TEXAS WATER DEVELOPMENT BOARD

REPORT 155

GROUND-WATER RESOURCES OF FORT BEND COUNTY, TEXAS

By

J. B. Wesselman
United States Geological Survey

This report was prepared by the U.S. Geological Survey
under cooperative agreement with the
Texas Water Development Board.

August 1972

Reprinted by the Texas Department of Water Resources

January 1983

Published and distributed
by the
Texas Department of Water Resources
Post Office Box 13087
Austin, Texas 78711

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ABSTRACT

Fresh water is available in Fort Bend County only from the Chicot and Evangeline aquifers of Tertiary and Quaternary age. The Jasper aquifer, of Tertiary age, which is the deepest hydrologic unit, contains some slightly saline water in the northwestern part of the county.

The Evangeline aquifer contains fresh water at depths of more than 2,200 feet below mean sea level. The thickness of the water-bearing sands ranges from 100 to 600 feet and averages about 300 feet. The average coefficient of permeability is probably about 250 gpd (gallons per day) per square foot.

The thickness of sands containing fresh water in the Chicot aquifer ranges from 200 to 400 feet and averages about 350 feet. The average coefficient of permeability is estimated to be about 645 gpd per square foot. Most of the ground water pumped in the county comes from the Chicot aquifer.

The total thickness of sands containing fresh water in Fort Bend County averages about 650 feet. Assuming a porosity of 30 percent, about 120 million acre-feet of fresh water is in storage in the aquifers, and about 45 million acre-feet is in storage in the upper 500 feet of sediments.

The aquifers are pierced or displaced by eight salt domes and associated faults. At some locations over the domes, there is very little or no fresh ground water. In areas not affected by the domes, wells that are capable of yielding from 500 to 4,000 gpm (gallons per minute) of fresh water can be constructed in the Chicot aquifer. Wells of similar capacity can be constructed in the Evangeline aquifer, except in the southern part of the county and near the salt domes.

The quality of the fresh water contained in the aquifers is generally suitable for irrigation, public supply, and most industrial uses. However, in the vicinity of salt domes, the concentrations of dissolved solids and chlorides may exceed the standards for drinking water recommended by the U.S. Public Health Service. The ground water is generally very hard.

About 59 mgd (million gallons per day) of ground water was used for all purposes in 1968. About 39 mgd was used for irrigation, 14 mgd was used for industry, 5 mgd was used for public supply, and about 1 mgd was used for rural-domestic supply and livestock needs. The use of ground water for irrigation probably has stabilized, but because population growth is continuing the use of ground water for industry and municipal supply will increase. The perennial supply of ground water is estimated to be about 150 mgd, or 2 to 3 times the present withdrawal rate.

Since about 1900, water levels in the Evangeline aquifer have declined by amounts that range from less than 60 feet in the northwestern part of the county to more than 190 feet in the eastern part. Since 1947, water levels in the lower unit of the Chicot aquifer have declined less than 10 feet in the western part of the county and about 130 feet in the eastern part. Since 1947, water levels in the upper unit of the Chicot have declined less than 10 feet in the southwestern half of the county and more than 40 feet along the northeast edge.

The decline in water levels has been accompanied by compaction of subsurface material and subsidence of the land surface. The maximum subsidence during the period 1943-64 was more than 1 foot.

GROUND-WATER RESOURCES OF FORT BEND COUNTY, TEXAS

INTRODUCTION

Location and Extent of the Area

Fort Bend County is on the Gulf Coastal Plain of southeast Texas, south and west of the city of Houston (Figure 1). The county has an area of 862 square miles and a population (1970) of 51,410. Fort Bend County, which is adjacent to the Houston metropolitan area, is bordered by Harris, Brazoria, Wharton, Austin, and Waller Counties. The area is about 50 miles northwest of the Gulf of Mexico.

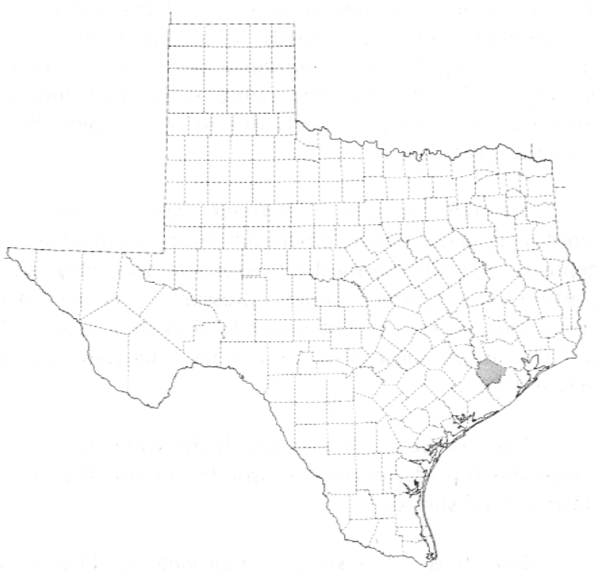

Figure 1.—Location of Fort Bend County

Purpose and Scope of the Investigation

The investigation of the ground-water resources of Fort Bend County began in September 1967 as a cooperative project of the U.S. Geological Survey and the Texas Water Development Board. The purpose of the investigation was to determine and evaluate the ground-water resources of the county. The results of the investigation are presented in this report, which include an analytical discussion of the occurrence and availability of ground water and a tabulation of basic data obtained during the investigation.

The scope of the investigation encompassed the collection, compilation, and analysis of data related to ground water, including: Determination of the location and extent of the water-bearing formations; the chemical quality of the water they contain; the quantity of water being withdrawn, and the effects of these withdrawals on the water levels; 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. The following items were included in the study:

1. An inventory of all industrial, public supply, and irrigation wells, and a representative number of domestic and livestock wells (Table 4). Locations of the wells are shown on Figure 29.

2. Analysis of electrical logs and drillers' logs of water wells and oil tests to determine the hydrologic correlations (Figures 30-33), to determine the thickness of water-bearing sands (Figures 27-28), to determine the altitude of the base of fresh water and the base of slightly saline water (Figures 3, 7, and 8), and to determine the altitude of the base of the Evangeline and Chicot aquifers (Figures 4-5).

3. An inventory of the withdrawal of ground water for public supply, industrial use, and irrigation (Figure 13).

4. Aquifer tests to determine the hydraulic characteristics of the water-bearing sands (Table 2).

5. Determination of altitudes of water wells from topographic maps.

6. Measurements of water levels in wells and tabulation of water-level records (Table 6).

7. Collection and compilation of climatological records (Figures 11-12).

8. Analyses of water samples to determine the chemical quality of the water (Table 7).

9. Compilation of data on land-surface subsidence.

Economic Development

The economy of Fort Bend County is sustained by agriculture, including the production of cattle, cotton, rice, and feed grains; petroleum production; and sulfur mining. In addition, a major sugar refinery, a large power plant that supplies electricity to the Houston-Galveston area, and many small petrochemical plants contribute to the economy. Salt is produced from the Blue Ridge Salt Dome, and gravel and sand are produced at various locations in the county. A lightweight aggregate plant is located near Clodine.

Well-Numbering System

The well-numbering system used in this report is the system adopted by the Texas Water Development Board for use throughout the State. In this system, each 1-degree quadrangle in the State is given a number consisting of two digits from 01 to 89. These are the first two digits in the well number. Each 1-degree quadrangle is divided into 7½-minute quadrangles which are given a 2-digit number from 01 to 64. These are the third and fourth digits of the well number. Each 7½-minute quadrangle is divided into 2½-minute quadrangles given single digit numbers from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2½-minute quadrangle is given a 2-digit number in the order in which it was inventoried, starting with 01. These are the last two digits of the well number.

In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefixes for Fort Bend and adjacent counties are as follows: Austin, AP; Brazoria, BH; Fort Bend, JY; Harris, LJ; Waller, YW; and Wharton, ZA.

As an example, well JY-65-26-501, one of the public-supply wells at Richmond, is in the 1-degree quadrangle 65, in the 7½-minute quadrangle 26, in the 2½-minute quadrangle 5, and was the first well inventoried, 01.

Definitions of Terms

Most definitions of the terms used in this report are adapted from Meinzer (1923), the American Geological Institute (1960), Langbein and Iseri (1960), or Ferris and others (1962).

Acre-foot.—The volume of water required to cover 1 acre to a depth of 1 foot (43,560 cu. ft. or 325,851 gal.). The term is commonly used in measuring the volume of water in storage in an aquifer or a surface reservoir or volume of water used for various purposes.

Alluvium.—Sediments deposited by streams including flood-plain deposits and terrace deposits. Also called alluvial deposits.

Aquiclude.—A formation, group of formations, or part of a formation, which although porous and capable of absorbing water slowly, will not transmit it fast enough to yield an appreciable supply to a well or spring.

Aquifer.—A formation, group of formations, or part of a formation that is water bearing.

Aquifer test, pumping test.—The test consists of the measurement at specific intervals of the discharge and water level of the well being pumped and the water levels in nearby observation wells. Formulas have been developed to show the relationship of the yield of a well, the shape and extent of the cone of depression, and the properties of the aquifer (such as the specific yield, porosity, and coefficients of permeability, transmissibility, and storage).

Aquifer test, recovery test.—The test consists of the measurement at specific intervals of the water level in a pumped well and in nearby observation wells. (See definition: *Aquifer test, pumping test.*) Measurements are begun shortly after the pump is stopped and are continued as the water levels rise to (or recover) their previous positions.

Artesian aquifer, confined aquifer.—Artesian (confined) water occurs where an aquifer is overlain by deposits of lower permeability (for example, clay) that confine the water under pressure greater than atmospheric pressure. The water level in an artesian well will rise above the top of the aquifer. The well may or may not flow.

Artesian well.—One in which the water level rises above the top of the aquifer, whether or not the water flows at land surface.

Base flow of a stream.—Fair-weather flow in a stream supplied by ground-water discharge.

Brine.—Water containing more than 35,000 mg/l (milligrams per liter) of dissolved solids.

Cone of depression.—A conical depression in the water table or piezometric surface surrounding a discharging well.

Drawdown.—The lowering of the water table or piezometric surface caused by pumping (or artesian flow). In most instances, drawdown is the difference, in feet, between the static level and the pumping level.

Electrical log.—A graph showing the variation in the electrical properties of the rocks and their fluid contents when penetrated in a well. The electrical properties are natural potentials and resistivities to induced electrical currents, some of which are modified by the presence of the drilling mud.

Evapotranspiration.—Water withdrawn by evaporation from a land area, a water surface, moist soil, or the water table, and the water consumed by transpiration.

Fault.—A fracture in the earth's crust, along which the rocks on one side have been displaced relative to those on the other.

Flood plain.—The lowland that borders a stream. A flood plain is usually dry, but is subject to flooding.

Formation.—A body of rock that is sufficiently homogeneous or distinctive and extensive enough to be regarded as a mappable unit; usually named for a locality where a typical section of the formation is exposed.

Fresh water.—Water containing less than 1,000 mg/l of dissolved solids.

Gaining stream.—A stream or reach of a stream that receives water from the zone of saturation.

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

Hydrologic cycle.—The complete cycle of phenomena through which water passes, commencing as atmospheric water vapor, passing into liquid or solid form as precipitation, thence along or into the ground, and returning to the form of atmospheric water vapor by means of evaporation and transpiration.

Lithology.—The character of a rock, expressed in terms of its mineral composition, its structure, the grain size, and arrangement of its component parts.

Milligrams per liter (mg/l).—As commonly measured and used, milligrams per liter are numerically equivalent to the milligrams of a substance in a liter of water.

Moderately saline water.—Water containing 3,000 to 10,000 mg/l of dissolved solids.

Permeability, coefficient of.—The rate of flow of water in gallons per day through a cross section of 1 square foot under a unit hydraulic gradient.

Piezometric surface.—An imaginary surface that everywhere coincides with the static level of the water in the aquifer. The surface to which the water from a given aquifer will rise under its full head.

Porosity.—The ratio of the aggregate volume of interstices (openings) in a rock or soil to its total volume, usually stated as a percentage.

Recharge of ground water.—The process by which water is absorbed and is added to the zone of saturation. Also used to designate the quantity of water that is added to the zone of saturation, usually given in acre-feet per year or in million gallons per day.

Recharge, rejected.—The natural discharge of ground water in the recharge area of an aquifer by springs, seeps, and evapotranspiration, which occurs when the rate of recharge exceeds the rate of transmission in the aquifer.

Saline water.—Water containing 1,000 mg/l or more of dissolved solids.

Specific capacity.—The rate of yield of a well per unit of drawdown, usually expressed as gallons per minute per foot of drawdown. If the yield is 250 gpm and the drawdown is 10 feet, the specific capacity is 25 gpm per foot.

Specific yield.—The quantity of water that an aquifer will yield by gravity if it is first saturated and then allowed to drain; the ratio expressed in percentage of the volume of water drained to the volume of the aquifer that is drained.

Storage.—The volume of water in an aquifer, generally given in acre-feet.

Storage coefficient.—The volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Storage coefficients of artesian aquifers may range from about 0.00001 to 0.001; those of water table aquifers may range from about 0.05 to 0.30.

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

Transpiration.—The process by which water vapor escapes from a living plant, principally from the leaves, and enters the atmosphere.

Very saline water.—Water containing 10,000 to 35,000 mg/l of dissolved solids.

Water-table aquifer (unconfined aquifer).—An aquifer in which the water is unconfined; the upper surface of the zone of saturation is under atmospheric pressure only, and the water is free to rise or fall in response to the changes in the volume of water in storage. A well penetrating an aquifer under water-table conditions becomes filled with water to the level of the water table.

Previous Investigations

The first reports on ground water that included information on Fort Bend County were prepared by Singley (1893), Darton (1905), Fuller and Sanford (1906), Taylor (1907), and Deussen (1914). Elledge and Turner (1937) inventoried 165 wells west of the Brazos River, and Livingston and Turner (1939) inventoried 51 wells east of the Brazos River in Fort Bend County.

Several reports of ground water in the Houston district included a part of Fort Bend County. Wood (1956) and Wood, Gabrysch and Marvin (1963) discussed the availability of ground water in the gulf coast region of Texas which includes Fort Bend County. Cronin and others (1963) included part of Fort Bend County in their reconnaissance study of the Brazos River Basin. Cronin and Wilson (1967), in a report on the water-bearing characteristics of the flood-plain alluvium along the Brazos River, included a part of the flood plain in Fort Bend County. Wilson (1967) included data from wells in Fort Bend County.

Acknowledgments

The author is indebted to the property owners in Fort Bend County for supplying information about their water wells and for permitting access to their properties; to the well drillers who supplied information on the wells; and to the officials representing the municipalities, industries, and water districts for supplying data and cooperating in aquifer tests in their wells.

The cooperation received from Dr. H. A. Bernard and R. J. LeBlanc, Shell Oil Company and Shell Development Company; Dr. M. A. Hanna, Gulf Oil Company, retired; Dr. Saul Aronow, Lamar State College of Technology; and personnel of the Soil Conservation Service office at Rosenberg, Texas, is gratefully acknowledged.

HYDROLOGIC AND GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

The geologic units composing the aquifers in Fort Bend County range in age from Miocene to Holocene. They are, from oldest to youngest, the Fleming Formation, Goliad Sand, Willis Sand, Bently Formation, Montgomery Formation, Beaumont Clay, and the Quaternary alluvium (Table 1).

The outcrops of the Beaumont Clay, the Montgomery Formation, and Quaternary alluvium are shown on the geologic map (Figure 2). The older formations crop out in the counties north of Fort Bend County. One or more of the formations may be absent at any specific location due to nondeposition or erosion, and the sand-clay ratio of the formations varies considerably from location to location. Sand occurs in bands which may be either parallel or perpendicular to the coastline. The bands paralleling the coast probably represent long-shore deposits. The perpendicular bands contain both fluvial and deltaic deposits and represent the filling of river valleys, bays, and parts of the gulf during sea-level fluctuations.

Regionally, all of the formations dip toward the gulf at an angle greater than the slope of the land surface; they generally thicken and occur at progressively greater depths in the gulfward direction.

Bernard, LeBlanc, and Major (1962, p. 219) give the following rates of dip for the tops of the formations in the vicinity of the Brazos River: Willis Sand, 10 feet per mile; Bentley Formation, 3 feet per mile; Montgomery Formation, 2.5 feet per mile; and the Beaumont Clay, 1.8 feet per mile. Wilson (1967, p. 8) estimates the dip of the Fleming Formation to be 40 to 60 feet per mile and the dip of the bottom of the Goliad Sand to be 40 feet per mile.

The regional dip of the Tertiary beds has been altered by the intrusion of salt domes and by faulting. The overlying Quaternary beds are relatively unaffected by these faults except in the immediate vicinity of some of the salt domes.

Eight salt domes have been located in Fort Bend County (Figure 4), and all except the Thompson and Sugar Land Domes penetrate the Pleistocene beds. The caprock over the salt domes contains anhydrite, gypsum, limestone, and sulfur. Commercial oil and gas deposits occur in traps in the caprock material and in the sands over and around the domes.

Earlier investigators in the gulf coast region of Texas attempted to delineate aquifer units on the basis of geologic formations, but in the younger sediments, the aquifers generally consist of parts of one or more geologic formations.

White, Rose, and Guyton (1940), and Lang, Winslow, and White (1950), subdivided the fresh water-bearing sediments in the Houston district into zones that were either predominantly sand or clay. They tentatively correlated these zones with the geologic formations at the outcrop (Table 1). Zones 1, 3, 5, and 7 of Lang, Winslow, and White (1950) contain more sand than clay; zones 2, 4, and 6 contain more clay than sand. They also recognized that most of the individual beds of sand or clay are rarely continuous over long distances and that they often lense, grade into, and interfinger with each other. In Galveston County, Pettit and Winslow (1957) divided the beds and mapped a separate massive unit, the Alta Loma sand of Rose (1943).

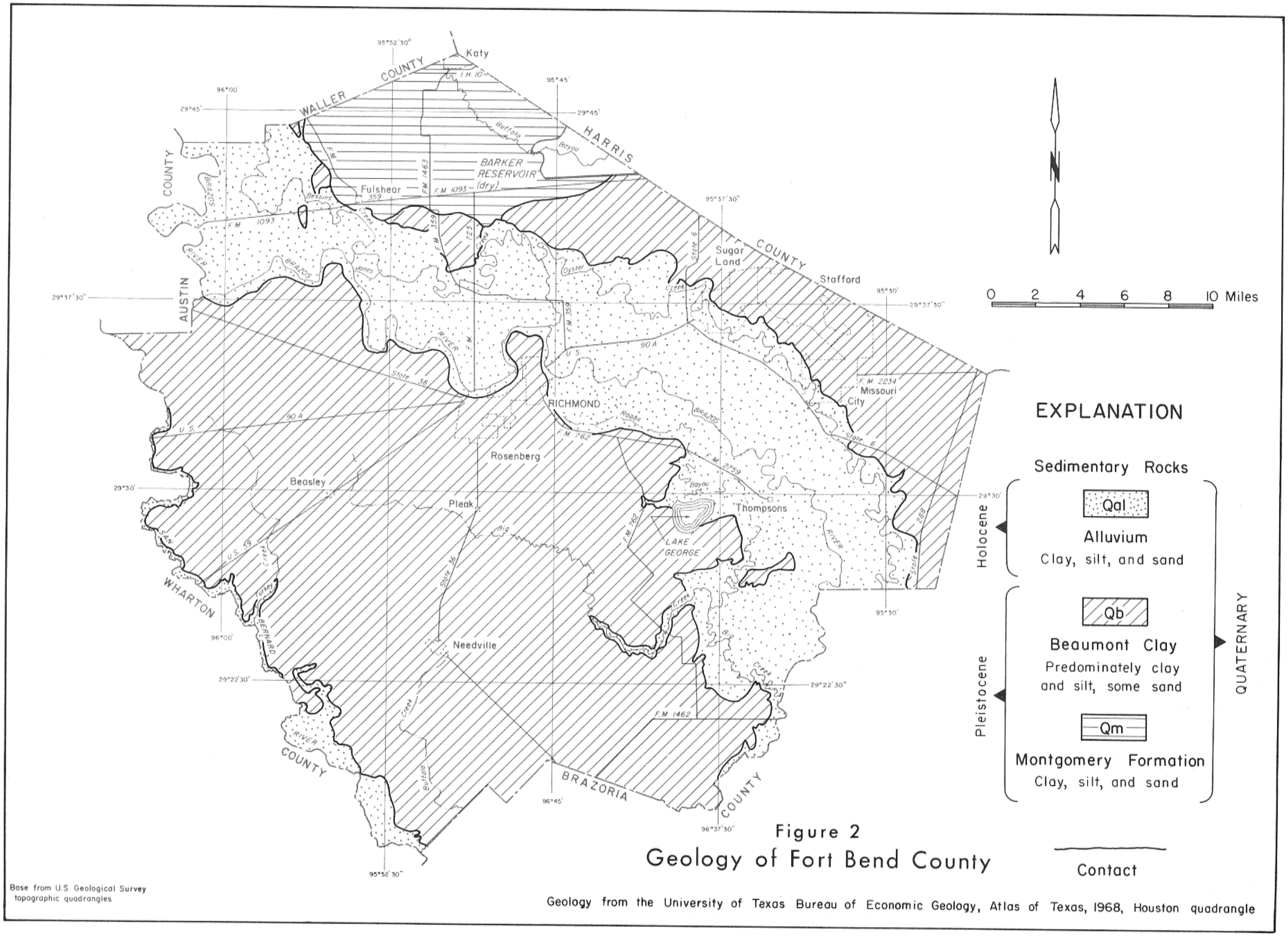

Figure 2
Geology of Fort Bend County

Table 1.--Correlation of Geologic and Hydrologic Units

THIS REPORT: System	THIS REPORT: Series	THIS REPORT: Stratigraphic Unit	THIS REPORT: Aquifer	WOOD AND GABRYSCH (1965): Houston district	SANDEEN AND WESSELMAN (1972): Brazoria County	WILSON (1967): Austin and Waller Counties	HAMMOND (1969): Matagorda County	LANG, WINSLOW, AND WHITE (1950): Houston district	PETITT AND WINSLOW (1957): Galveston County
QUATERNARY	Holocene	Quaternary alluvium	Chicot aquifer: Upper unit	Confining layer and Alta Loma Sand of Rose (1943)	Chicot aquifer: Upper unit	Alluvium of the Brazos River	Gulf Coast aquifer	Recent	Recent
QUATERNARY	Pleistocene	Beaumont Clay	Chicot aquifer: Upper unit	Confining layer and Alta Loma Sand of Rose (1943)	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)	Gulf Coast aquifer	Beaumont Clay	Beaumont Clay
QUATERNARY	Pleistocene	Montgomery Formation	Chicot aquifer: Upper unit	Confining layer and Alta Loma Sand of Rose (1943) / Heavily pumped layer	Chicot aquifer: Upper unit	Evangeline aquifer	Gulf Coast aquifer	Beaumont Clay / "Alta Loma Sand"	Beaumont Clay / "Alta Loma Sand"
QUATERNARY	Pleistocene	Bentley Formation	Chicot aquifer: Lower unit	Confining layer and Alta Loma Sand of Rose (1943) / Heavily pumped layer	Chicot aquifer	Evangeline aquifer	Gulf Coast aquifer	Beaumont Clay / "Alta Loma Sand"	Beaumont Clay / "Alta Loma Sand"
QUATERNARY	Pleistocene	Willis Sand	Chicot aquifer: Lower unit	Confining layer and Alta Loma Sand of Rose (1943) / Heavily pumped layer	Chicot aquifer	Evangeline aquifer	Gulf Coast aquifer		
TERTIARY	Pliocene	Goliad Sand	Evangeline aquifer	Heavily pumped layer	Evangeline aquifer	Evangeline aquifer	Gulf Coast aquifer	Zone 7, Zone 6, Zone 5, Zone 4	Lissie Formation
TERTIARY	Miocene	Fleming Formation	Evangeline aquifer	Heavily pumped layer		Evangeline aquifer		Zone 3	
TERTIARY	Miocene	Fleming Formation	Burkeville aquiclude	Zone 2		Burkeville aquiclude		Zone 2	
TERTIARY	Miocene	Fleming Formation	Jasper aquifer			Jasper aquifer		Zone 1	

Wood and Gabrysch (1965) grouped zones 3 through part of zone 7 of Lang, Winslow, and White (1950) into one hydrologic unit which they called the "heavily pumped layer." Most large wells in the Houston area pump water from all or part of this layer. In southern Harris and Galveston Counties, the "heavily pumped layer" underlies the Alta Loma sand of Rose (1943). In Fort Bend County, where the Alta Loma sand is not recognized, Wood and Gabrysch (1965) projected their "heavily pumped layer" to the surface .

Baker and others (1963) in the Sabine River Basin and Baker (1965) in Jackson County grouped several geologic formations of the gulf coast into one unit called the Gulf Coast aquifer, which is composed of all sediments that contain fresh to slightly saline water. Hammond (1969) also used this concept, but separated a "heavily pumped zone" in Matagorda County.

Wesselman (1967) subdivided the formations above the Catahoula Sandstone in Jasper and Newton Counties into four hydrologic units: The Jasper aquifer, Burkeville aquiclude, Evangeline aquifer, and Chicot aquifer. These subdivisions were based on differences in lithology, water levels in wells, and permeabilities of the individual units.

In this report, the Burkeville aquiclude is correlated with zone 2 of Lang, Winslow, and White (1950); the Evangeline aquifer is correlated with the "heavily pumped layer" in southern Harris County; and the Chicot aquifer is correlated with the Alta Loma sand and overlying beds. These correlations are illustrated in Figures 30, 31, 32, and 33.

Jasper Aquifer

The Jasper aquifer does not contain fresh water in Fort Bend County, but electrical logs indicate that the formation contains slightly saline water in the northwest part of the county. The maximum thickness of the sands containing slightly saline water is about 100 feet (Figure 3).

The top of the Jasper aquifer correlates with Zone 1 of Lang, Winslow, and White (1950). According to Wilson (1967), the dip of the top of the Jasper aquifer in Austin and Waller Counties is 40 to 60 feet per mile. In Fort Bend County, the top of the aquifer dips at about 50 feet per mile.

Because no water wells have been completed in the Jasper aquifer in Fort Bend County, no aquifer tests were conducted. Wilson (1967, Table 2, p. 15) presented data from the analysis of the drawdown and recovery of water levels in a well screening 51 feet of sand in this aquifer in Austin County. The coefficients of transmissibility and permeability based on drawdowns were 10,800 gpd (gallons per day) per foot and 212 gpd per square foot, respectively. Based on recovery, the coefficients were 13,900 gpd per foot and 272 gpd per square foot, respectively.

The coefficient of permeability from nine tests in six wells completed in the upper part of the Jasper aquifer in Montgomery and Liberty Counties ranged from 150 to 300 gpd per square foot and averaged 240 gpd per square foot (Popkin, 1971). The range in the coefficients of permeability in the Jasper aquifer in Montgomery County probably encompasses the average coefficient of permeability in Fort Bend County.

Burkeville Aquiclude

The Burkeville aquiclude, which is composed of clay of the Fleming Formation, separates the Jasper aquifer from the Evangeline aquifer. The Burkeville is not mapped on Figure 4, but the base of the Evangeline aquifer is the top of the aquiclude. In the area where the Evangeline contains fresh water, the Burkeville is equivalent to zone 2 of Lang, Winslow, and White (1950) in the Houston district.

Evangeline Aquifer

The Evangeline aquifer, which overlies the Burkeville aquiclude and underlies the Chicot aquifer (except over some salt domes) ranges in thickness from 1,200 to 2,200 feet. The base of the aquifer is shown on Figure 4, and its relation to the other aquifers is shown on Figures 30-33.

In most of Fort Bend County, the Evangeline aquifer is composed of 400 to 700 feet of sand. The percentage of sand in the section ranges from about 33 to about 40 percent. The thickest sand beds and thickest fresh-water sections occur in the eastern half of the county.

The hydraulic properties of the aquifer are summarized in Table 2. The coefficients of transmissibility and permeability at the only well tested that was completed exclusively in the Evangeline aquifer (JY-65-26-812) were 65,700 gpd per foot and 350 gpd per square foot respectively. Only part of the aquifer was screened; therefore, the coefficient of transmissibility of the total thickness of the aquifer is greater than indicated by the test. The coefficient of permeability is higher than the average of about 250 gpd per square foot reported for the Houston district (Wood and Gabrysch, 1965, p. 65), or the average of 215 gpd per square foot in Austin and Waller Counties (Wilson, 1967).

The sands composing the Evangeline aquifer in Fort Bend County are similar to those in the Houston district; therefore, the average permeability is probably about 250 gpd per square foot. Based on an average coefficient of permeability of 250 gpd per square foot and a maximum sand thickness of 690 feet, the

Table 2.--Hydraulic Properties of the Aquifers and Wells

Water-bearing unit: C, Chicot; Cu, upper Chicot; Cl, lower Chicot; E, Evangeline.
D - Drawdown; R - Recovery.

WELL	DEPTH OF WELL (FT)	WATER-BEARING UNIT	DATE OF TEST	TOTAL SAND THICKNESS INCLUDED IN SCREENED INTERVAL (FT)	COEFFICIENT OF TRANSMISSIBILITY (GPD PER FT)	FIELD COEFFICIENT OF PERMEABILITY (GPD PER FT^2)	REMARKS
JY-65-19-801	256	C	July 2, 1969	60±	84,000	1,400±	Recovery test. 1-hr. specific capacity 37 gpm per ft.
25-202	292	C	June 24, 1969	116±	110,000	950±	Recovery test. 1-hr. specific capacity 11.6 gpm per ft.
203	280	C	June 24, 1969	110±	78,000	710	Recovery test. 1-hr. specific capacity 8.3 gpm per ft.
26-602	400	Cu,Cl	July 28, 1955	250	104,000	410	Recovery test. 1-hr. specific capacity 51 gpm per ft.
603	518	Cl	June 25, 1969	130±	84,500	650	Recovery test. 1-hr. specific capacity 8.8 gpm per ft.
812	1,313	E	Aug. 9, 1967	185±	65,700	350	Recovery test. 20 min. specific capacity 25 gpm per ft.
33-502	590	C	July 28, 1955	--	126,000	--	Recovery test. 1-hr. specific capacity 69 gpm per ft.
802	365	Cl	Oct. 25, 1967	--	13,200 D 15,400 R	--	Interference test. Well JY-65-33-803 pumping. Storage coefficient $1x10^{-4}$.
803	363	Cl	Oct. 25, 1967	38	14,000	370	Recovery test. 1-hr. specific capacity 5.5 gpm per ft.
34-301	314	Cl,Cu	June 26, 1969	--	47,000	--	Recovery Test.
901	636	Cl,Cu	July 27, 1955	320	120,000	375	Recovery Test. 1-hr specific capacity 49 gpm per ft.
35-303	803	Cl,E	1956	--	110,000 1/	--	Interference test. Well JY-65-35-304 pumping Storage coefficient $1x10^{-3}$
304	853	Cl,E	1967	193±	114,000 1/	590	Drawdown test.
304	853	Cl,E	1967	193±	122,000 1/	630	Recovery test.
710	508	Cl	June 30, 1969	165±	55,000	330	Recovery test. 1-hr. specific capacity 19 gpm per ft.
42-303	1,090	Cl,E	July 28, 1955	420	125,000	300	Recovery test. 1-hr. specific capacity 79 gpm per ft.
43-201	1,158	Cl,E	July 27, 1955	555	156,000	280	Recovery test. 1-hr. specific capacity 79 gpm per ft.
44-101	874	Cl,E	June 16, 1967	--	88,700	--	Recovery test. 1-hr. specific capacity 49 gpm per ft.

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maximum coefficient of transmissibility is about 170,000 gpd per foot. The average fresh-water sand thickness in the county is about 300 feet; therefore, the average transmissibility of the fresh-water part of the Evangeline is probably about 75,000 gpd per foot.

Storage coefficients of the Evangeline aquifer were not determined in Fort Bend County, but on the basis of a large number of tests in the Houston district (Wood and Gabrysch, 1965, p. 16), the coefficients for the aquifer in the area are probably about 0.001 to 0.002.

The yields of 11 wells tapping the Evangeline aquifer ranged from 180 to 2,232 gpm (gallons per minute), Table 4. The specific capacity measured in well JY-65-26-812 was 25 gpm per foot of drawdown.

Chicot Aquifer

The Chicot aquifer is a sequence of sand and clay beds which overlie the Evangeline aquifer. The basis for differentiation of the units is differences in stratigraphic position, lithology, and permeability. The altitude of the base of the aquifer is shown in Figure 5. The subsurface relationships are shown in Figures 30-33.

The percentage of sand thickness in the Chicot aquifer ranges from about 40 percent in the eastern part of the county to about 75 percent in the north and northwestern parts of the county. The aquifer contains fresh water only, except in some areas over and adjacent to the salt domes.

The Chicot aquifer is subdivided into upper and lower units (Figures 30-33). In most of the southeastern part of the county, the two units are separated by a layer of clay, which is 200 to 300 feet below the land surface. The two units merge and generally function as a single aquifer in the northwestern part of Fort Bend County.

At most locations in Fort Bend County, water in the Chicot aquifer occurs under artesian conditions. However, in the major stream valleys, the upper unit of the aquifer is in hydraulic continuity with the surficial sand deposits, and therefore under water-table conditions. In the Katy area of the extreme northern part of the county, water levels have been lowered as much as 90 feet below the surface. This depressurizing has resulted in converting the aquifer in this area from artesian to water-table conditions.

The Chicot aquifer is the most permeable unit in Fort Bend County. The coefficients of transmissibility for the aquifer ranged from 13,200 to 126,000 gpd per foot in 11 tests (Table 2). The coefficient of permeability from eight tests ranged from 330 to about 1,400 gpd per square foot; the average is about 645 gpd per square foot. Based on an average sand thickness of 350 feet and an average coefficient of permeability of 645 gpm per square foot, the average transmissibility is about 225,000 gpd per foot.

The yields of wells completed in the Chicot aquifer are as much as 4,200 gpm. Specific capacities of the wells ranged from 5.5 to 69 gpm per foot of drawdown. The storage coefficient determined from one test was 0.0001.

CHEMICAL QUALITY OF GROUND WATER

Chemical analyses of water from wells in Fort Bend County are given in Table 7. The locations of the wells sampled are identified on Figure 29 by a bar over the well number. The source and significance of the dissolved-mineral constituents and properties of water, which are reported in the analyses, are given in Table 3.

The various criteria used in determining water-quality standards are bacterial content, temperature, color, taste, odor, and the concentrations of chemical constituents. No bacterial analyses were made in this study. The results of analyses for insecticides and herbicides, made on samples from four wells, were negative.

The U.S. Public Health Service (1962, p. 7) has established standards for the chemical quality of water to be used by common carriers engaged in interstate commerce. These standards are useful in evaluating domestic and public water supplies. According to these standards, chemical substances should not be present in a water supply in excess of the listed concentrations if more suitable supplies are available or can be made available at reasonable cost. The following are the limits of concentration in mg/l (milligrams per liter) for some of the constituents:

SUBSTANCE	CONCENTRATION (mg/l)
Chloride (Cl)	250
Fluoride (F)	0.7[1]
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

[1] According to the U.S. Public Health Service (1962, p. 41), the optimum fluoride level depends on the climatic conditions, because the amount of water drunk is influenced primarily by air temperature. The optimum value of 0.7 mg/l in Fort Bend County is based on the annual average of daily maximum air temperatures of 80.0°F at Sugar Land.

Table 3.—Source and Significance of Dissolved-Mineral Constituents and Properties of Water

CONSTITUENT OR PROPERTY	SOURCE OR CAUSE	SIGNIFICANCE
Silica (SiO_2)	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 mg/l of iron in surface waters generally indicates acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stains laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. U.S. Public Health Service (1962) drinking-water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3)	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. U.S. Public Health Service (1962) drinking-water standards recommend that the sulfate content should not exceed 250 mg/l.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. U.S. Public Health Service (1962) drinking-water standards recommend that the chloride content should not exceed 250 mg/l.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptbility of the individual. (Maier, 1950)
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest pollution. U.S. Public Health Service (1962) drinking-water standards suggest a limit of 45 mg/l. Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding. Nitrate has been shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	U.S. Public Health Service (1962) drinking-water standards recommend that waters containing more than 500 mg/l dissolved solids not be used if other less mineralized supplies are available. Waters containing more than 1000 mg/l dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all the hardness is due to calcium and magnesium. All the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness as much as 60 ppm are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; more than 180 mg/l, very hard.
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.

In addition to meeting the desired standards of the U.S. Public Health Service, the water should be free of odor and turbidity; and it should not contain color to the extent that it is objectionable to the user. The water should not be excessively corrosive to the water-supply system.

Water containing concentrations of chloride that exceed 250 mg/l and an equivalent amount of sodium may have a salty taste, and excessive concentrations of manganese and iron in a water supply tend to stain utensils and to discolor laundry.

Consumption of water with a high nitrate content has been related to infant cyanosis or "blue baby" disease. Water having a nitrate content of more than 45 mg/l is potentially dangerous for infant feeding. High nitrate concentrations may also indicate pollution of the water supply by sewage or organic material.

The hardness of water, caused mainly by calcium and magnesium, is important in a water supply although no limits have been established by the U.S. Public Health Service. Excessive hardness causes an increase in the comsumption of soap and induces the formation of scale in hot water heaters and water pipes.

The chemical quality necessary for the industrial use of water depends on the intended use, such as cooling, boiler-feed, or product processing. Each of these categories has different water-quality requirements. Hem (1959, p. 253) and Todd (1959, p. 186-187) summarize the water-quality tolerances for a number of industries.

The suitability of water for irrigation depends upon the chemical quality of the water, the types of crops, the soil structure and composition, irrigation and drainage methods, and climate. Some of the more important chemical characteristics that are considered in the evaluation of water for irrigation are: (1) the sodium concentration, an index of the sodium or alkali hazard, SAR (sodium-adsorption ratio); (2) the concentration of soluble salts, an index of the salinity hazard; (3) the amount of RSC (residual sodium carbonate); and (4) the concentration of boron.

A classification frequently used for judging the quality of water for irrigation was proposed by the U.S. Salinity Laboratory Staff (1954, p. 69-82). This classification is based primarily on the salinity hazard as measured by the electrical conductivity of the water and the sodium hazard as measured by the SAR. A high percentage of sodium in the soil or in the irrigation water tends to make the soil impermeable.

A diagram of this classification, with results of chemical analyses plotted according to the aquifer from which the water was pumped, is shown in Figure 6. The salinity hazard ranges from medium to high. The sodium hazard is low in all but five samples, which have a medium sodium hazard.

Wilcox (1955, p. 15-16) stated that this classification is not directly applicable to supplemental irrigation water used in areas of high rainfall. The analyses as plotted on Figure 6 indicate that all of the water would be suitable for supplemental irrigation in Fort Bend County.

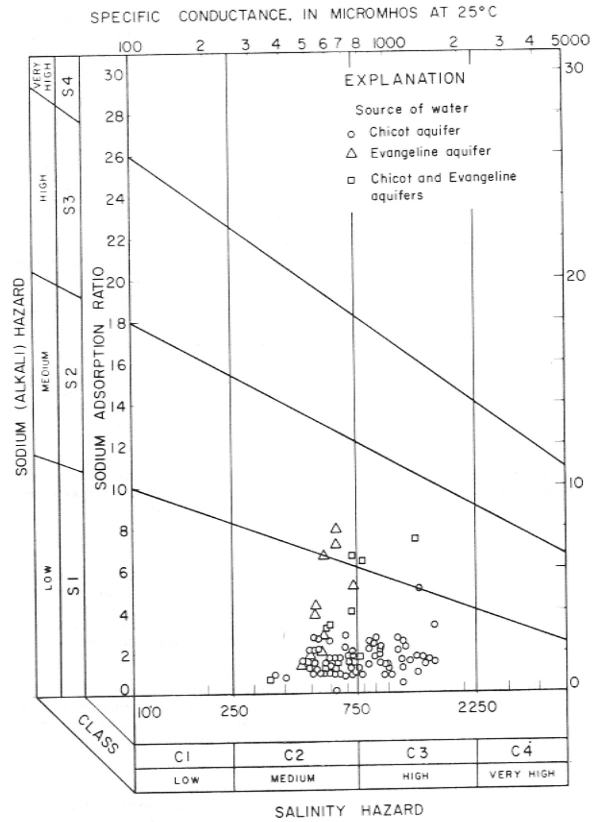

Figure 6.—Classification of Irrigation Waters

The RSC is another factor used in judging the suitability of water for irrigation. Excessive RSC may cause the water to be alkaline, causing the organic material in the soil to dissolve. Wilcox (1955, p. 11) suggests the following limits for the RSC content of irrigation waters: More than 2.5 epm (equivalents per million), not suitable; 1.25 to 2.5 epm, marginal; and less than 1.25 epm, safe. The maximum RSC for the 95 analyses listed in Table 7 was 5.54 epm. Of the 95 analyses, 57 were in the safe range, 22 were in the marginal range, and 16 exceeded the 2.5 epm limit.

Boron is essential to plant growth, but it is toxic at concentrations only slightly more than the optimum value. Scofield (1936, p. 286) indicated that a boron concentration of 1 mg/l is permissible for irrigating most boron-sensitive crops; a concentration of 3 mg/l is permissible for the more boron-tolerant crops. Most small grains and cotton are considered semi-tolerant to boron. Of 52 determinations for boron, none exceeded 1 mg/l concentration.

Rice is moderately tolerant to salinity. According to Shutts (1953, p. 871-884), the commonly accepted tolerances of rice to sodium chloride 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 for jointing to heading.
3,400	Harmful before booting; tolerable from booting to heading.
5,100	Harmful at all stages.

Chloride concentrations of more than 250 mg/l were exceeded in water from 14 wells in the county; 10 of these wells were near salt domes. Well JY-65-26-403 is not near a salt dome, but the water from this well has probably been affected by ground-water circulation near the Orchard Dome. The other three wells not near salt domes are shallow (90, 60, and 38 feet deep) and are located in the southwest part of the county. The cause of the high chloride concentrations in the water from these wells is not known. The U.S. Public Health Service standard for dissolved solids (500 mg/l) was exceeded in samples from 73 of 226 wells, but many of the wells yielding water containing chlorides in excess of 500 mg/l dissolved solids were in the vicinity of salt domes.

Ground water in the county is generally very hard. Soft water (less than 60 mg/l hardness) was obtained from only four production wells, two in the Evangeline aquifer at Sugar Land and two in the lower unit of the Chicot aquifer in the Blue Ridge Dome area. The data show that the softer water is contained in the deeper sands.

Iron exceeded 0.3 mg/l in samples from 24 wells. Many of the wells yielding high iron concentrations were completed, at least in part, in the upper unit of the Chicot aquifer. However, samples with high iron content were obtained from wells completed in each aquifer.

Fluoride determinations were made in 97 of the analyses. Nine of these exceeded the optimum value of 0.7 mg/l, five of which were in the vicinity of the Blue Ridge Dome. The highest concentration of fluoride was 1.8 mg/l. The average fluoride concentration was 0.4 mg/l, considerably lower than the optimum amount.

The concentration of nitrate was less than 15 mg/l in all samples except from well JY-66-32-907, which contained 157 mg/l of nitrate. This shallow well (30 ft. deep), which furnishes water to stock, is probably contaminated by organic material.

The concentration of sulfate did not exceed the 250 mg/l recommended by the Public Health Service in any of the water samples. Only four analyses showed concentrations greater than 100 mg/l; the highest was 242 mg/l.

To provide information on the presence and extent of pesticides in ground water, pesticide analyses were made on four samples of ground water. The water was analyzed for nine insecticides (aldrin; DDD; DDE; DDT; dieldrin; endrin; heptachlor; heptachlor epoxide; and lindane) and three herbicides (2,4-D; silvex; and 2,4-5-T) recommended for monitoring by the Federal Committee on Pest Control (Green and Love, 1967, p. 13-16). Samples of water were taken Jan. 28, 1969, from wells JY-65-26-501, JY-65-27-312, and JY-65-34-701, which are 840, 1,606, and 435 feet deep, respectively. A sample was taken on June 10, 1969, from well JY-65-18-111, 1,000 feet deep. The analyses indicated that no pesticides were present in the water sampled.

Relationship of Fresh Water to Saline Water

The geologic formations composing the fresh-water aquifers in Fort Bend County consist of sediments that were deposited in or near the Gulf of Mexico. These sediments either contained salt water at the time of deposition or were deposited in fresh water and filled with salt water at a time of higher sea level.

At some time after deposition, the sea receded and the process of recharge and discharge began. Fresh water furnished to the recharge area began to force the saline water to the discharge areas until the pressure exerted by the fresh water equaled the pressure of the salt water. Winslow and others (1957) presented a complete discussion of this process in relation to adjoining Harris County.

Several hundred electrical logs of test holes in Fort Bend and adjoining counties were used to construct the maps showing the base of fresh water and the base of slightly saline water in the aquifers in Fort Bend County.

The approximate altitude of the base of fresh water is shown on Figure 7. The approximate altitude of the base of slightly saline water in the Jasper aquifer is shown on Figure 3; the approximate base of slightly saline water in the Evangeline and Chicot aquifers is shown on Figure 8.

The contours shown on Figure 7 are very irregular, which indicates that there is no smooth or constant-trending interface between fresh and saline water. The irregularities in the base of fresh water in the northern part of the county are probably related to the interconnection of the Chicot and Evangeline aquifers.

Unique relationships between fresh water and saline water often are found near the salt domes which pierce the aquifers. The presence of the salt domes has apparently affected the quality of the water in the vicinity of at least some of the domes. The interbedding of sands containing fresh water with beds containing saline water in the vicinity of the Orchard, Big Creek, and Long Point Domes is shown on Figures 32 and 33. Areas of interbedding of sands containing fresh water with beds containing saline water in the Chicot aquifer are shown on Figure 28. The presence of the saline water is related, at least in part, to the presence of the salt domes.

The sands of the Evangeline aquifer are thinned and arched over the Sugar Land Dome (Figure 4), and the top of the dome is beneath the Burkeville aquiclude. The anomaly in the base of fresh water (Figure 7) is probably due to incomplete flushing of the sands rather than degradation of the water by the salt dome.

A diagram illustrating ground-water circulation around salt domes, published by Hanna (1958, Figure 8), is reproduced as Figure 9. Hanna described the movement as follows: "Water in these sloping beds is under artesian head. Figure 8 is an idealized block diagram showing how these artesian waters in the formation will flow upward around a salt dome if an escape route is available. Water does not move down around these salt domes but upward and goes into the shallow sands or to the surface. "

Heavy pumping from the lower unit of the Chicot aquifer and from the Evangeline aquifer has changed the pressure relationships. At some of the domes, water may now be moving downward instead of upward.

Protection of Water Quality in Oil-Field Operations

A potential source of contamination of the fresh-water sands in Fort Bend County is from the improper disposal of oil-field brines. The following tabulation from the records of the Railroad Commission of Texas lists the reported quantity and methods of disposal of salt water produced in the oil fields of Fort Bend County in 1967:

OIL FIELD	SALT-WATER PRODUCTION BARRELS	METHOD OF DISPOSAL: INJECTION WELLS		UNDERLINED PITS	
		BARRELS	PERCENT	BARRELS	PERCENT
Barb-Mag	30,050	30,050	100	0	0
Big Creek	359,449	353,345	98.3	6,104	1.7
Blue Ridge 1/	177,756	152,161	85.6	25,425	14.3
Blue Ridge (east)	31,091	31,091	100	0	0
Blue Ridge (north)	24,000	0	0	24,000	100
Boling	82,420	70,520	85.5	11,900	14.5
Clodine	112,017	53,617	48	58,400	52
Clodine (SW)	120	0	0	120	100
Clodine (north)	27,375	0	0	27,375	100
Fulshear	49,175	0	0	49,175	100
Katy	5,523	0	0	5,523	100
Moores	657,147	657,147	100	0	0
Nash Dome	59,362	17,885	30.2	41,477	69.8
Needville	301,290	301,290	100	0	0
Randon	1,054	0	0	1,054	100
Sugar Land	491,333	491,333	100	0	0
Thompson (north)	358,337	29,861	8.3	328,476	91.7
Thompson (south)	662,271	662,271	100	0	0
Thompson (seg. 13-A)	54,191	54,191	100	0	0
Thompson (SE)	36,757	36,757	100	0	0
Thompson	12,766,682	12,766,682	100	0	0
Totals	16,287,400	15,708,201	96.5	579,029	3.5

1/ One hundred seventy barrels (0.1 percent) was in the production tanks.

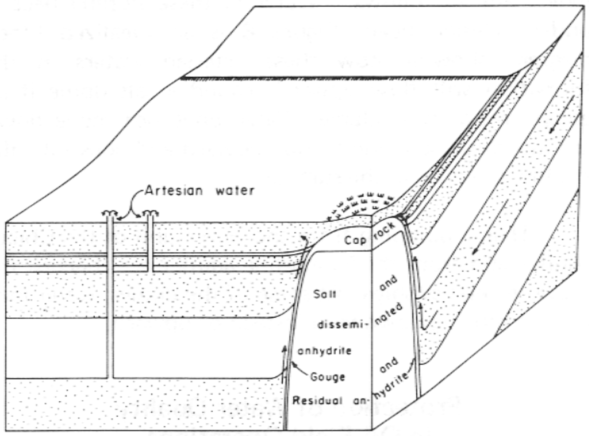

Figure 9.—Ground-Water Circulation Around Salt Domes

This tabulation shows that 96.5 percent of the salt water produced in 1967 was returned to the ground by injection, and about 3.5 percent of the salt water was placed in unlined pits. At least part of the water seeped from the pits into the ground, and part of it probably made its way to the streams.

Because of this source of contamination, State law now prohibits disposal of salt water in pits, but improper construction of disposal wells could also result in the contamination of fresh-water sands. Therefore, State laws require permits to be issued for disposal by wells.

Another potential source of ground-water contamination exists where improperly cased oil or gas wells may allow upward movement of brine from the underlying formations into the zones of fresh and slightly saline water.

The Texas Railroad Commission, in its effort to eliminate contamination by oil-field brines, has issued rules regarding the minimum casing requirements in some oil fields. A comparison between the depths of sands containing fresh to slightly saline water and the surface-casing requirements in oil fields in Fort Bend County is shown on Figure 10. This illustration shows that the fresh to slightly saline water is not adequately protected in five of the seven fields that have field rules.

RECHARGE, MOVEMENT, AND DISCHARGE OF GROUND WATER

Recharge to the Aquifers

The climate of Fort Bend County is predominatly maritime; rainfall, which is the source of most of the ground-water recharge, is abundant. The average monthly temperature, evaporation, and precipitation at

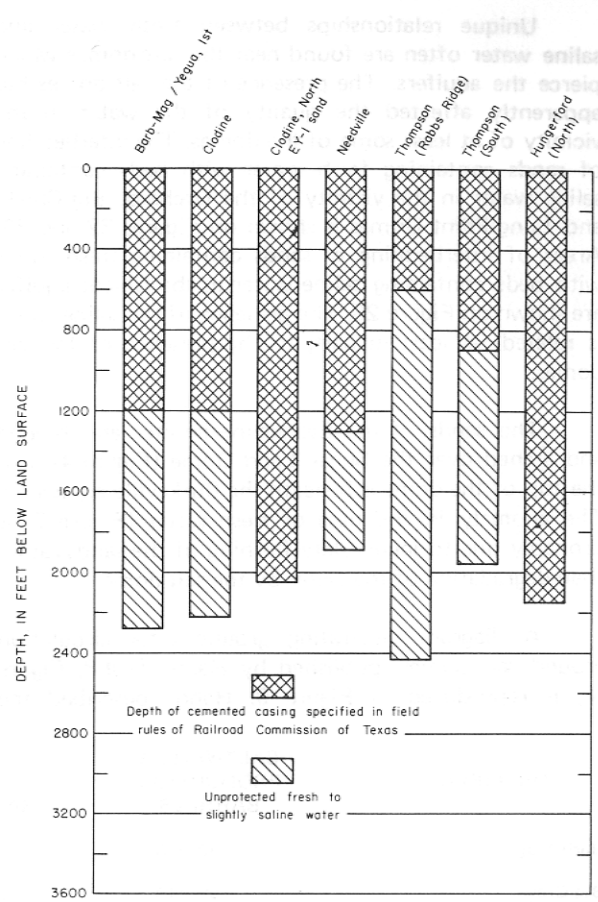

Figure 10.—Comparison Between the Depths of Sands Containing Fresh to Slightly Saline Water and the Surface-Casing Requirements in Oil and Gas Fields

Sugar Land is shown on Figure 11. The annual precipitation at Sugar Land during the period 1899-1968 is shown on Figure 12. The illustrations show that the precipitation is about evenly distributed throughout the year; however, most of the recharge probably occurs in the winter, because much of the precipitation is consumed by evapotranspiration during the summer.

Recharge to the aquifers, except for parts of the upper unit of the Chicot, occurs principally in the outcrop areas in adjoining Austin, Waller, and Harris Counties. In Austin and Waller Counties, the Goliad Sand, which composes much of the Evangeline aquifer, is overlapped by the Willis Sand in most places (Wilson, 1967, p. 31, 34). Recharge to the Goliad must occur by percolation of water through the Willis into the sandy units of the Goliad. Thus, in the area of overlap, much of the recharge to the Evangeline aquifer occurs through basal sands of the Chicot.

Wilson (1967, p. 31) further states that physiographically the recharge areas in Austin and Waller Counties range from the relatively flat Willis, Bentley,

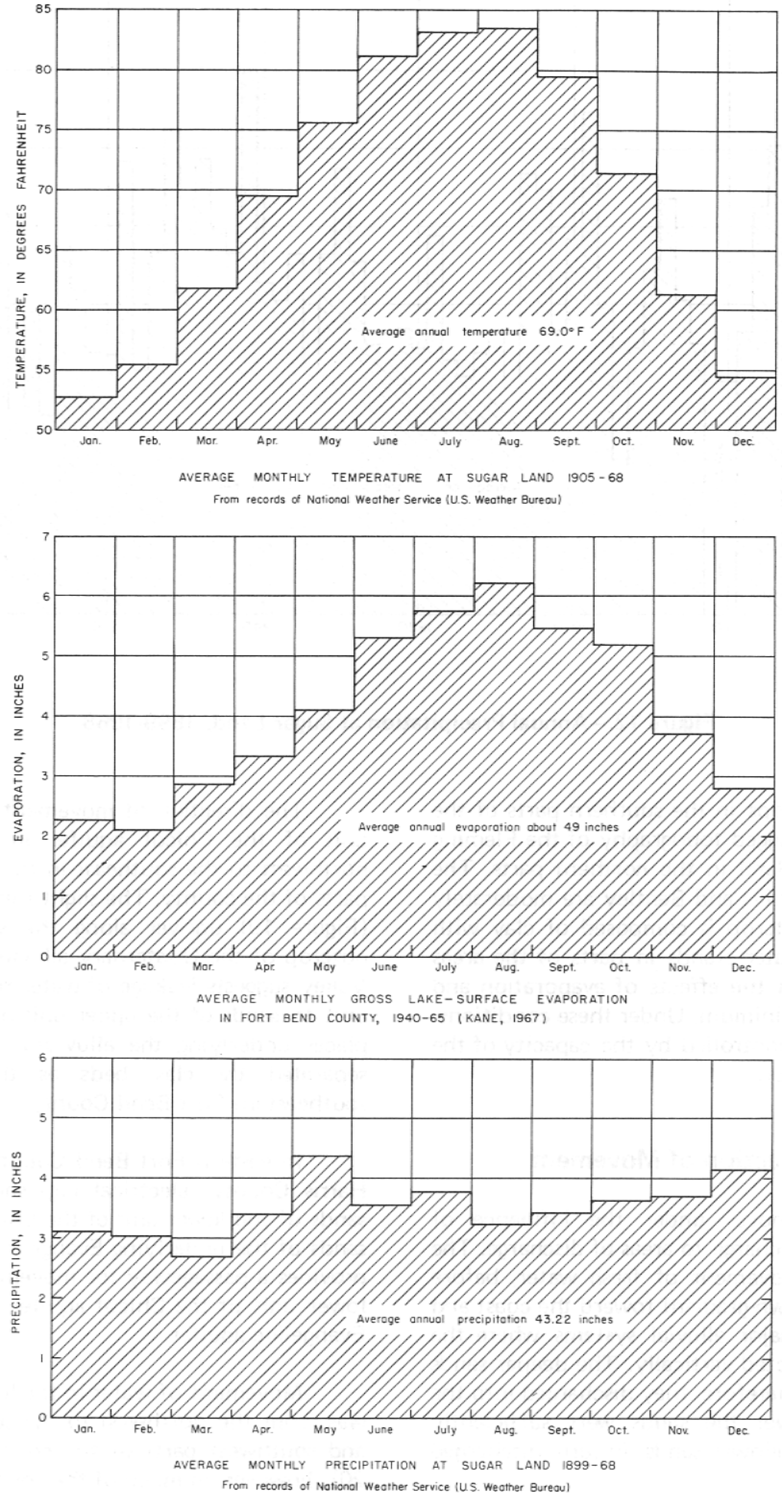

Figure 11

Average Monthly Temperature, Precipitation, and Gross Lake-Surface Evaporation at Sugar Land

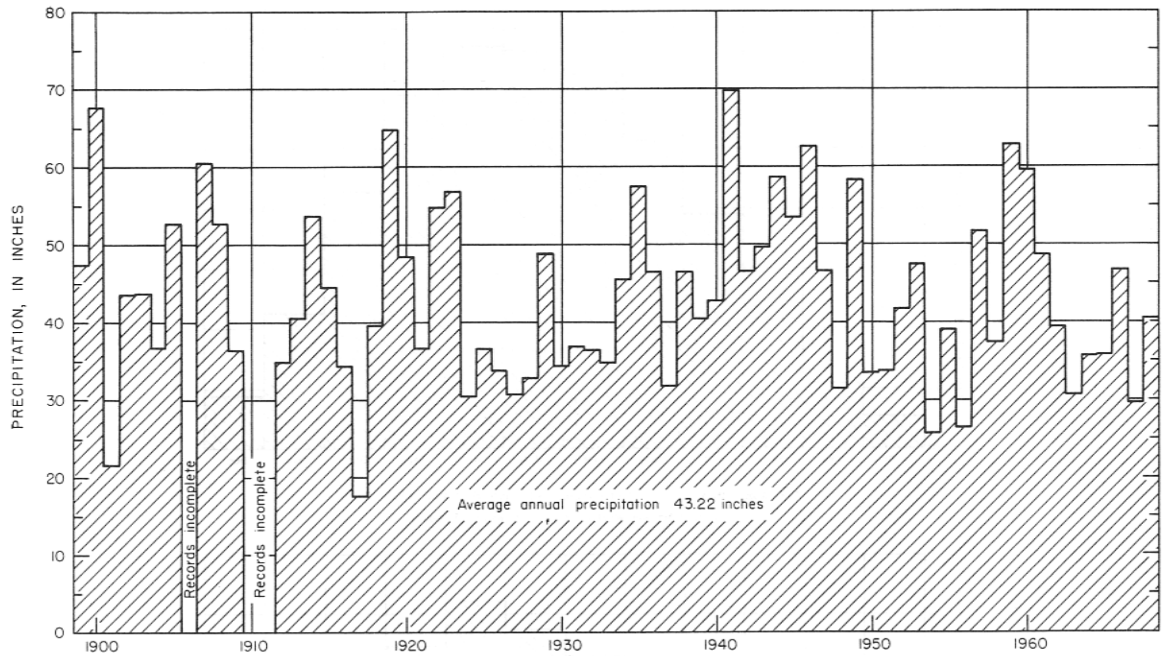

Figure 12.—Annual Precipitation at Sugar Land, 1899-1968

and Montgomery outcrops in the southern parts of the counties to the more rugged topography of the Fleming Formation and Willis Sand in the northern parts. The outcrop areas of the Willis and Bentley are moderately sandy; the Fleming outcrop is composed of clay with some sand intervals. Water stands in parts of the areas during the winter when the effects of evaporation and transpiration are at a minimum. Under these conditions, the rate of recharge is controlled by the capacity of the aquifers to transmit water.

Rate and Direction of Movement

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. The general direction of movement of fresh water, before pumping began, was down-gradient toward the coast and toward areas in the major alluvial systems where the aquifers are interconnected vertically. The deeper sands had the highest head; therefore, they discharged into the overlying sands wherever the sands were sufficiently interconnected. The shallower sands, in turn, discharged to the streams.

Heavy withdrawals from the aquifers, especially in the Houston and Katy areas, have altered the movement patterns. Now the highest head is in the upper unit of the Chicot aquifer; the lowest head is in the Evangeline aquifer. Therefore, in addition to the horizontal component of movement, the water is moving downward instead of upward.

The direction of movement of water in the lower unit of the Chicot aquifer in 1947 was from the northwest to the southeast in the central and southwest parts of the county. The slight trend of the contour lines (Figure 19) upriver along the southern edge of the outcrop of the Quaternary alluvium in the Brazos River Valley suggests leakage of water from sands of the lower unit to sands of the upper unit of the Chicot. In many places underlying the alluvium, the two units are not separated by clay beds as they are in most of southeastern Fort Bend County.

In eastern Fort Bend County and in southwestern Harris County, electrical logs show that some massive sands of the lower unit of the Chicot are in contact with sands of the underlying Evangeline. The interconnection provides a passageway for movement of water from the lower unit of the Chicot aquifer to the lower-pressured Evangeline aquifer.

Movement of water in the lower unit of the Chicot was from the northwest to the southeast in the central and southwest parts of the county in 1968-69 (Figure 20); however, in much of the county, the movement was toward the east and northeast. In the eastern part of the county, an increase in the altitude of the piezometric surface is outlined on Figure 20 by the 10-foot contour in the vicinity of the Thompson oil field. This "high" probably reflects water levels in the upper unit of the Chicot where it is in direct connection with the lower unit.

The altitude of the piezometric surface of the upper unit of the Chicot aquifer in 1947 was greater than the altitude of the Brazos River (Figure 23). The contours show that the movement of water in the aquifer was to the southeast and toward the river. By 1968-69, the direction of movement had changed along the northeastern boundary of the county, and water was moving out of the county toward the northeast (Figure 24).

The average gradient of the piezometric surface in the lower unit of the Chicot aquifer in 1968-69 was about 5.5 feet per mile (Figure 20). If the porosity of the sand is about 30 percent and the permeability is about 645 gpd per square foot, the water in the aquifer was moving about 0.30 foot per day (110 feet per year).

The average gradient of the piezometric surface in the upper unit of the Chicot aquifer (Figure 24) in southern Fort Bend County in 1968-69 was about 2.5 feet per mile. Assuming a porosity of 30 percent and a permeability of 645 gpd per square foot, the water was moving at a rate of about 0.14 foot per day (51 feet per year). The gradient of the piezometric surface in the upper unit was about 20 feet per mile along the northeastern border of the county in 1968-69. In this area, the water was moving at a rate of about 1.1 feet per day (400 feet per year).

Discharge From the Aquifers

Ground water is discharged naturally through seeps and springs and by evaporation and transpiration. Ground water is discharged artificially by wells which in turn affects the natural discharge.

Before large-scale pumping began, probably a large percentage of the water infiltrating to the water table was being discharged to the streams because the aquifers were saturated. That is, more water was entering the aquifer than could be transmitted downdip. The amount of this rejected recharge has decreased because of ground-water development which has lowered the water levels in sands near the surface. In places, the water table has been lowered below the stream levels, which results in water moving from the streams into the aquifers. Sufficient information is not available to estimate the amount of natural discharge in the county. Estimates of the amount of water pumped from wells are given in the following section on development and use of ground water.

DEVELOPMENT AND USE OF GROUND WATER

Pumpage of Ground Water

Fort Bend County was settled in the early 1800's, and the first wells were developed for domestic-supply and livestock use. During the plantation era that followed, some ground water probably was used for irrigation.

In the late 1800's the cultivation of rice stimulated the construction of irrigation wells. By 1900, withdrawals of ground water largely for irrigation may have averaged several mgd.

The use of ground water has increased greatly since 1900, and by 1960, the withdrawal rate was approximately 35 mgd; in 1968, it was approximately 59 mgd. The following table shows the pumpage of ground water by use for 1968.

Estimated Pumpage of Ground Water in Fort Bend County, 1968

USE	MILLION GALLONS PER DAY	ACRE-FEET PER YEAR
Industrial use	13.6	15,200
Municipal supply	5.0	5,600
Irrigation	39.2	43,900
Rural-domestic and livestock use	1.3	1,500
Totals 1/	59	66,000

1/ Totals are rounded to two significant figures.

Estimates of annual pumpage for the period 1960-68 are shown on Figure 13. The data show that the principal use of ground water was for irrigation—about 66 percent of the total in 1968. Industry used about 23 percent of the water; only about 11 percent of the water was pumped for municipal supply and rural-domestic and livestock uses. A significant increase (about 13 mgd) in pumpage for rice irrigation in 1967 was caused by increases in acreage allotments.

Well Construction

The type of well construction used in Fort Bend County depends on the desired capacity of the well, the intended use of the water, the allowable cost of construction, and the methods employed by the 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. The diameter of the holes ranges from 3 to 6 inches with 2- to 4-inch casing and screen commonly being used. Each well is normally completed with a single interval of screen (r to 20 feet in length), which is set within the water-bearing unit. Most of these wells are

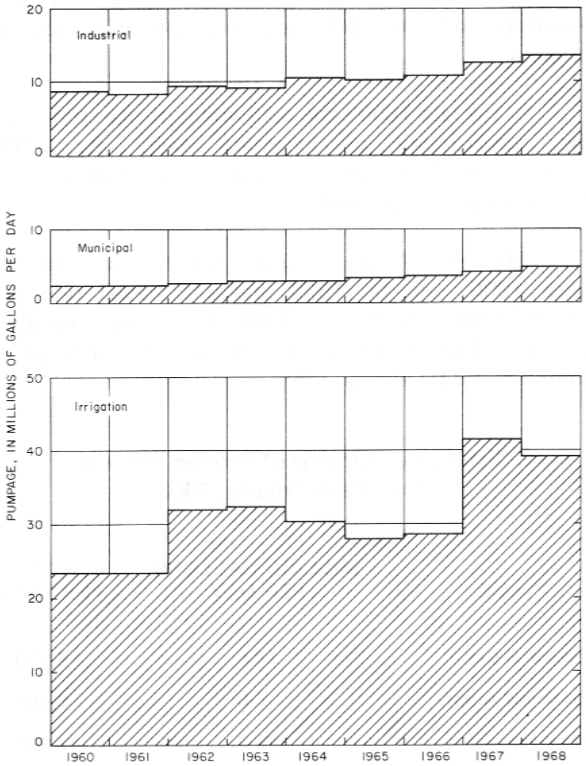

Figure 13.—Estimated Pumpage of Ground Water, 1960-68

equipped with jet or submergible pumps powered by electric motors.

Large-capacity wells such as those used for irrigation, industry, or public supply are drilled by hydraulic-rotary methods. First a test hole (usually 6 inches in diameter) is drilled and logged to determine the depth and thickness of the sand intervals. Water samples and formation samples may be collected to determine the aquifer characteristics and water quality. If the test-hole log and other data indicate that sufficient water-bearing sands are present, the test hole is then reamed to make the well.

Construction of municipal or industrial wells usually differs from that of irrigation wells. A public-supply or industrial well is screened in selected sand units, while irrigation wells generally use slotted casing that extends from near the surface through the entire depth of the well. Casing that is slotted above the pumping level should be avoided, because water (and entrained air) cascading into the well may decrease pump efficiency and durability.

The upper part of the test hole of a municipal or industrial well is usually reamed to 14 to 30 inches in diameter. Then, 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 slightly less than that of the surface casing. The reamed hole is then underreamed usually to 30 inches in diameter in the sections to be screened. Eight- to 12-inch 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 sorted gravel. The gravel-pack stabilizes the hole and provides a transfer medium for water moving from the sand into the well, thus increasing the effective diameter of the well.

Large-capacity wells are developed and tested by using large-capacity test pumps. The wells are then fitted with deep-well turbine pumps powered by internal combustion engines or electric motors. Fawcett (1963, p. 16) discusses the methods used for construction of such wells in the Houston area.

Water Levels and the Effects of Pumping

Before ground-water withdrawals began, the aquifers in Fort Bend County were in a state of natural hydraulic equilibrium. The hydraulic head of the water (water level) in an aquifer was controlled by the altitude of the surface of the ground-water body in the recharge areas, the altitude of the natural discharge areas, and the permeabilities of the aquifers. Originally, water in any sand bed had a higher head than the water in the overlying sand bed because the deeper sand beds crop out at successively higher altitudes.

The natural equilibrium is disturbed by pumping of the ground water. As water is withdrawn, a slope in the piezometric surface is established toward the pumped well from all directions. This sloping surface assumes the shape of an inverted cone that is called the cone of depression. As pumping continues, the cone of depression becomes larger until equilibrium is reached—that is, until the hydraulic gradient is sufficient to force water through the aquifer at a rate equal to the discharge. Withdrawal from wells drilled close together creates cones of depression that may intersect and cause additional lowering of water levels.

Estimates of water-level declines that will be caused by pumping may be made if the hydrologic characteristics of the aquifer are known. The theoretical relationship between drawdown and distance from the center of pumping for different aquifer coefficients is shown in Figure 14. Calculations of drawdown are based on a withdrawal of 1 mgd for 1 year from an aquifer having transmissibilities and storage coefficients as shown. For example, if the transmissibility and storage coefficient are 50,000 gpd per foot and 0.001, respectively; the drawdown or decline in the water level would be 12 feet at a distance of 1 mile from a well or group of wells discharging 1 mgd for 1 year. If the transmissibility and storage coefficient are 5,000 gpd per foot and 0.0001, respectively, the same pumping rate for the same time would cause 84 feet of decline at the same distance.

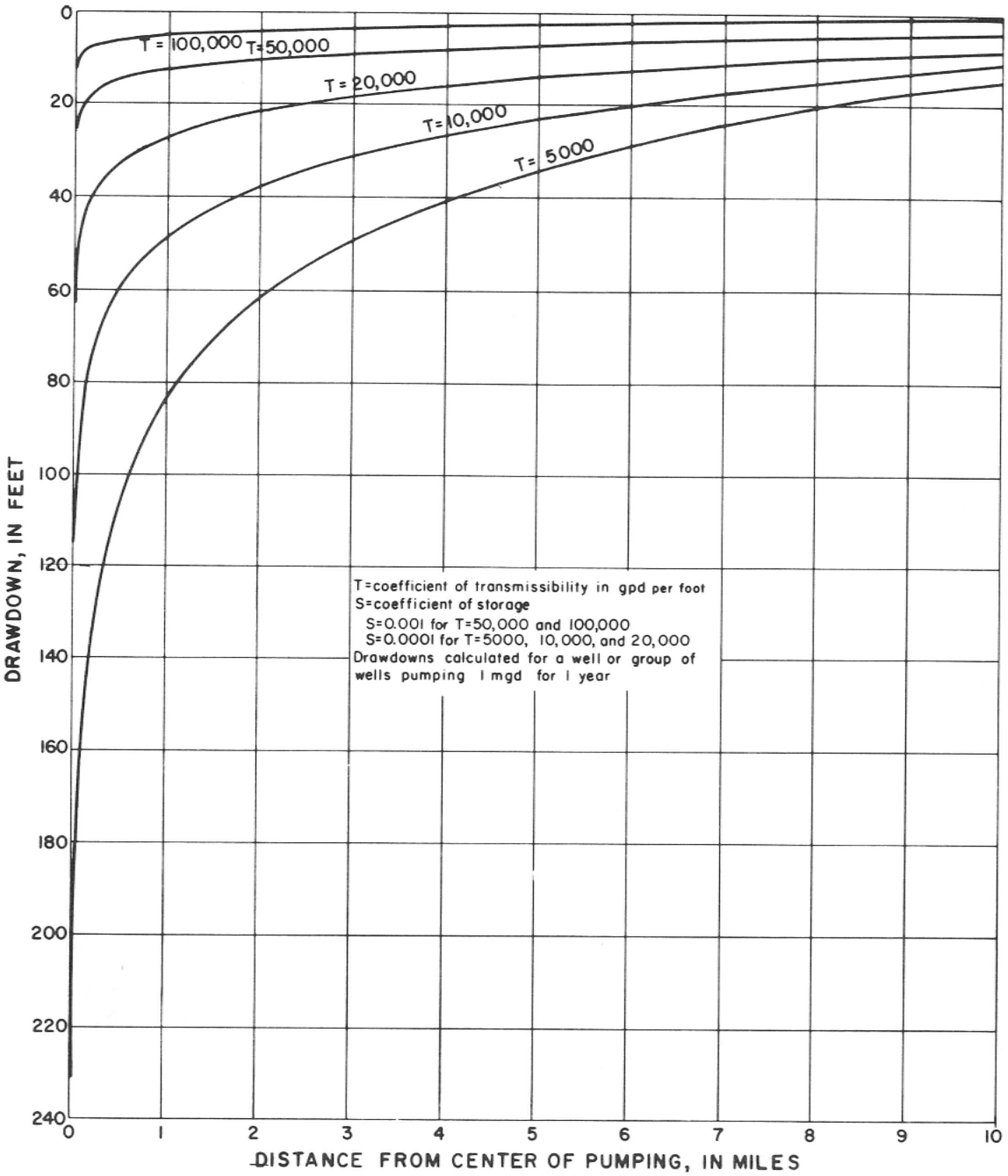

Figure 14.—Relation of Drawdown to Aquifer Coefficients and Distance

Figure 15 shows the relation of drawdown to distance and time as a result of pumping from an aquifer. with characteristics similar to those found in the artesian aquifers in Fort Bend County. This figure shows that the rate of increase of drawdown decreases with time. For example, the drawdown at 100 feet from a well is 11 feet after 1 mgd has been pumped for 1 year, and the drawdown is about 14 feet after 1 mgd has been pumped for 100 years. The total drawdown at any one place within the cone of depression (or influence) of several wells is the sum of the influences of the several wells.

The equilibrium curve shown on Figure 15 is the time-drawdown relation when a line source of recharge is 25 miles from the point of discharge.

Figure 16 shows the relation of drawdown to distance and time as a result of pumping a well completed in a water-table aquifer with characteristics similar to those that could be expected in the upper unit of the Chicot aquifer. The drawdown is less than that in an artesian aquifer because under water table conditions, the storage coefficient is larger.

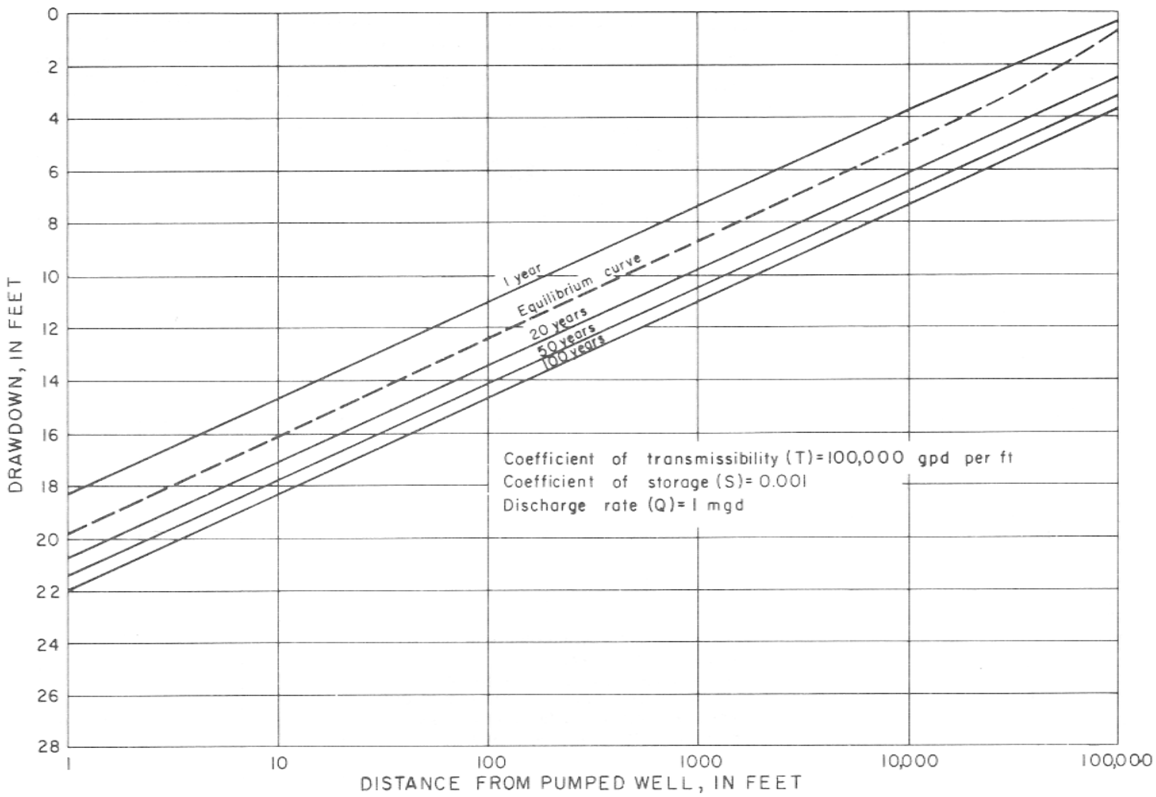

Figure 15.—Relation of Drawdown to Time and Distance as a Result of Pumping Under Artesian Conditions

Decline of Water Levels in the Aquifers

The altitudes of the original water levels in the aquifers in Fort Bend County are not known. However, the pressures in the deeper sands were sufficient to cause water to flow naturally from some wells. Deussen (1914) listed four wells that flowed and 24 wells that did not flow in Fort Bend County. The flowing wells were completed at depths ranging from 910 to 1,760 feet. Darton (1905) reported a head of 9 feet above land surface in one of the four flowing wells. This well, which was 1,550 feet deep, was located at Sugar Land.

Evangeline Aquifer

The flowing wells described by Deussen (1914) were completed in the Evangeline aquifer. In 1968, there were only 12 wells in the county that were completed solely in this aquifer. The highest water level measured in the Evangeline in 1968 was 61 feet below land surface in well JY-65-17-404. The lowest level measured was 194 feet below land surface in a well near Stafford. On the basis of these measurements, the decline in the piezometric surface of the Evangeline aquifer since about 1900 has ranged from about 60 feet in the northwest part of the county to more than 190 feet in the eastern part.

Hydrographs showing the fluctuations in water levels in two wells in the Evangeline aquifer are shown on Figure 17. The water level in well JY-65-17-404 at Simonton declined about 42 feet between 1947 and 1968. The water level in well JY-65-27-312 declined about 168 feet in the 46 years of record 1920-66; it declined about 140 feet during the 23 years from 1943 to 1966. The water level in well JY-65-17-404 has been affected by pumping in the irrigation area near Katy and in the Houston district. Most of the decline in well JY-65-27-312 was probably caused by withdrawals of water in the Houston area. The rates of decline were about 2 feet per year in the well nearest the outcrop (JY-65-17-404) since 1947 and more than 6 feet per year in well JY-65-27-312 since 1943.

Chicot Aquifer

The upper and lower units of the Chicot aquifer merge in the northern part of Fort Bend County. This area, where the Chicot is basically one aquifer, is shown on Figures 19-21 and 23-25. Even though the units merge, some clay lenses within the aquifer cause small differences in water levels between the shallow and deep parts. Water levels in shallow wells are more representative of levels in the upper unit, and these were

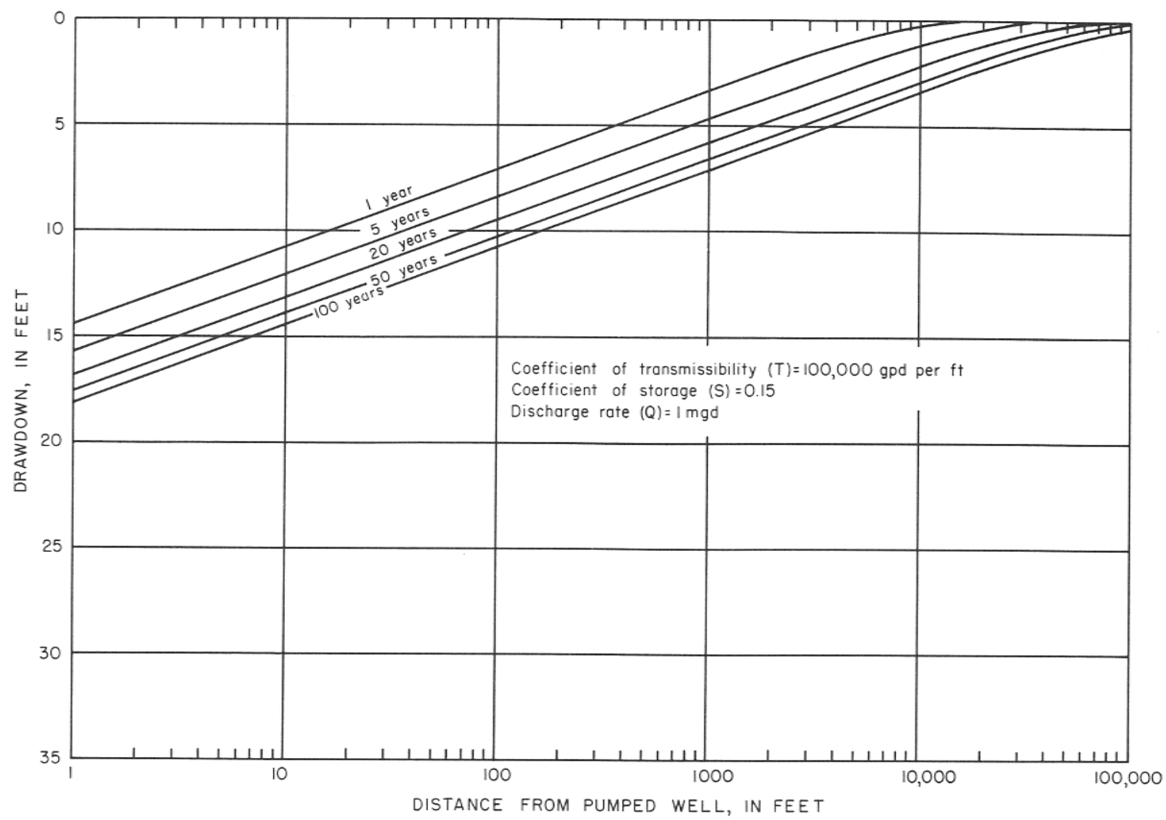

Figure 16.—Relation of Drawdown to Time and Distance as a Result of Pumping Under Water-Table Conditions

used to project the contours of water levels (Figures 19-21). Water levels in the deeper wells in the Chicot were used to project the contours of water levels in the lower unit (Figures 23-25).

No regional map of water levels in the Chicot as a unit was prepared, but three hydrographs of wells completed in the Chicot aquifer are shown on Figure 18.

Well JY-65-25-301 is an irrigation well near the industrial well field that supplies the sulfur mine at Orchard. At this location, the water level has fluctuated in response to the industrial pumpage since 1947, but there has been less than 10 feet net decline.

Wells JY-65-10-702 and JY-65-10-703, near Katy, show the effects of the pumpage for irrigation. Well JY-65-10-703 is 170 feet deep and well JY-65-10-702 is screened from 176 to 346 feet below land surface. The water level in the deeper well has been a few feet lower than that in the shallow well, although about 4 feet of the difference is due to the difference in altitude. The average rate of decline since 1947 (the period of more rapid decline) has been about 1.7 feet per year.

Lower Unit of the Chicot Aquifer

The original piezometric surface of the lower unit of the Chicot aquifer was probably higher than land surface at least at some locations. Well JY-65-28-806, in the southeastern part of the county, reportedly flowed when drilled in 1935. The well was located on the bank of the Brazos River at an altitude of about 57 feet.

The approximate altitudes of water levels in wells in the lower unit of the Chicot aquifer in 1947 and 1968-69 are shown on Figures 19 and 20. Figure 21 shows the decline of water levels between 1947 and 1968-69.

The decline of water levels in the lower unit of the Chicot ranged from less than 10 feet in western Fort Bend County to about 130 feet in the Blue Ridge Dome area. The rates of decline, estimated from the data compiled on Figure 21, ranged from less than 0.5 foot per year in western Fort Bend County to about 6 feet per year in the Blue Ridge Dome area. In most of the county, the rate was less than 3 feet per year. Much of the decline in the eastern part of the county is probably

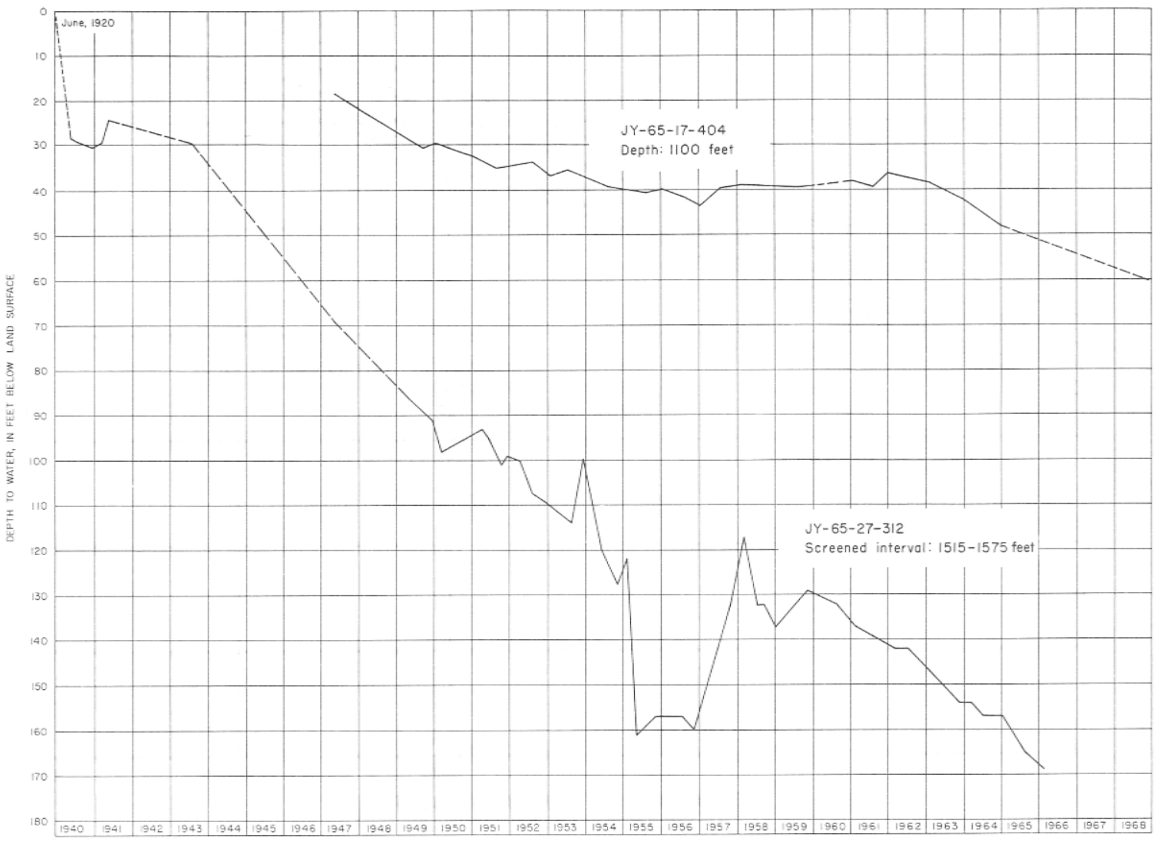

Figure 17.—Fluctuations of Water Levels in Wells Tapping the Evangeline Aquifer

due to movement of water out of the lower unit of the Chicot aquifer into the lower-pressured Evangeline aquifer which underlies the Chicot.

Hydrographs of five wells completed in the lower unit of the Chicot aquifer are shown on Figure 22. Three of the wells, JY-65-28-402, JY-65-28-403, and JY-65-28-404 are near each other in the southeastern part of the county, but produce water from different depths. The rates of decline in the wells are about equal (3 feet per year), but the depth to water is related to the depth of the well; the deeper the screen setting, the lower the water level. This condition indicates that water is moving from the shallower to the deeper sands.

The hydrograph of well JY-65-29-403 in northeastern Fort Bend County shows a decline in water level of about 80 feet at an average rate of about 5 feet

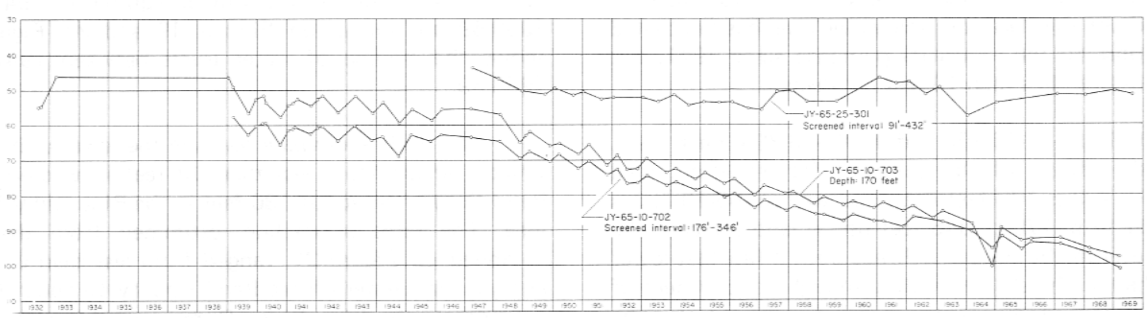

Figure 18.—Fluctuations of Water Levels in Wells Tapping the Chicot Aquifer

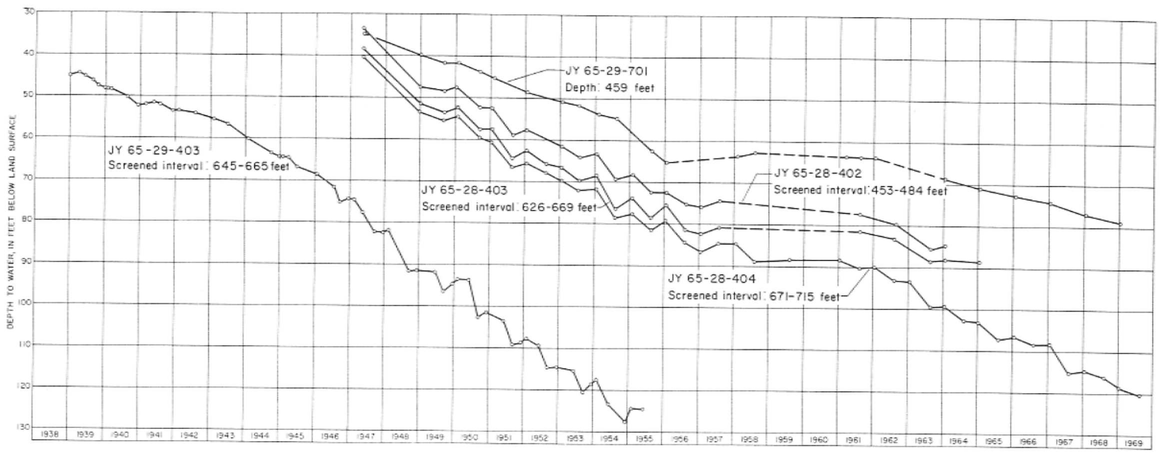

Figure 22.—Fluctuations of Water Levels in Wells Tapping the Lower Unit of the Chicot Aquifer

per year from 1938 to 1955. In well JY-65-29-701, about 5 miles south of JY-65-29-403, the water level decline was about 44 feet and the average rate of decline was about 2 feet per year from 1947 to 1969. The difference in rates of decline at these two locations, although from different periods, reflects differences in the depths and locations of the two wells. Well JY-65-29-701 is 459 feet deep. Well JY-65-29-403 is screened between 645 and 665 feet. Well JY-65-29-403 is in the Blue Ridge Dome area, where the lower unit of the Chicot aquifer is probably in hydraulic continuity with the Evangeline aquifer.

Upper Unit of the Chicot Aquifer

Originally, the water levels in wells completed in the upper unit of the Chicot aquifer were slightly below the land surface at most locations.

The approximate altitudes of water levels in wells in the upper unit of the Chicot aquifer in 1947 and 1968-69 are shown on Figures 23 and 24. Figure 25 shows the decline of water levels between 1947 and 1968-69.

The contours shown on Figure 23 indicate that the alluvium of the Brazos River acted as a conduit to the upper unit of the Chicot aquifer in Fort Bend County in 1947. In 1969 (Figure 24), the contours still trended upstream, which indicates that the river still drains the upper unit of the Chicot along most of its length in the county.

Near Richmond, however, the altitude of the water surface in well JY-65-26-305 was 35 feet above sea level in 1969. According to the topographic map of the area, the normal altitude of the water surface in the Brazos River, just east of the well, is approximately 44 feet. The hydraulic gradient in this local area indicates that this section of the river is a losing reach.

The lowering of water levels in the upper unit of the Chicot aquifer must be caused by leakage into deeper sands because no large amounts of water are being withdrawn from the upper unit in this area. The nearest sustained withdrawal is from the lower unit of the Chicot by the city of Richmond.

The decline in water levels during the period 1947 to 1968-69 shown by Figure 25 ranged from less than 10 feet in most of the southwestern half of the county to more than 40 feet along the northeastern edge. The rate of decline for this period ranged from less than 0.2 foot per year to about 2 feet per year. The declines at the closed 10- and 20-foot contour lines in eastern and central Fort Bend County are probably due to leakage from the upper unit to the lower unit of the Chicot. Drainage to the lower unit may also have caused most of the 10- to 40-foot declines in eastern Fort Bend County because there are no sustained withdrawals from the upper unit in these areas. The decline in the area encircled by the 10-foot contour line south of Beasley in the western part of the county probably reflects withdrawals by irrigation wells.

Land-Surface Subsidence

One of the effects of ground-water development in Fort Bend County is subsidence of the land surface caused by the lowering of water levels. The withdrawals of water from the artesian aquifers results in an immediate decrease in hydraulic pressure, which partially supports the weight of the overburden. With this reduction in pressure, an additional load is transferred to the skeleton of the aquifer; and 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 results in subsidence of the land surface.

This phenomenon of land-surface subsidence resulting from the withdrawals of ground water has been observed in several places on the gulf coast of Texas and has been reported by Pettit and Winslow (1957), Wood and Gabrysch (1965), and Gabrysch (1970).

The extent of land-surface subsidence in Fort Bend County is shown on Figure 26. This map (adapted from Gabrysch, 1970, Figure 7) shows that subsidence has occurred in the eastern one-third of the county between 1943 and 1964. The maximum subsidence for the period exceeded 1 foot, and water levels in the lower unit of the Chicot aquifer and in the Evangeline aquifer declined more than 100 feet during the same period. Elsewhere in the county, water-level declines have been less than 50 feet, and as a result, less than 0.5 foot of subsidence has occurred.

AVAILABILITY OF GROUND WATER

Large quantities of fresh ground water are available almost everywhere in Fort Bend County. The Evangeline aquifer contains from 100 to more than 600 feet of sands containing fresh water. The Chicot aquifer contains from 200 to more than 400 feet of fresh-water sands. The sand thicknesses in both aquifers are shown on Figures 27 and 28.

Large-capacity fresh-water wells (wells capable of yielding 500 to 4,000 gpm) can be constructed anywhere in the county except in the areas affected by salt domes. However, care should be taken in choosing locations for new wells because 100 to 600 feet of sand containing saline water underlies or is interbedded with sands containing fresh water in the Evangeline aquifer. Also, saline water occurs in sands in the Chicot aquifer near the salt domes.

The average thickness of sand containing fresh water in transient storage in Fort Bend County is about 650 feet (300 feet in the Evangeline aquifer and 350 feet in the Chicot aquifer). Based on a porosity of 30 percent, this sand contains about 120 million acre-feet of water; however, it is economically impractical to recover more than a small percentage of this total amount of water.

Pumping lifts of as much as 500 feet are probably economical in Fort Bend County for most purposes. The amount of water in storage above a depth of 500 feet is about 15 trillion gallons (45 million ac-ft). Of this amount, possibly one-half or 7.5 trillion gallons (23 million ac-ft) could be pumped. At the 1968 rate of withdrawal (58 mgd), this supply would last for 350 years.

These estimates are based on the assumption that there is no recharge to the aquifers. More realistically, recharge does occur and is taken into consideration in the following estimates of availability and development:

1. Wells will be installed in such a way that water levels will be lowered to a maximum depth of 500 feet along a line of discharge 33 miles long, approximately parallel to the coastline and extending through Stafford from the western edge to the eastern edge of the county.

2. The aquifers are recharged only at the outcrops, and all recharge is assumed to occur along a line parallel to the strike and in the middle of the outcrop.

3. For computation of water available from storage:

   (a) The altitude of the water levels is the same and remains the same at all points along the center line of the outcrop; the altitude of the water levels is the same at all points along the salt-water interface; and the altitude of the water levels is the same at all points along the line of discharge.

   (b) The net coefficient of storage is 0.10 and includes those parts of the storage coefficient related to water released from storage as the result of draining, compaction, and depressurizing.

   (c) The slope of the water surface will be constant after drawdown to 500 feet at the line of discharge.

4. For computations of the average transmission capacity of the aquifer (defined here as the quantity of water which can be transmitted through a given width of an aquifer at a given hydraulic gradient):

   (a) No further decline in the water levels will occur along the line source of recharge.

   (b) The hydraulic gradient is the slope of a straight line from the water level at the line source of recharge to the water level along the line of discharge.

   (c) The average hydraulic gradient is the average of the present hydraulic gradient and the maximum hydraulic gradient that can be attained with a water level at a depth of 500 feet at the line of discharge.

   (d) All sands between the line source of recharge and the line of discharge

transmit water from the outcrop area to the line of discharge, and the assumed average coefficient of transmissibility of these sands is 250,000 gpd per foot.

(e) The only increase in the amount of water moving toward the line of discharge from the coastal side is the water released from storage as a result of lowering the water levels.

Calculations based on these assumptions show that at the present gradient, about 35 mgd is being transmitted to the theoretical line of discharge. At the present rate of withdrawal (58 mgd), water levels will never be drawn down to a depth of 500 feet below the land surface. If 500 mgd were withdrawn, it would take more than 50 years to dewater the sands above 500 feet, after which time 150 mgd would be continuously available.

Probably one of the best tools available for analyzing a complex ground-water system is the electrical analog model. Basically, the model is constructed of resistors and capacitors pulsed by electrical current. The electrical system is analogous to the hydraulic system, and permits a very rapid analysis of changes in water levels with changes in pumping.

An analog model of the Houston area, which included a part of Fort Bend County, was constructed in 1963 by the U.S. Geological Survey in cooperation with the city of Houston and the Texas Water Development Board. Wood and Gabrysch (1965) reported the details and results of the construction of this model. Their report included illustrations which showed the computed decline of water levels to 1970 based on 416 mgd of ground-water pumpage. From unpublished analyses using the model, it was concluded that possibly as much as 750 mgd could be pumped without lowering the water levels below 500 feet by the year 2020, if the pumping centers were spread across the northwestern part of the area of the model. By comparison, much of the Chicot aquifer is more prolific in Fort Bend County than in Harris County, but the areal extent is not as great. Considering quantity only, probably less than 500 mgd could be developed in Fort Bend County.

CONCLUSIONS AND NEEDS FOR ADDITIONAL STUDIES

Ground-water use is an essential factor in the economic development of Fort Bend County, but only a small part of this resource is presently being used. Enough water is available to supply several times the present rate of withdrawal on a perennial basis, and much larger withdrawals could be made for extensive periods of time.

The quality of the fresh ground water needs to be protected. The placement of wells and the choice of which sands to develop should be regulated in order to minimize the deterioration of the quality of the water. This is especially true in the salt-dome areas and in the fresh water-salt water interface areas.

The effects of withdrawals of ground water in the county have been minor. Most of the water-level declines are due to pumping in the adjoining areas, especially in Harris County. The water-level declines have resulted, however, in subsidence of the land surface in some area.

Increased withdrawals will cause additional declines in water levels and additional subsidence of the land surface. The location and magnitude of the declines will be dependent on recharge, the extent of hydraulic continuity between the aquifers, the permeability of the aquifers, and the amount and location of withdrawals.

An expanded and continuing program of data collection and analysis should be established in Fort Bend County to obtain more detailed data and to keep pace with development. The program should include the following items:

1. An extensive network of observation wells to determine water levels periodically should be established. Wells screened in individual sands in each of the aquifers at many locations in the county should be added to the wells currently being measured. If satisfactory observation wells are not available at locations such as in the heavily pumped Katy rice irrigation area, the Blue Ridge Dome area, and the alluvial areas where recharge is occurring, a program of locating and drilling suitable wells should be initiated.

2. An extensive network of observation wells to determine water quality and changes in water quality should be established. Water samples should be collected and analyzed on a systematic basis. All large wells should be sampled when drilled and resampled at a later date. Resampling should be frequent in the salt-dome areas, where poorer quality water might be encroaching on the fresh-water sources. Considerable development of the aquifers in the Blue Ridge area is planned, and establishment of a monitoring system in this area is needed now.

3. Aquifer tests to determine the aquifer characteristics should be made in existing wells not previously tested and in new wells when they are drilled.

4. Low-flow studies should be made in the streams to help determine the areas and amounts of ground-water recharge.

5. The Houston electrical analog model should be refined. This model is the best tool available for the analysis of pumping effects.

6. Bench marks should be re-leveled periodically to determine the magnitude of land-surface subsidence.

This program should be coordinated with similar programs in adjacent areas. Recent studies, similar to the Fort Bend study, have been completed in all adjacent and nearby counties except Wharton and Colorado Counties. For optimum development of the water resources in the entire area, detailed ground-water investigations in these counties should be made.

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