45	200

WELL RY-67-40-401--Continued

	Thickness (feet)	Depth (feet)
Sandrock	55	255
Sand, gray, thin streaks	18	273
Clay, red and streaks, blue shale	127	400
Sand, thin streaks	2	402
Clay, red and white	84	486
Rock	14	500
Clay, white, dense and pale blue sticky shale	82	582
Sand, gray	32	614
Sand, gray	21	641
Shale	19	660

WELL RY-67-47-604

Owner: City of Yoakum, park well 1
Driller: Dawson Drilling Co.

	Thickness (feet)	Depth (feet)
Sand	5	5
Caliche	7	12
Clay	18	30
Sand, soft	20	50
Sand, hard	40	90
Clay	30	120
Sand	60	180
Sand and hard lime	30	210
Sand and gravel, hard	40	250
Lime and shale	20	370
Rock, red, hard	40	410
Sand and gravel, hard	60	470
Clay and shale, soft	55	525
Shale, soft	50	575
Sand, rough	10	585
Shale, soft	45	630
Shale, rough	10	640
Shale, soft	10	650
Sand	35	685
Shale, brown, soft	45	730
Sand, hard or shale	20	750
Shale, soft	30	880
Sand and gravel	105	985
Shale	20	1,005
Sand, hard	40	1,045
Sand and shale	160	1,205

WELL RY-67-48-702

Owner: Texas A&M University well 2
Driller: L. C. Capps

	Thickness (feet)	Depth (feet)
Clay	20	20
Shale	90	110
Sand and shale streaks	50	160
Shale streaks	20	180
Shale	62	342

WELL RY-67-48-702--Continued

	Thickness (feet)	Depth (feet)
Sand	11	353
Shale and sand	13	366
No record	59	425
Sand	4	429
Shale and lime	21	450
Shale	33	483
Shale, broken and lime	77	560

WHARTON COUNTY

WELL ZA-65-41-102

Owner: J. B. Harrison
Driller: Crowell Brothers

	Thickness (feet)	Depth (feet)
Clay	20	20
Sand	48	68
Clay	12	80
Gravel	35	115
Clay	38	153
Sand	22	175
Clay	11	186
Sand, shaly	16	202
Sand and shell	48	250
Shale	25	275
Sand	25	300
Shale	7	307
Sand	26	333
Shale	8	341

WELL ZA-65-41-929

Owner: Texas Gulf Sulfur Co.
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Topsoil	3	3
Brown clay	72	75
Sand and fine gravel	60	135
Blue shale	15	150
Sand	15	165
Blue shale	19	184
Sand	21	205
Blue shale	15	220
Sand and shale streaks	25	245
Red shale	28	273
Sand	3	276
Red shale and sand streaks	30	306
Fine sand	29	335

WELL ZA-65-41-929--Continued

	Thickness (feet)	Depth (feet)
Sand and fine gravel	89	424
Shale and sand streaks	30	454
Sand and streaks of shale	30	484
Sand and gravel	30	514
Sand, gravel, and shale streaks	60	574
Sand and shale	26	600

WELL ZA-65-49-404

Owner: Trull & Herlin
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Clay	8	10
Sand and clay	48	58
Clay	12	70
Sand	19	89
Sand and gravel	15	104
Coarse gravel and sand	26	130
Clay	13	143
Sand	6	149
Sandy clay	96	245
Shale	24	269
Sand	5	274
Shale	10	284
Sand	7	291
Shale	8	299
Sand	8	307
Shale	23	330
Sand	30	360
Shale	41	401
Sand	24	425
Shale	12	437
Sand, broken	13	450
Sandy shale	14	464

WELL ZA-65-49-404--Continued

	Thickness (feet)	Depth (feet)
Sand	39	503
Shale	4	507
Sandy shale	8	515
Shale	10	525
Sand	18	543
Hard sandy shale	12	555
Sand, broken	32	587
Shale	10	597
Hard sandy shale	18	615
Sand	31	646
Sand, broken	24	670
Sandy shale	7	690
Sand	28	718
Shale	37	755
Sand	20	775
Shale	15	790
Sand	23	813
Shale	50	863
Hard shale	7	870
Sandy shale	8	878
Hard sandy shale	19	897
Rock	2	899
Sand, gravel, and lime	71	970
Hard sandy shale	15	985
Sand	27	1,012
Hard sandy shale	7	1,019
Sand	24	1,043
Shale	7	1,050
Sand	21	1,071
Hard shale	29	1,100

WELL ZA-66-31-701

Owner: Tom Arlt
Driller: Johnson & Johnson Drilling & Supply Co.

	Thickness (feet)	Depth (feet)
Sand and soil	18	18
Gravel	18	36
Sand	2	38
Clay and soil	52	90
Coarse sand	50	140
Gravel	20	160
Clay and gravel	60	220
Clay and sand	40	260
Clay	60	320
Clay and sand	49	369

WELL ZA-66-31-906

Owner: Tenn. Gas Trans. Co., East Bernard plant #3
Driller: McMasters & Pomeroy

	Thickness (feet)	Depth (feet)
Clay and boulders	9	9
Caliche	11	20
Sand and gravel	31	51
Clay	49	100
Sand and gravel	40	140
Clay	9	149
Gravel and boulders	58	207
Shale	34	241
Sand, hard	33	274
Shale and hard sand	55	329
Shale	12	341
Sand and shale	36	377
Rock	1	378
Shale and boulders	9	387
Sand	27	414
Clay	58	472
Shale	72	544
Rock	2	546
Shale and boulders	60	606
Sand	8	614
Shale	28	642
Clay and boulders	9	651
Sand	12	663
Clay	17	680
Clay and boulders	56	736
Sand	10	746
Clay and boulders	12	758
Sand	10	768
Shale	11	779
Sand	6	785
Clay	19	804
Rock	2	806
Shale	4	810
Sand	6	816
Rock	1	817
Sand	13	830
Rock	2	832
Sand	4	836
Clay	18	854
Sand	46	900
Clay	10	910
Sand	5	915

	Thickness (feet)	Depth (feet)
WELL ZA-66-31-906--Continued		
Shale	3	918
Sand	3	921
Shale	13	934
Sand	39	973
Shale	2	975
Sand	15	990
Shale	10	1,000

WELL ZA-66-38-603

Owner: Arthur Anderson
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Surface clay	19	19
Sand	13	32
Clay	19	51
Sand, gravel	72	123
Clay	11	134
Sand, gravel	34	168
Clay, sand breaks	16	184
Sand, gravel	18	202
Clay, rock	30	232
Sand, rock	47	279
Clay	11	290
Sand, rock	54	344
Clay	22	366
Sand, rock	37	403
Clay	9	412
Sand, rock	6	418
Clay	24	442
Sand, rock	43	485
Clay	60	545
Sand, rock	8	553
Clay	14	567
Sand, rock	21	588
Clay	40	628
Sand, rock	23	651
Clay	38	689
Sand and rock	56	745
Clay	10	755
Sand, rock	17	772
Clay	40	812
Sand	18	830
Clay	23	853
Sand	11	864
Clay	36	900

WELL ZA-66-39-601

Owner: Mrs. W. A. Northington
Driller: Leonard Mickelson

	Thickness (feet)	Depth (feet)
Soil and clay	12	12
Sand	15	27
Shale	5	32
Sand, rocky	22	54
Sand and shale	29	82
Sand	9	91
Shale	53	144
Sand	28	172
Shale	10	182
Sand, rocky	28	210
Shale	3	213
Sand	7	220
Shale	20	240
Sand, rocky	62	302
Shale	7	309
Sand, rocky	27	336

WELL ZA-66-45-608

Owner: Henry Zboril
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Surface clay	28	28
Sand	18	46
Clay	11	57
Sand, gravel	22	79
Clay	5	84
Sand, gravel	71	155
Clay	10	165
Sand and rock	5	170
Clay	8	178
Sand and rock	14	192
Clay	3	195
Hard rock	4	199
Clay	14	213
Sand and rock	10	223
Clay	16	239
Sand and rock	5	244
Clay	8	252
Sand and rock	5	257
Clay	22	279
Sand and rock	42	321
Clay	9	330
Sand and rock	22	352

	Thickness (feet)	Depth (feet)
WELL ZA-66-45-608--Continued		
Clay	44	396
Sand and rock	18	414
Clay	7	421
Sand and rock	54	475
Clay	78	553
Sand and rock	58	611
Clay	10	621
Sand and rock	11	632
Clay	31	663
Sand and rock	16	679
Clay	21	700

WELL ZA-66-46-203

Owner: Pryor Ranch
Driller: Leonard Mickelson

	Thickness (feet)	Depth (feet)
Soil and clay	12	12
Sand and gravel	111	123
Lime and rock	23	146
Gravel	46	192
Rock	7	199
Gravel and rock	37	236
No record	15	251

WELL ZA-66-46-701

Owner: Gene Reitz
Driller: Crowell Drilling Co.

	Thickness (feet)	Depth (feet)
Clay	30	30
Sand	40	70
Clay	54	114
Gravel	11	125
Rock	1	126
Sand	4	130
Rock	1	131
Sand and hard streaks	23	154
Clay	8	162
Sand and gravel	78	240
Hard	20	260
Sand	7	267
Rock, hard	8	275
Sand and hard streaks	35	310
Hard	22	332

WELL ZA-66-47-412

Owner: J. E. Heyne Estate
Driller: Leonard Mickelson

	Thickness (feet)	Depth (feet)
Soil and clay	38	38
Sand and gravel	43	81
Clay	12	93
Lime rock	2	95
Clay	34	129
Gravel and sand	30	159
Clay, rocky	58	217
Rocky sand	62	279
Rock	9	288
Rocky	6	294
Sand, rocky	38	332

WELL ZA-66-48-404

Owner: City of Wharton #2 (old #5)
Driller: Layne-Texas Co.

	Thickness (feet)	Depth (feet)
Topsoil and clay	26	26
Clay, red	30	56
Sand and gravel	45	101
Clay, red	74	175
Sand	10	185
Clay	21	206
Sand layers and rock	17	223
Shale, sandy and shale	57	280
Sand and layers of rock	18	298
Shale	11	309
Sand, gravel, and rocks	35	344
Sand streaks and shale	23	367
Shale, sandy, and streaks of sand rock	24	391
Sand	16	407
Shale, sandy	7	414
Sand	19	433
Shale, sandy, lime and streaks of sand	30	463
Sand and layers of hard lime	25	488
Shale, hard	12	500
Sand	6	506
Shale	6	512
Sand and layers of rock and lime	38	550
Sand	34	584
Sand and lime	10	594
Shale	6	600

WELL ZA-66-48-404--Continued

	Thickness (feet)	Depth (feet)
Sand, hard, and streaks of lime	23	623
Shale	26	649
Rock	1	650
Shale	14	664
Sand and streaks of shale and rock	14	678
Shale, hard	8	686
Sand	4	690
Shale, sandy, and streaks of sand	15	705
Sand, fine gravel, and streaks of rock	44	749
Sand, coarse	89	838
Shale	5	843
Sand, loose, and streaks of shale	29	872
Shale and layers of sand	24	896
Shale, blue	34	930
Sand and layers of shale	40	970
Shale, red and blue	70	1,040
Sand with few shale breaks	33	1,073
Shale and streaks of sand	11	1,084
Sand	19	1,103
Shale, sandy shale, and layers of sand	32	1,135
Sand	8	1,143
Shale and sandy shale	29	1,172
Shale	26	1,198

WELL ZA-66-52-208

Owner: E. G. Goff
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Surface, clay	30	30
Sand, gravel	37	67
Clay	6	73
Sand	21	94
Clay	27	121
Sand	14	135
Clay	17	152
Sand, gravel	27	179
Clay	7	186
Sand, gravel	19	205
Clay	27	232
Sand, rock	8	240
Clay	8	248
Sand	15	263
Clay	9	272

WELL ZA-66-52-208--Continued

	Thickness (feet)	Depth (feet)
Sand, rock	20	292
Clay	10	302
Sand, rock	17	319
Clay	6	325
Sand	61	386
Clay	9	395
Sand, rock	24	419
Clay	45	464
Sand, rock	23	487
Clay	87	574
Sand, rock	18	592
Clay	14	606
Sand, rock	38	644
Clay	6	650
Sand, rock	78	728
Clay	36	764
Sand, rock	5	769
Clay	28	797
Sand, rock	24	821
Clay	5	826
Sand	14	840
Clay	48	868
Sand, rock	69	937
Clay	7	944
Sand, rock	17	961
Clay	51	1,012
Sand, rock	18	1,030
Clay	115	1,145
Sand, rock	55	1,200
Shale, hard	70	1,270
Sand	10	1,280
Shale	17	1,297
Rock, sand breaks	19	1,316
Sand	23	1,339
Shale, hard	9	1,348
Sand	6	1,354
Shale	8	1,362
Sand	7	1,369
Shale	30	1,399

WELL ZA-66-53-508

Owner: M. L. Bain
Driller: Crowell Drilling Co.

	Thickness (feet)	Depth (feet)
Clay	34	34
Sand	14	48
Clay	45	93
Sand and gravel	32	125
Shale	10	135
Sand	21	156
Shale	32	188
Sand	32	220
Shale	15	235
Rock	7	242
Hard shale	28	270
Sand and hard shale	20	290
Shale	30	320
Sand	12	332
Rock	2	334
Shale	13	347
Sand and hard shale	23	370
Shale	15	385
Sand	6	391
Hard	4	395
Sand	40	435
Rock	5	440
Sand and hard shale	30	470
Shale	36	506
Sand	14	520
Shale	6	526
Sand and hard shale	29	555
Hard	9	564
Sand and hard shale	20	584
Shale	64	648
Sand	32	680
Shale	8	688
Sand	16	704
Shale	8	712
Sand	23	735
Shale	6	741

WELL ZA-66-54-603

Owner: City of El Campo #3
Driller: Otto Mickelson

	Thickness (feet)	Depth (feet)
Surface soil	8	8
Sand	30	38
Clay	8	46
Clay and layers of sand	17	63
Sand	5	68
Clay and layers of sand	25	93
Clay	38	131
Sand	7	138
Clay and layers of sand	11	149
Sand	5	154
Gravel	8	162
Sand	5	167
Clay and lime rock	21	188
Sand	11	199
Clay	3	202
Sand	18	220
Clay	24	244
Sand	5	249
Clay and soft rock	15	264
Clay, rocky	25	289
Sand, rocky	4	293
Clay, rocky	49	342
Sand	12	354
Rock, soft	1	355
Sand	36	391
Rock	1	392
Gumbo, rocky	16	408
Rock, soft	8	416
Sand	6	422
Gumbo and boulders	18	440
Sand	5	445
Gumbo, boulders, and sand	35	480
Sand	6	486
Gumbo, boulders, and sand	17	503
Sand	16	519
Gumbo, boulders, and sand	9	528
Sand	16	544
Gumbo, boulders, and sand	13	557
Gumbo	7	564
Sand	19	583
Gumbo, hard	12	595
Pack sand	5	600

	Thickness (feet)	Depth (feet)
WELL ZA-66-54-603--Continued		
Rock, hard	1	601
Pack sand	5	606
Sand	14	620
Gumbo and boulders	11	631
Sand	25	656
Gumbo	24	680
Gumbo and boulders	5	685
Sand	43	728
Gumbo, sand, and boulders	16	744
Sand	15	759
Rock	1	760
Gumbo	30	790
Sand	33	823
Gumbo	37	860
Sand	20	880
Shale	10	890
Sand	26	916
Shale	9	925
Sand	102	1,027
Shale	8	1,035
Sand	42	1,077
Shale	41	1,118
Sand	44	1,162
Shale	38	1,200
Sand and shale	30	1,230
Shale	15	1,245
Sand	20	1,265
Shale	89	1,354
Sand	46	1,400

WELL ZA-66-55-711

Owner: Harlan Nelson
Driller: Leonard Mickelson

	Thickness (feet)	Depth (feet)
Soil and clay	44	44
Sand	16	50
Clay	10	60
Sand	25	85
Clay	5	90
Sand	25	115
Clay	5	120
Sand	17	137
Clay	38	175
Sand	5	180
WELL ZA-66-55-711--Continued		
Clay	3	183
Coarse sand	14	207
Clay	6	213
Sand	15	228
Clay	17	245
Sand	13	258
Clay	6	264
Sand	10	274
Clay	43	317
Sand	15	332
Clay	15	347
Sand	10	357
Clay	5	362
Rock, sand	49	411
Clay	10	421
Rock, sand	25	446
Rock	3	449
Clay	15	464
Lime rock, sand	1	465
Clay	34	499
Rock, sand	88	587
Rock	5	592
Rock, sand	9	601
Clay	3	604

WELL ZA-66-56-101

Owner: Bollinger Brothers
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Topsoil	4	4
Clay	6	10
Sand	163	173
Clay	46	219
Sand	21	240
Clay	32	272
Sand	9	281
Clay	75	356
Sand	111	467
Rock	1	468
Sand	3	471
Rock	1	472
Sand	24	496
Clay	9	505
Sand	19	524

	Thickness (feet)	Depth (feet)
WELL ZA-66-56-101--Continued		
Clay	12	536
Sand, rocky	44	580
Sand with clay strips	19	599
Sand, rocky	82	681
Clay	11	692
Rock	1	693
Sand	9	702
Clay	53	755
Sand	63	918
Rock	5	923
Clay	5	928
Sand	82	1,010
Bottom clay	--	1,010

WELL ZA-66-61-301

Owner: Wharton County WC&ID #1, Louise #1
Driller: Texas Water Wells

	Thickness (feet)	Depth (feet)
Surface	3	3
Clay	15	18
Sand	52	70
Clay, sandy	15	85
Sand	25	110
Gravel	8	118
Caliche, sandy	44	162
Sand	13	175
Clay and caliche	22	197
Caliche, sandy	23	220
Sand and gravel	28	248
Caliche, sandy	77	325
Sand	21	346
Caliche, hard, sandy	75	421
Clay, sandy	24	445
Caliche, sandy	16	461
Sand and caliche	29	490
Caliche, sandy	10	500
Sand	27	527
Clay, red	35	562
Clay, sandy	20	582
Clay	15	597
Sand	37	634
Clay	7	641
Clay, red	15	656
Clay, sandy	9	665

	Thickness (feet)	Depth (feet)
WELL ZA-66-61-301--Continued		
Sand	13	678
Clay, red	10	688

WELL ZA-66-62-714

Owner: Frank Zboril
Driller: Katy Drilling Co.

	Thickness (feet)	Depth (feet)
Surface clay	10	10
Sand	35	45
Clay	23	68
Sand	82	150
Clay	44	194
Sand	22	216
Clay	19	235
Sand	22	257
Clay	16	273
Sand	21	294
Clay	4	298
Sand	16	314
Clay	5	319
Sand	49	368
Clay	36	404
Sand, rock	57	461
Clay	10	471
Sand, rock	9	480
Clay	12	492
Sand	10	502
Clay	24	526
Sand, rock	12	538
Clay	19	557
Sand, rock	35	592
Clay	18	610
Sand, rock	7	617
Clay	46	663
Sand	19	682
Clay	11	693
Sand	46	739
Clay	10	749
Sand	17	766
Clay	26	780
Sand, rock	24	804
Clay	8	812
Sand, rock	27	839
Clay	14	853

	Thickness (feet)	Depth (feet)
WELL ZA-66-62-714--Continued		
Sand, rock	22	875
Clay	15	890
Sand	43	933
Clay	7	940
Sand, rock	37	977
Clay	13	990
Sand, rock	21	1,011
WELL ZA-66-62-908		
Owner: A. R. Zieschang, Jr.		
Driller: Crowell Drilling Co.		
Clay	12	12
Sand	42	54
Clay	14	68
Sand	12	80
Clay	32	112
Sand	70	182
Shale	32	214
Sand	34	248
Shale	20	268
Sand	14	282
Shale	15	297
Sand	13	310
Hard shale	10	320
Sand	16	336
Shale	29	365
Sand	23	388
Shale	4	392
Sand	12	404
Shale	106	510
Sand and hard shale	40	550
Shale	12	562
Sand and hard shale	15	577
Shale	23	600
Sand and hard shale	32	632
Rock	3	635
Sand	5	640
WELL ZA-66-64-103		
Owner: Wade Roberts		
Driller: Leonard Mickelson		
Soil and clay	101	101
Sand and gravel	36	137
Clay	23	160
WELL ZA-66-64-103--Continued		
Clay layers and gravel	31	191
Clay	32	223
Clay layers and gravel	63	286
Clay	10	296
Sand and gravel	97	393
Clay	25	418
Sand	80	498
Clay	9	507
Sand and gravel	57	564
Clay	15	579
Sand	16	595
Clay	8	603
Rocky sand	31	634