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Report 186

GROUND-WATER RESOURCES OF GRIMES COUNTY, TEXAS

September 1974

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GROUND-WATER RESOURCES OF GRIMES COUNTY, TEXAS

BY

E. T. Baker, Jr., C. R. Follett,
G. D. McAdoo, and C. W. Bonnet
United States Geological Survey

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GROUND-WATER RESOURCES OF GRIMES COUNTY, TEXAS

By

E. T. Baker, Jr., C. R. Follett,
G. D. McAdoo, and C. W. Bonnet
United States Geological Survey

ABSTRACT

Fresh to slightly saline ground water is available everywhere in Grimes County. The Yegua Formation, Jackson Group, Catahoula Sandstone, Fleming Formation, and flood-plain alluvium are the sources of almost all water presently (1971) being pumped. The Carrizo, Queen City, and Sparta Sands have varying capacities for potential development, but are not tapped by wells. The Willis Sand and terrace deposits contain only small quantities of water, are tapped by only a few wells, and have a relatively small areal extent,.

Only 1.63 million gallons per day of ground water was used for all purposes in 1970. Of this amount, 53 percent was used for public supply, 38 percent for irrigation, and 9 percent for ruraldomestic and livestock needs. Because of the small pumpage, regional water-level declines have been insignificant.

The ground water is of good chemical quality. Much of it is suitable for public-supply, ruraldomestic, and industrial use with little or no treatment; and the overall appraisal of the ground water for irrigation with respect to plant growth and soil effects is favorable. The better quality water, in general, is associated with the younger aquifers.

Relatively large amounts of water are available for future development. A total of 52 million gallons per day of fresh to slightly saline water is available from the Sparta Sand, Yegua Formation, Jackson Group, Catahoula Sandstone, Fleming Formation, and the flood-plain alluvium on a long-term basis without depleting the supply. In addition, smaller but undetermined amounts of fresh to slightly saline water are available from the Carrizo, Queen City, and Willis Sands and from the terrace deposits. Wells that are properly constructed can be expected to yield more than 500 gallons per minute from most of the aquifers.

GROUND-WATER RESOURCES OF GRIMES COUNTY, TEXAS

INTRODUCTION

Grimes County, an area of 801 square miles, is in the Gulf Coastal Plain of southeast Texas. Anderson, the county seat, is about 60 miles northwest of Houston and about 105 miles east of Austin (Figure 1). The economy depends almost entirely on agriculture, and most of the income is from beef, dairy cattle, and field crops.

The purpose of the Grimes County study was to evaluate the ground-water resources of the county, with particular emphasis on the source, occurrence, quantity, and quality of the ground water suitable for public-supply, industrial, and irrigation use. The study included determination of the location and extent of the aquifers and the chemical quality of the water they contain, any changes in ground-water conditions that have occurred in the area, the quantity of water being pumped and the effects of this pumpage on water levels and water quality, the hydraulic characteristics of the important aquifers, and an estimate of the quantity of ground water available for future development from each of the important aquifers.

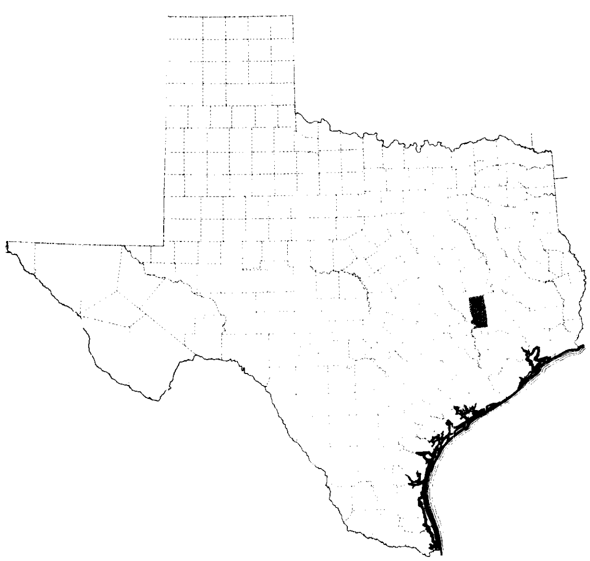


Figure 1.—Location of Grimes County

The study, which began in 1970, was a cooperative project of the U.S. Geological Survey and the Texas Water Development Board. Prior to this study, little detailed information was available regarding the ground-water potential in Grimes County. Taylor (1907, p. 42) briefly noted the occurrence of flowing wells in the county; Turner (1939) and Cromack (1943) collected records of wells, drillers' logs, and chemical analyses; Sundstrom, Hastings, and Broadhurst (1948, p. 120-123) collected basic data on the public-supply wells in various towns in the county; Cronin, Follett, Shafer, and Rettman (1963), Peckham and others (1963), and Wood, Gabrysch, and Marvin (1963) made reconnaissance studies of ground water in the Brazos and Trinity River basins and Gulf Coast region, respectively, which included parts of the county; and Cronin and Wilson (1967) studied the water-bearing characteristics of the flood-plain alluvium along the Brazos River, including a part of the county.

The assistance of the following firms, agencies, and individuals and the cooperation of city officials and private well owners are appreciated: Falkenbury Drilling Co., Navasota, Texas; B. C. Kolbachinski, Anderson, Texas; Carl Ryan Drilling Co., Bryan, Texas; Jack Waldron, Layne Texas Co., Houston, Texas; U.S. Soil Conservation Service, Navasota, Texas; and W. H. Wolters, County Agent, Navasota, Texas.

The well-numbering system used in this report is described in the section entitled "Well-Numbering System" (p. 57), and the technical terms used in describing the ground-water resources are defined in the section entitled "Definitions of Terms" (p. 58).

OCCURRENCE AND DISTRIBUTION OF GROUND WATER

General Stratigraphy and Structure of the Area

The geologic units that contain fresh water—that water containing less than 1,000 mg/l (milligrams per liter) dissolved solids—and slightly saline water (1,000 to 3,000 mg/l) dissolved solids range in age from Eocene to Holocene. They consist mainly of beds of sand, silt, and clay or shale in varying thicknesses; limestone, gravel, and lignite occur in lesser amounts.

Most of the geologic units containing fresh to slightly saline water crop out in belts of varying width that trend northeastward (Figure 2). Most of the strata are inclined or dip southeastward toward the Gulf of Mexico at an angle greater than the land surface; therefore, the formations are found at progressively greater depths in a Gulfward direction. The formations in Grimes County dip from about 200 feet per mile to less than 15 feet per mile; the steeper dips generally are associated with the older formations.

In places, the geologic units are displaced by faults. The most widespread faulting extends northeastward from near Singleton and Roans Prairie to Walker County. At least 180 feet of throw is evident along one of the nine faults mapped in this area.

Description of the Geologic Units

The formations that contain fresh to slightly saline water in Grimes County are, from oldest to youngest: The Carrizo Sand, Queen City Sand, Sparta Sand, Yegua Formation, and Jackson Group of Eocene age; the Catahoula Sandstone and Fleming Formation of Miocene age; the Willis Sand of Pliocene (?) age and terrace deposits of Pleistocene age; and the flood-plain alluvium of Holocene age.

The Reklaw, Weches, and Cook Mountain Formations of Eocene age, which overlie the Carrizo, Queen City, and Sparta Sands, respectively, do not yield appreciable quantities of water in Grimes County. The stratigraphic correlation and depth of the geologic units and the quality of the water along a line A-A' are shown on Figure 3. Table 1 summarizes the thickness, lithologic characteristics, age, and water-bearing properties of formations. General lithologic descriptions of the rocks penetrated by various water wells in the county are given in the table of drillers' logs (Table 9).

For general discussion of well yields, the following ratings will be used: Small, less than 50 gpm (gallons per minute); moderate, 50 to 500 gpm; and large, more than 500 gpm.

Carrizo Sand

The Carrizo Sand, which overlies the Wilcox Group, crops out about 25 miles northwest of Grimes County in Robertson and Leon Counties. It consists of light-gray, fine to coarse, poorly sorted, noncalcareous sand. The unit contains partings of light-gray to black, silty, carbonaceous clay, The approximate maximum thickness in Grimes County is 185 feet.

No wells tap the Carrizo Sand in Grimes County although the aquifer contains slightly saline water in the northwestern part of the county. In this area, where the top of the aquifer is about 1,700-2,000 feet below land surface, the Carrizo is capable of yielding large amounts of slightly saline water.

Reklaw Formation

The Reklaw Formation, which overlies the Carrizo, crops out in Robertson and Leon Counties. It consists of brownish black, carbonaceous, silty clay and minor amounts of fine to medium glauconitic sand. The approximate maximum thickness in the northern part of Grimes County is 300 feet.

The Reklaw is not an aquifer, but functions as a confining layer for the Carrizo Sand.

Queen City Sand

The Queen City Sand, which overlies the Reklaw Formation, crops out about 20 miles northwest of Grimes County in Robertson and Leon Counties. It consists of light gray to yellowish orange, carbonaceous, fine sand and some interbeds of brownish gray, silty, sandy clay. The approximate maximum thickness in the northern part of Grimes County is 350 feet.

No wells tap the Queen City Sand in Grimes County although the aquifer is capable of yielding large amounts of fresh to slightly saline water in the northwestern part of the county. In this area, the top of the aquifer is about 1,000-l ,700 feet below land surface. Most of the water is contained in massive sand beds in the lower half of the aquifer. Sand beds in the upper half have partings of clay and contain poorer quality water.

Weches Formation

The Weches Formation, which overlies the Queen City Sand, crops out in Robertson and Leon Counties. It consists of dark-brown, glauconitic, silty clay, and greensand which is mostly glauconite. Locally, it forms layers of iron ore and clay-ironstone concretions. The approximate maximum thickness in the northern part of Grimes County is 100 feet.

The Weches is not an aquifer, but functions as a confining layer for the Queen City Sand.

Sparta Sand

The Sparta Sand, which overlies the Weches Formation, crops out about 12 miles northwest of Grimes County in Robertson and Leon Counties. It consists of very pale orange to grayish brown, well-sorted, very fine to fine sand and some laminated, carbonaceous, clay interbeds. The approximate maximum thickness of the Sparta Sand in the northern third of Grimes County is 350 feet.

Table 1.—Geologic Units and Their Water-Bearing Properties

SYSTEM	SERIES	GEOLOGIC	APPROXIMATE MAXIMUM THICKNESS (FT)	LITHOLOGY	WATER-BEARING PROPERTIES
Quaternary	Holocene	Flood-plain alluvium	80+	Fine to coarse, reddish tan sand, gravel, silt, and reddish brown to brown clay	Yields small to large amounts of fresh water to irrigation wells south of Navasota.
	Pleistocene	Terrace deposits	32+	Fine to coarse reddish brown to brown sand, gravel, silt, and clay.	Yields small to large amounts of fresh water to rural-domestic and livestock wells and large pits south of Navasota.
Tertiary(?)	Pliocene(?)	Willis Sand	100	Fine to medium, reddish sand, silt, clay, and siliceous gravel of granule to pebble size, including some fossil wood. Iron oxide concretions are abundant.	Yields small amounts of fresh water to rural-domestic and livestock wells.
Tertiary	Miocene	Fleming Formation	1,200	Light-gray to yellowish gray, fine to coarse sand, silt, and calcareous clay. Sand highly indurated in places.	Yields small to moderate amounts of fresh water to public-supply, irrigation, rural-domestic, and livestock wells.
		Catahoula Sandstone	1,500	Light-gray, sandy, tuffaceous clay and mudstone in the upper part and coarse quartz sand in the lower part. Fossil wood is common.	Yields small to moderate amounts of fresh to slightly saline water to public-supply, irrigation, rural-domestic, and livestock wells.
	Eocene	Jackson Group	1,600	Gray, laminated to massive, fine to medium sand; brown, lignitic clay; indurated, massive fine- to medium-grained sandstone; and brown tuffaceous siltstone.	Yields small to moderate amounts of fresh to moderately saline water to irrigation, rural-domestic, and livestock wells.
		Yegua Formation	1,175	Light-gray, calcareous, glauconitic, fine to medium sand, interbedded with indurated, fine-grained sandstone and brownish sandy clay. Fossil wood and lentils of lignite are common.	Yields small to moderate amounts of fresh to moderately saline water to public-supply, rural-domestic, and livestock wells.
		Cook Mountain Formation	530	Brownish-gray to brown, fossiliferous clay and some sandy glauconitic clay.	Not an aquifer.
		Sparta Sand	350	Very pale orange to grayish-brown, well-sorted, very fine to fine sand and some laminated carbonaceous clay interbeds.	Not known to be tapped by wells but is capable of yielding large amounts of fresh to slightly saline water in the northern third of the county.
		Weches Formation	100	Dark-brown, glauconitic, silty clay and green sand which is mostly glauconite.	Not an aquifer.
		Queen City Sand	350	Light-gray to yellowish orange, carbonaceous, fine sand and some interbeds of brownish gray, silty, sandy clay.	Not tapped by wells but is capable of yielding large amounts of fresh to slightly saline water in the northwestern part of the county.
		Reklaw Formation	300	Brownish-black, carbonaceous, silty clay and minor amounts of fine to medium glauconitic sand.	Not an aquifer.
		Carrizo Sand	185	Light-gray, fine to coarse, poorly sorted, noncalcareous sand; some partings of light-gray to black, silty, carbonaceous clay.	Not tapped by wells, but is capable of yielding large amounts of slightly saline water in the northwestern part of the county.

No wells are known to tap the Sparta Sand in Grimes County although the formation is capable of yielding large amounts of fresh to slightly saline water in the northern third of the county. In this area, the top of the formation ranges in depth below land surface from about 700 to 2,700 feet or from about 500 to more than 2,200 feet below mean sea level (Figure 4). Most of the water and the water of best quality is contained in the massive sand beds in the lower half of the aquifer.

Cook Mountain Formation

The Cook Mountain Formation, which overlies the Sparta Sand, crops out in Robertson, Brazos, Leon, and Madison Counties. It consists of brownish gray to brown, fossiliferous clay and some sandy, glauconitic clay. The approximate maximum thickness in the northern part of Grime; County is 530 feet.

The Cook Mountain Formation is not an aquifer, but functions as a confining layer for the Sparta Sand.

Yegua Formation

The Yegua Formation, which overlies the Cook Mountain Formation, crops out in Brazos, Madison, and Grimes Counties. In Grimes County, the outcrop, which is about 10 miles wide, extends across the northern part of the county (Figure 2). The Yegua consists of light gray, calcareous, glauconitic, fine to medium sand, interbedded with indurated fine-grained sandstone and brownish sandy clay. Fossil wood and lentils of lignite are common. The approximate maximum thickness of the aquifer in the northern half of Grimes County is about 1 ,175 feet.

Figure 5 shows an outcrop of the Yegua Formation in a roadcut 1.8 miles west of Lola. About 15 feet of fine to medium, light gray, friable sand, a few layers of shale, and a lens of lignite are exposed in the roadcut.

The Yegua Formation yields small to moderate amounts of fresh to moderately saline water to public-supply, rural-domestic, and livestock wells on the outcrop of the aquifer and a few miles southeast of the outcrop. Slightly saline water in the formation extends as far southeast as Shiro and Navasota. At these sites, depths below land surface to the top of the formation are 1,600 to 2,200 feet or about 1,200 to 1,900 feet below mean sea level (Figure 6).

Jackson Group

The Jackson Group, which overlies the Yegua Formation, crops out in a band 8-10 miles wide across the north-central part of the county. From Singleton eastward to Walker County, the outcrop of Jackson is broken by several closely spaced faults (Figure 2).

The Jackson Group consists of gray, laminated to massive, fine to medium sand; brown, lignitic clay; indurated, massive, fine- to medium-grained sandstone; and brown tuffaceous siltstone. Some of the sandstone beds in the upper part of the group form prominent ledges that can be traced for several miles along strike and downdip. The approximate maximum thickness of the Jackson is 1,600 feet.

Two views of the upper part of the Jackson Group are shown on Figure 7. The roadcut shown in Figure 7A exposes about 16 feet of section including lenticular sand, shale, and lignite. The abandoned railroad cut shown in Figure 7B exposes about 5 feet of hard, light gray, ledge-forming, very f ine-grained sandstone underlain by friable sand; this sandy section is easily identifiable on electric logs in the subsurface.

The Jackson Group yields small to moderate amounts of fresh to moderately saline water to irrigation, rural-domestic, and livestock wells on the outcrop of the aquifer and a few miles southeast of the outcrop. Slightly saline water in the aquifer extends as far southeast as near Stoneham and Plantersville, where the depth below land surface to the top of the Jackson is about 2,200 feet, or 1,800 feet below mean sea level (Figure 8).

Catahoula Sandstone

The Catahoula Sandstone, which overlies the Jackson Group, crops out in a belt 3-5 miles wide across the central part of the county. From Singleton to Walker County line, the outcrop is broken by several closely spaced faults (Figure 2).

The Catahoula Sandstone mainly consists of light gray, sandy, tuffaceous clay and mudstone in the upper part and coarse quartz sand, in places indurated by opal cement, in the lower part. Fossil wood is common. Figure 9 shows an outcrop of the lower part of the Catahoula Sandstone in a roadcut 3.0 miles north of Shiro on Farm-to-Market Road 2620. About 12 feet of very coarse sand and sandstone, very fine sand, and silty, tuffaceous clay are exposed in the roadcut. The thickness of the Catahoula increases greatly downdip and reaches an approximate maximum of 1,500 feet in the southeastern corner of the county.

The Catahoula Sandstone yields small to moderate amounts of fresh to slightly saline water to public-supply, irrigation, rural-domestic, and livestock wells on the outcrop of the aquifer and a few southeast of the outcrop. The depth to the top of the aquifer in the southeastern part of the county, where the aquifer still contains fresh to slightly saline water, is about 1,300

Figure 5.—Outcrop of the Yegua Formation, 1.8 Miles West of Iola

feet below land surface or about 1,050 feet below mean sea level (Figure 10).

Fleming Formation

The Fleming Formation, which overlies the Catahoula Sandstone, crops out in much of the southern half of the county (Figure 2). The towns of Navasota and Anderson are near the northwestward extent of the formation, where a prominent cuesta marks its contact with the underlaying Catahoula Sandstone.

The Fleming Formation consists of light gray to yellowish gray, fine to coarse sand, silt, and calcareous clay. In places, the sand is highly indurated. Good exposures of the formation may be seen in a road material pit 1.4 miles north of Navasota at the intersection of a county road with Farm-to-Market Road 244 and a roadcut 5.75 miles northeast of Navasota on State Highway 90. Figure 11 is a view of the basal Fleming at the latter site where nearly 20 feet of buff, cross-bedded, medium to coarse sand with reworked shell fragments are exposed. The approximate maximum thickness of the Fleming Formation is 1,200 feet in the southeastern part of the county.

The Fleming Formation yields small to moderate amounts of fresh water to public-supply, irrigation, rural-domestic, and livestock wells.

Willis Sand

The Willis Sand, which overlies the Fleming Formation, crops out in the southeastern part of the county. The largest expanse is in the area south of Stoneham and Plantersville. Smaller isolated outcrops occur on the higher elevations north of this area, the northernmost outcrop being a few miles east of Shiro (Figure 2).

The Willis Sand consists of fine to medium, reddish sand, silt, clay, and siliceous gravel of granule to pebble size, and includes some fossil wood. Iron-oxide concretions are abundant and are locally used as road material. The approximate maximum thickness of the Willis is 100 feet in the southeastern part of the county. This thickness is based on work by Bernard, Le Blanc, and Major (1962, p. 218), who indicate that the base of the Willis Sand in the southeastern part of Grimes County is about 250 feet above sea level.

A. Roadcut 1.4 Miles East of Carlos on State Highway 30

B. Abandoned Railroad Cut 1.3 Miles North of Piedmont by
Farm-to-Market Road 3090

Figure 7.—Outcrops of the Jackson Group

Figure 9.—Outcrop of the Catahoula Sandstone, 3.0 Miles North of Shiro

The Willis Sand yields small amounts of fresh water to shallow rural-domestic and livestock wells on the outcrop of the aquifer.

Terrace Deposits

The terrace deposits overlie parts of the Yegua Formation, Jackson Group, Catahoula Sandstone, and Fleming Formation and are exposed along the valley walls of the Brazos and Navasota Rivers. All of the exposures are isolated remnants, the largest covering about 15 square miles in and near the town of Navasota. The surface of the terrace deposits is higher in elevation and is slightly more eroded than that of the adjacent flood-plain alluvium.

The terrace deposits consist of fine to coarse, reddish brown to brown sand, gravel, silt, and clay that is slightly indurated in places. The maximum thickness of the deposits is not known, but is probably more than 32 feet near the town of Navasota.

The water-yielding capacity of the terrace deposits is not well known, but south of the town of Navasota, pits dug into the deposits are reported to have yielded large amounts of fresh water for irrigation. Rural-domestic and livestock wells also tap the terrace deposits in this area for small amounts of fresh water.

Flood-Plain Alluvium

The flood-plain alluvium is exposed as a sinuous band mainly in the valleys of the Brazos and Navasota Rivers, but also along many of the smaller streams. It rests on the truncated surfaces of the bedrock formations. The most extensive deposit is south of the town of Navasota along the Brazos River and near the mouth of the Navasota River.

The flood-plain alluvium is composed of fine to coarse, reddish tan sand, gravel, silt, and reddish brown to brown clay. Composition of the alluvium differs from place to place. The individual beds or lenses of sand pinch out or grade laterally and vertically into finer or coarser materials. In general, the finer material is in the upper part of the deposit, and the gravel, whether mixed with sand or clean and well sorted, commonly occurs in the lower part. The maximum thickness of the flood-plain alluvium in Grimes County is more than 80 feet.

The flood-plain alluvium yields small to large amounts of fresh water to irrigation wells south of the town of Navasota.

SOURCE AND REPLENISHMENT OF GROUND WATER

The principal source of ground water in Grimes County is rainfall on the land surface in the county and

Figure 11.—Outcrop of the Fleming Formation, 5.75 Miles Northeast of Navasota

in adjacent areas. Of the 41.61 inches of average annual precipitation in Grimes County (Figure 12), only a small amount reaches the water table. It is this small amount of fresh water that replenishes the aquifers and replaces the water that is removed by pumping and natural discharge.

The principal areas of replenishment to sand beds supplying water to wells in Grimes County depend upon the location and depth of the wells. For example, a sandy zone in the Jackson Group 1,000 feet deep in a well in the Anderson area would reach the land surface a few miles south of Carlos, where it would be replenished by rainfall. In this example, the sandy zone dips southeastward about 160 feet per mile. On the other hand, a sandy zone in the Fleming Formation 1,000 feet deep in a well near the extreme south-central part of the county would be replenished by rainfall a few miles north of Navasota. Here the southeastward dip is about 75 feet per mile for this younger and less steeply dipping formation.

DIRECTION AND RATE OF MOVEMENT OF GROUND WATER

The ground water underlying Grimes County is moving constantly but very slowly. The water moving out of the county beneath the surface or being discharged within the county is replenished by water moving into the county from updip areas in the adjacent counties to the north or by rainfall within the county. The general direction of movement of the ground water is southeastward toward the Gulf of Mexico. Locally, however, in areas of heavy pumping, the direction of movement is toward these areas from all directions.

Figure 13, which shows the altitude of water levels in wells tapping the Yegua and Fleming Formations, indicates in a general way the direction of movement of the water. The water moves at right angles to the contours and in the direction of decreasing altitude. Figure 13 shows that the potentiometric surface in the Yegua Formation is inclined southeastward at an average of about 5 feet per mile. The potentiometric surface in the Fleming Formation is inclined generally southward at an average slope of about 7 feet per mile.

The rate of movement of the ground water depends upon the size of the open spaces and interconnecting passages in the aquifers and the inclination of the potentiometric surface. Based on average hydraulic gradients as determined from Figure 13, and on known or assumed porosities and hydraulic conductivities, the average velocity of the ground water in the Yegua and Fleming Formations in Grimes County is 10 and 185 feet per year, respectively. However, when wells are pumped, the potentiometric surface is locally

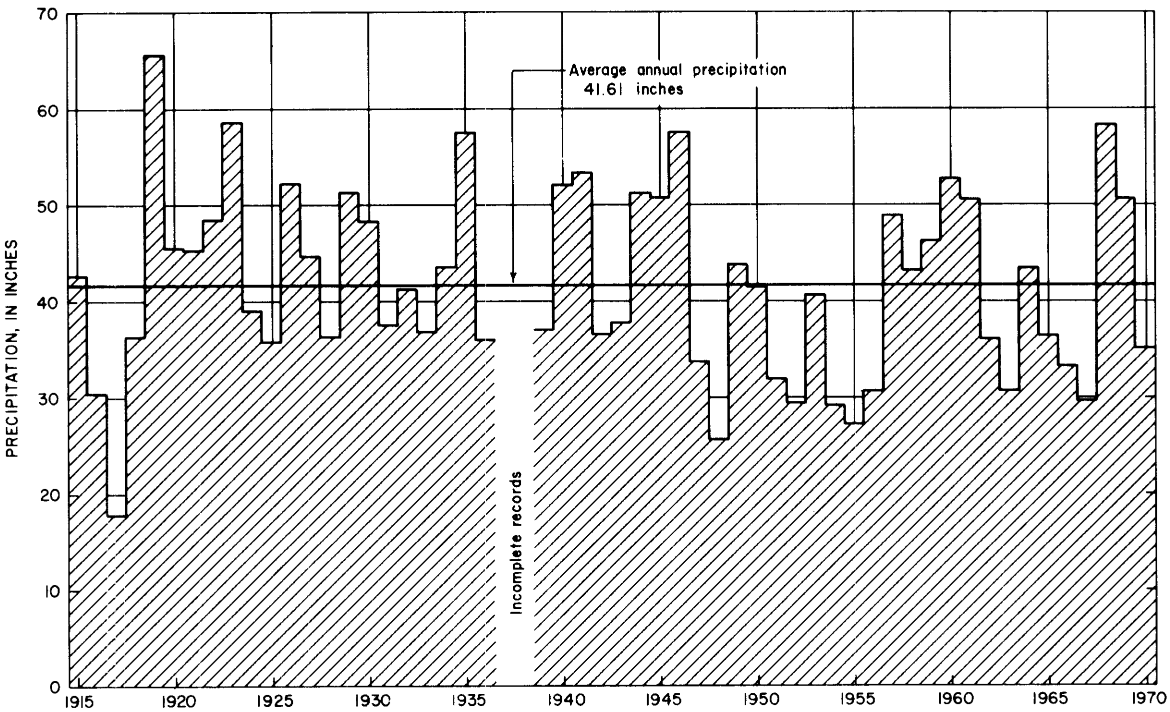


Figure 12.—Annual Precipitation at Anderson, 1915-70

depressed around the wells and is steeply sloping, thereby increasing the rate of movement. This causes greater volumes of water to be directed to the wells from the areas of recharge or replenishment.

DISCHARGE OF GROUND WATER

The aquifers in Grimes County discharge water by natural processes and by pumping from wells. The more important methods of natural discharge are seepage into streams, springflow, and evaporation.

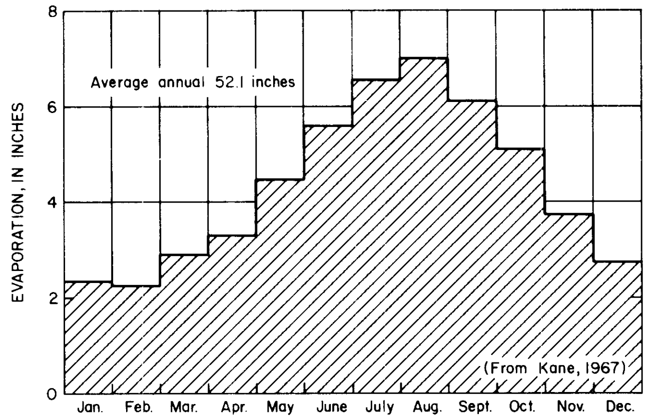
Seepage of ground water into streams in the outcrop areas of the aquifers represents a loss of ground water in Grimes County. This loss can be considered rejected recharge—that is, water that enters the areas of replenishment, but cannot move downward into the main body of the aquifers under the present slope of the water table; the water, therefore, moves toward stream valleys where it is discharged as seepage and springflow.

Seepage is common along the Brazos and Navasota Rivers and along the larger streams that are tributary to these rivers, thereby sustaining their flow even during most periods of below-normal rainfall.

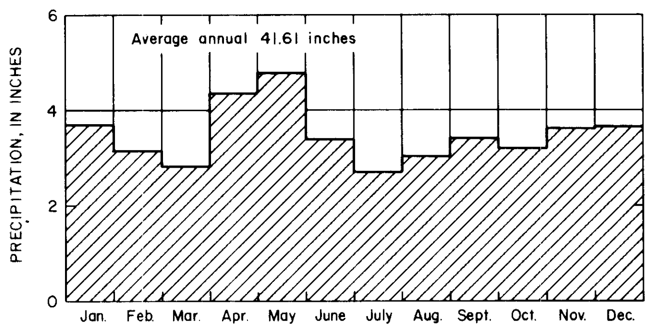
According to Wood (1956, p. 30-33), in studies made in the Gulf Coast region of Texas where annual rainfall averages between 40 and 50 inches, about 1 inch or more of water from rainfall that enters the outcrop of the aquifers is discharged to the streams as rejected recharge or base flow. On this basis, about 40 mgd (million gallons per day) of ground water is discharged by seepage and springflow into the streams of Grimes County.

Evaporation in Grimes County consumes a significant amount of water. The average annual gross lake-surface evaporation of 52.1 inches is 1.25 times the average annual precipitation. Evaporation is greatest during the hot summer months when precipitation is relatively low and when the soil-moisture demand to sustain plant life is high (Figure 14). However, evaporation from the soil is less than that from a free-water surface. Thus, the 52.1 inches of annual evaporation from a free-water surface is considerably greater than the actual evaporation from the soil. Nevertheless, the moisture evaporated from the soil decreases the potential replenishment of ground water to the aquifers.

The withdrawal of ground water by wells represents a quantity of water discharged from the aquifers. In 1970, about 1.6 mgd or 1,800 acre-feet was withdrawn by wells in Grimes County.

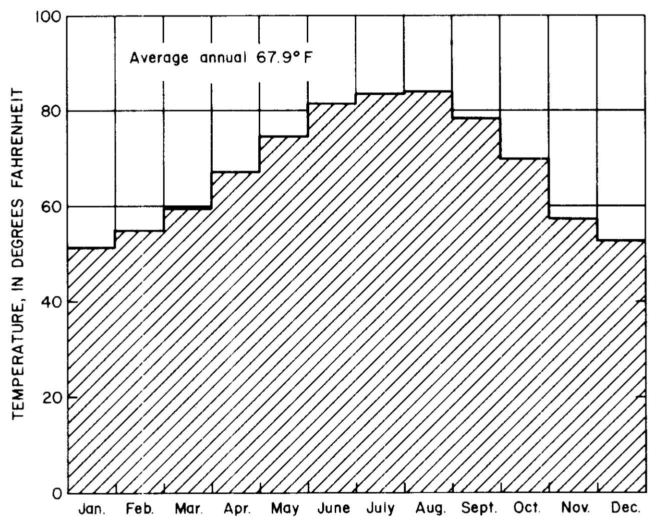


Average monthly gross lake-surface evaporation in Grimes County, 1940-55



Average monthly precipitation at Anderson, Grimes County, 1914-70

(From National Oceanic and Atmospheric Administration)



Average monthly temperature at Madisonville, Madison County, 1948-60

(From National Oceanic and Atmospheric Administration)

Figure 14

Average Monthly Gross Lake-Surface Evaporation, Precipitation, and Temperature

HYDRAULIC CHARACTERISTICS OF THE AQUIFERS

"The worth of an aquifer as a fully developed source of water depends largely on two inherent characteristics: Its ability to store and its ability to transmit water," (Ferris and others, 1962, p. 70). These characteristics are expressed as the storage coefficient and the transmissivity.

Aquifer tests were made in six wells tapping the Yegua Formation, Catahoula Sandstone, and Fleming Formation. Other aquifers in the county were not tested, because of a lack of suitable wells. The test data were analyzed by the Theis nonequilibrium method (Theis, 1935) and the Theis recovery method (Wenzel, 1942, p. 95). The results are shown in Table 2.

The transmissivity of a section of sand in the Yegua Formation, which was determined by testing well KW-59-16-803, was 250 feet squared per day. This figure should be considered representative of the interval of sand screened in the well and is not the transmissivity of the entire formation.

Aquifer tests were made in three wells (KW-60-25-804, KW-60-33-101, and KW-60-33-102) producing from the Catahoula Sandstone. The transmissivities were 160, 370, 430, and 650 feet squared per day. These values should be considered representative of the intervals of sands screened in each well and not of the entire formation.

Aquifer tests were made in two wells (KW-59-56-301 and KW-60-34-102), tapping the Fleming Formation. The transmissivities, 4,000 and 4,500 feet squared per day, again must be considered only as representative of the intervals of sand screened in the wells.

An average transmissivity of 5,600 feet squared per day was obtained for the flood-plain alluvium in Brazos, Burleson, Robertson, and Falls Counties by Cronin and Wilson (1967, p. 27), who used the results of 351 specific capacities in estimating transmissivities. This transmissivity should be considered representative of the entire formation as the wells probably screened all of the saturated sand in the alluvium. A similar average transmissivity could be expected from the flood-plain alluvium in Grimes County.

Storage coefficients could not be determined during any of the tests in Grimes County. However, on the basis of aquifer tests in adjoining counties, an average storage coefficient for artesian conditions in Grimes County is estimated to be about 0.0006. The storage coefficient for water-table conditions in Grimes County is estimated to be about 0.15.

The transmissivities and storage coefficients may be used to predict the drawdown of water levels caused by pumping a well or group of wells or by a general increase in pumping in an area. Figure 15 shows the theoretical relation of drawdown of water levels to different transmissivities and distance. The calculations of drawdown were based on a well or group of wells pumping 100 gpm continuously for 1 year from an extensive aquifer having a storage coefficient of 0.0006 and transmissivities as shown on the different curves.

As a result of pumping 100 gpm continuously for 1 year from an aquifer having an assumed transmissivity of 500 feet squared per day, the water level would decline about 20 feet at a distance of 1,000 feet from the well; it would decline about 10 feet at 5,000 feet and about 6 feet at 10,000 feet. Because drawdown is directly proportional to the pumping rate, the drawdown for rates other than 100 gpm can be determined by multiplying the drawdown values shown in Figure 15 by the proper multiple or fraction of 100.

Figure 16 shows the relation between time and distance to drawdown caused by a well or group of wells pumping 100 gpm from an artesian aquifer of infinite extent having a storage coefficient of 0.0006 and a transmissivity of 500 feet squared per day. The rate of drawdown decreases with time, but the water level will continue to decline indefinitely until a source of recharge is intercepted to offset the pumpage and reestablish equilibrium in the aquifer. Because the drawdown is directly proportional to the pumping rate, the drawdown for rates other than 100 gpm can be determined by multiplying the drawdown values shown in Figure 16 by proper multiple or fraction of 100.

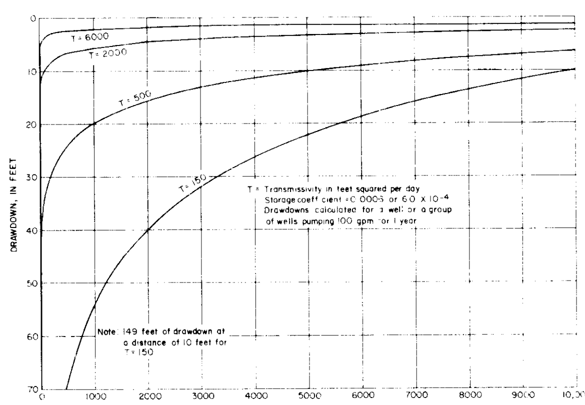


Figure 15.—Relation of Drawdown in an Artesian Aquifer to Transmissivity and Distance

Note that Figures 15 and 16 show that the drawdown caused by a pumping well is greatest near the pumping well and that the drawdown decreases as the distance from the pumping well increases. This

Table 2.—Summary of Aquifer Tests

WELL	AQUIFER	SCREENED INTERVAL (FT)	DISCHARGE (GPM)	TRANSMISSIVITY (FT^2/DAY)	HYDRAULIC CONDUCTIVITY (FT/DAY)	SPECIFIC CAPACITY		REMARKS
						(GPM/FT)	TIME (HOURS)	
KW-59-16-803	Yegua Formation	560-590	43	250	8.3	—	—	Recovery in pumped well
KW-59-56-301	Fleming Formation	222-262, 282-292	420	4,000	80	—	—	Do.
KW-60-25-804	Catahoula Sandstone	138-153	73	650	43	2.5	1.7	——
KW-60-33-101	do.	269-289	60	370	18	2.3	2.6	Drawdown in pumped well
			60	430	22	—	—	Recovery in pumped well
KW-60-33-102	do.	607-630, 699-709, 745-755	16	160	3.7	—	—	Recovery in pumped well
KW-60-34-102	Fleming Formation	320-340, 350-360	102	4,500	150	6.4	1.7	Recovery in pumped well

relationship is the practical reason for properly spacing wells to reduce their mutual interference and thus reduce the pumping cost.

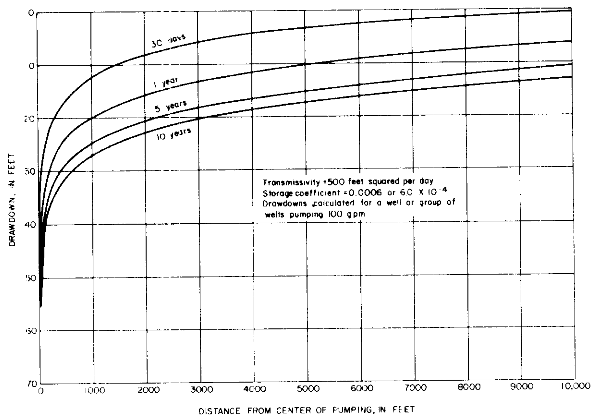


Figure 16.—Relation of Drawdown in an Artesian Aquifer to Time and Distance

Table 2 indicates that the hydraulic conductivity of the sands tested in Grimes County ranged from 3.7 to 150 feet per day. The largest hydraulic conductivity was associated with the Fleming Formation.

The specific capacity of a well is directly related to the transmissivity of the aquifer. Table 2 shows that the specific capacities of three wells ranged from 2.3 to 6.4 gpm per foot of drawdown. Specific capacities of wells tapping the same formation may differ widely because of the amount of sand screened, the difference in well construction, the degree of well development, and pumping time. The specific capacities of the irrigation wells that pump from the flood-plain alluvium south of Navasota are much greater than those in Table 2.

GROUND-WATER DEVELOPMENT

Pumpage of Ground Water

The inventory of 280 wells, springs, and oil tests (Table 8) includes only a part of the total number in the county; however, records of all municipal, industrial, and irrigation wells were obtained. Locations of the wells, springs, and oil tests are shown on Figure 26.

Records of the pumpage of ground water for all purposes for the years 1942, 1958, 1964, 1969, and 1970 are shown in Table 3. During these 5 years, 53 percent of the total ground water pumped was used for public supply, 38 percent for irrigation, and 9 percent for rural-domestic and livestock supply. Pumping of ground water for industrial use in Grimes County is relatively insignificant.

Table 3.—Pumpage of Ground Water, 1942, 1958, 1964, 1969, and 1970

	PUBLIC SUPPLY		IRRIGATION		RURAL-DOMESTIC AND LIVESTOCK		TOTALS	
YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR
1942	0.223	250	0	0	0.089	100	0.31	350
1958	.502	563	0.32	360	.15	170	.97	1,100
1964	.529	594	.23	260	.14	160	.90	1,000
1969	.634	711	.36	400	.14	160	1.1	1,300
1970	.870	975	.62	690	.14	160	1.6	1,800

The pumpage of ground water increased from 0.31 mgd or 350 acre-feet in 1942 to 1.6 mgd or 1,800 acre-feet in 1970. The relatively small amount of ground water pumped in 1942 was due to the fact that ground water was not used for irrigation in Grimes County until the 1950's and that the per capita use of water was much less in 1942 than in 1970. Of the 1.6 mgd used in 1970, 4 percent was pumped from the Yegua Formation, 3 percent from the Jackson Group, 43 percent from the Catahoula Sandstone, 28 percent from the Fleming Formation, 1 percent from the Willis Sand, and 21 percent from the flood-plain alluvium. Pumpage from the terrace deposits in 1970 was insignificant.

Public Supply

According to Sundstrom, Hastings, and Broadhurst (1948, p. 120-123), the withdrawal of ground water for public supply in Anderson, Bedias, Iola, Navasota, and Shiro was about 0.022 mgd, or 250 acre-feet in 1942. Between 1955 and 1970, their pumpage, plus that for Associates Group, Inc. in 1969-70 and Richards in 1970 (Table 4), ranged from 0.45 mgd (500 acre-feet per year) in 1961 to 0.87 mgd (980 acre-feet per year) in 1970. The water pumped for Associates Group, Inc. in 1969 and 1970 was used for filling and then maintaining the level of an artificial lake.

Table 4.—Public-Supply Pumpage of Ground Water, 1942 and 1955-70

(Amounts are approximate, because some of the pumpage was estimated. Totals are rounded to two significant figures.)

Other amounts are shown to nearest 0.001 mgd and to nearest acre-foot.

YEAR	ANDERSON		BEDIAS		IOLA		NAVASOTA		RICHARDS		SHIRO		ASSOCIATES GROUP (RECREATION)		TOTALS	
	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR	MGD	AC-FT PER YEAR
1942	0.010	11	0.012	13	0.005	6	0.190	213	–	–	0.003	3	–	–	0.22	250
1955	.020	22	.043	48	.015	17	.428	480	–	–	.010	11	–	–	.52	580
1956	.010	11	.044	49	.015	17	.524	587	–	–	.006	7	–	–	.60	670
1957	.011	12	.044	49	.015	17	.441	494	–	–	.004	4	–	–	.52	580
1958	.014	16	.033	37	.012	13	.437	490	–	–	.006	7	–	–	.50	560
1959	.015	17	.045	50	.020	22	.432	484	–	–	.006	7	–	–	.52	580
1960	.015	17	.012	13	.021	24	.415	465	–	–	.006	7	–	–	.47	530
1961	.015	17	.012	13	.019	21	.396	444	–	–	.006	7	–	–	.45	500
1962	.015	17	.012	13	.021	24	.487	546	–	–	.006	7	–	–	.54	610
1963	.015	17	.015	17	.022	25	.507	568	–	–	.006	7	–	–	.56	630
1964	.015	17	.012	13	.015	17	.480	538	–	–	.007	8	–	–	.53	590
1965	.016	18	.015	17	.013	15	.528	592	–	–	.007	8	–	–	.58	650
1966	.016	18	.012	13	.010	11	.499	559	–	–	.007	8	–	–	.54	610
1967	.016	18	.012	13	.021	24	.531	595	–	–	.008	9	–	–	.59	660
1968	.016	18	.012	13	.021	24	.491	550	–	–	.008	9	–	–	.55	620
1969	.011	12	.010	11	.022	25	.563	631	–	–	.008	9	0.008	9	.62	690
1970	.022	25	.011	12	.025	28	.624	699	0.007	8	.011	12	.17	191	.87	980

Irrigation

Ground water has never been used extensively for irrigation in Grimes County. In general, the precipitation is well distributed throughout the year and during many years it is adequate for growing crops and pasture grass, but when precipitation is below normal during the growing season, ground water or surface water is used for supplemental irrigation. Large annual differences in irrigation pumpage are common because the quantity used depends mainly upon the amount of rainfall.

According to the Texas Water Development Board (1971), 365, 261, and 400 acre-feet of ground water were used to irrigate 399, 415, and 550 acres in 1958, 1964, and 1969, respectively. Records indicate that in 1959 only nine irrigation wells (four wells on the upland and five wells on the flood plain) were in existence, and probably not all were used during any one year. Data collected in 1970 indicate that 22 irrigation wells were in the county, but not all were used in 1970, and an estimated 700 acre-feet of ground water was used to irrigate 430 acres. More than half of the ground water used for irrigation in 1970 was pumped from nine wells in the flood-plain alluvium.

Table 5.-Pumpage of Ground Water and Surface Water for Irrigation, and Acres Irrigated, 1958,1964,1969, and 1970

(Data for 1958,1964, and 1969 from Texas Water Development Board [1971] ; Data for 1970 Estimated)

YEAR	GROUND WATER		SURFACE WATER	
	ACRES	AC-FT PER YEAR	ACRES	AC-FT PER YEAR
1958	399	365	375	375
1964	415	261	804	594
1969	550	400	775	612
1970	430	700	610	900

The major irrigated crop on the upland is improved grass for pasture and hay, and the major irrigated crops on the flood-plain alluvium are cotton and grain sorghums. Most of the future development of ground water probably will be for improved grass on the upland and for cotton and grain sorghums on the flood plain. No large-scale development of ground water for irrigation is anticipated, although relatively large quantities are available for development on the upland and on the flood-plain alluvium.

Rural-Domestic and Livestock Supply

Use of ground water for rural-domestic and livestock supply in 1970 was estimated to be about 0.14 mgd, which is a 57 percent increase over that of 1942 (Table 3). The estimates of rural-domestic and livestock use as given in the table are based chiefly on the census of rural population and livestock in the county. Surface water from streams and earthen tanks supplied the water needs for some livestock.

Changes in Water Levels

Water levels in wells in Grimes County were measured during previous studies in 1942, 1959-60, 1963, and as part of this study in 1970-71. Only a few of the wells were measured more than one time. Although some of the records of water levels in these wells have been published previously, all are included in Table 8 in this report.

The available water-level measurements in wells in the county indicate mostly rising or declining trends due to natural causes such as time of year in which the water levels were measured and differences in rainfall. Except in the Navasota area, the pumpage throughout the county has been too small to have caused noticeable declines. The only area of relatively heavy pumpage is the Navasota well field.

All of the Navasota wells produce from the Catahoula Sandstone, and most of the wells have screened intervals between 178 and 343 feet. In these wells, water levels measured and reported between 1927 and 1970 indicate a decline of about 35 feet during the 44-year period. On the basis of three water levels measured and reported between 1906 and 1970 in two Navasota wells having depths from 765 to 830 feet, water levels declined 64 feet in the 64year period,

Although multiple water-level measurements in the region around Navasota are few, the decline of the water level of 10.2 feet from 1942 to 1959 in well KW-59-47-303, about 3 miles southwest of Navasota, is thought to have been due to the deepening and expansion of the cone of depression caused by the withdrawals at Navasota.

Well Construction and Yields

During pioneer days, water used for domestic purposes was obtained mostly from dug wells or shallow hand-bored wells; only a few fortunate people had springs or streams available. The dug, hand-bored, and early drilled wells usually penetrated only a few feet of the saturated zone and yielded small quantities of water. Most of the wells completed since 1930 have been drilled wells.

Figure 17 illustrates the three most common types of construction of present-day drilled wells in the report area: The straight-walled well, the underreamed and gravel-packed well, and the special construction used for irrigation wells on the upland and on the flood-plain alluvium.

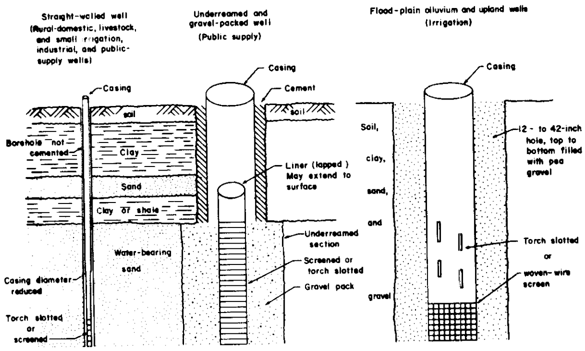


Figure 17.—Typical Construction of Rural-Domestic, Livestock, Public-Supply, Industrial, and Irrigation Wells

The straight-walled type of construction is commonly used for rural-domestic, livestock, and small irrigation, industrial, and public-supply wells if a relatively low-cost well is desired. The typical straight-walled well in the report area has a 4-inch casing to a depth below the expected pumping level, and 2-inch casing thereafter to total depth. The 2-inch casing is a cost-reducing factor. The 2-inch casing is slotted in part or all of the producing sand. A few wells use commercial screens instead of the slotted casing. The straight-walled type of construction, using larger-diameter casing, was used by the smaller municipalities in Grimes County. Most of the artesian wells that flow are cased with 2-inch casing from top to bottom.

The rural-domestic and livestock wells are equipped with windmills, pump jacks, jet pumps, or submersible pumps. The submersible pump was the type most frequently installed during the 1960's.

The underreamed and gravel-packed type of construction is generally used where a large yield is desired. Most of the Navasota public-supply wells are underreamed, screened, and gravel-packed in the water-bearing sand. The gravel pack in these wells increases the effective diameter of the well and allows more water to enter at a reduced velocity and with less head-loss. This reduces the drawdown (and pumping costs) and aids in retarding the entrance of sand into the well. The annular space between the bore-hole and the casing is filled with cement which increases the life of the well and reduces the chance of contamination from the surface.

Most of the irrigation wells on the upland are constructed differently from the underreamed and gravel-packed wells. These irrigation wells are constructed so that the bore is of the same diameter from top to bottom instead of underreamed; slotted casing is used instead of screen; gravel is used to fill the annular space from top to bottom; and the well is not cemented. These are cost-reducing factors.

When an irrigation well is to be drilled in the flood-plain alluvium, the area is usually explored by several test holes to find the most favorable location. The thickness and grain size of the water-bearing material are the most important factors considered in selecting the well site. A reverse-circulation rotary-type drilling rig is used to drill the hole, which is usually 36 to 42 inches in diameter. The hole generally is drilled into the bedrock to a depth 2 to 5 feet below the base of the alluvium. The entire depth of the hole is cased, the casing being placed as near as possible in the center of the hole. The casing used in the older wells generally consisted of corrugated galvanized culvert pipe 18 inches in diameter, with a woven wire screen (½-inch mesh) placed in the coarser sand and gravel.

To prolong the life of the older wells, torch-slotted steel liners have been placed inside the old casing in some wells. Currently, most of the wells being drilled are cased with torch-slotted steel casing from 10 to 18 inches in diameter. Approximately ½-to-1-inch gravel is used to fill the annular space between the casing and the wall of the hole. The well is then developed with a test pump; gravel is added, if necessary, to replace sand pumped out during well development (and throughout the life of the well if necessary to keep the hole filled). Following development, a short test is run to determine the specific capacity of the well, and the size of the pump and the power needed. In the flood plain of the report area, the typical irrigation well is equipped with a 6- or 8-inch turbine pump, set within 2 feet of the bottom of the well and operated with power supplied by an internal-combustion engine.

The yields of the wells in the county vary considerably depending upon the type of construction and intended use. Most of the rural-domestic and stock wells are pumped at less than 5 gpm. The straight-wall construction wells of the smaller municipalities have yields ranging from about 5 to 60 gpm. The underreamed and gravel-packed wells used by the city of Navasota have maximum yields of about 450 gpm. The irrigation wells on the upland have yields ranging from about 100 to 400 gpm, whereas the irrigation wells pumping from the flood-plain alluvium have yields ranging from about 400 to 800 gpm.

QUALITY OF GROUND WATER

The chemical substances in the ground water in Grimes County originate principally from the soil and rocks through which the water has moved. Consequently, the differences in chemical character of the water indicate in a general way the character of the rock formations that have been in contact with the water. The low rate of movement of ground water tends to inhibit mixing and diffusion. Lenses of sediments, such as tight sand and clay, form local barriers to ground-water movement and prevent uniform dispersion of water throughout the aquifer. As a result of these factors, variation in chemical quality of the water can be expected in various parts of the aquifers.

Table 6 lists the constituents and properties commonly determined by the U.S. Geological Survey and includes a résumé of their sources and significance. Table 10 contains 184 chemical analyses of water from selected wells and springs in Grimes County. The wells having chemical analyses are identified on the well-location map (Figure 26), by lines over the last 3 digits of the well numbers. Figure 18 shows the variation in the chemical content of the sampled water throughout the report area.

Suitability of the Water for Use

The suitability of a water supply depends upon the chemical quality of the water and the limitations imposed by the contemplated use of the water. Various criteria of water-quality requirements have been developed, including most categories of water quality: Bacterial content; physical characteristics, such as turbidity, color, odor, and temperature; chemical substances; and radioactivity. Usually water-quality problems of bacteria and physical characteristics can be alleviated economically, but the removal or neutralization of undesirable chemical constituents can be difficult and expensive.

Ground water of good chemical quality is available in Grimes County. Much of the water is suitable for public supply, rural-domestic, industrial use, and irrigation with little or no treatment.

Public- and Rural-Domestic Supply

The quality of water required for public- and rural-domestic supply can be stated in general terms—the water furnished to the consumer must be free of harmful chemical substances that adversely affect health; it must be free of turbidity, odor, and color to the extent that it is not objectionable to the user; and must not be excessively corrosive to the water-supply system. To produce such water with practical treatment, the quality of the raw water prior to treatment must not be below certain standards.

The safe limits for the mineral constituents found in water are usually based on the U.S. Public Health Service drinking-water standards. These standards were established in 1914, to control the quality of water used for drinking and culinary purposes on interstate carriers. The standards have been revised several times, the latest revision having been made in 1962 (U.S. Public Health Service, 1962), and have been adopted by the American Water Works Association as minimum standards for all public-water supplies.

According to the drinking-water standards, the limits in the following table should not be exceeded where more suitable supplies are or can be made available:

CONSTITUENT	MAXIMUM CONCENTRATION (MG/L)
Chloride	250
Sulfate	250
Nitrate	45
Iron	0.3
Fluoride	.8[a]
Dissolved solids	500

[a] Based on annual average of maximum daily air temperature of 80.1°F (26.5°C) for 14 years at Madisonville, Madison County.

Chloride and sulfate generally are not problems in ground water in Grimes County. More than 80 percent of the water samples analyzed for chloride and sulfate contained less than 250 mg/l of these constituents. The higher chloride and sulfate concentrations were associated with the older formations (for example, the Yegua Formation), and the lower concentrations were associated with the younger formations.

Nitrate is not a significant problem in the ground water of Grimes County. Almost all of the ground-water samples tested for nitrate showed the concentration to be less than 45 mg/l, and several of the samples contained no nitrate. Most of the few samples exceeding 45 mg/l nitrate were from shallow dug wells less than 40 feet deep and were not associated with any particular aquifer.

Iron is not a serious problem in the ground water of Grimes County. Slightly less than 80 percent of the ground-water samples analyzed for iron showed the concentration to be less than 0.3 mg/l. The lowest percentage of samples containing iron exceeding 0.3 mg/l was from the Yegua Formation.

Fluoride generally is not a problem in the ground water of Grimes County. More than 90 percent of the water samples analyzed for fluoride showed the

Table 6.—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.

concentration to be less than 0.8 mg/l. The samples containing fluoride in excess of 0.8 mg/l came from wells generally more than 500 feet deep in the Yegua Formation, Jackson Group, and Catahoula Sandstone.

The dissolved-solids content of water was less than 500 mg/l in about 40 percent of the samples analyzed for this characteristic and was less than 1,000 mg/l in 80 percent of the samples. Ground-water samples having the higher concentrations of dissolved solids were associated with the older aquifers. For example, only about 15 percent of the water samples from the Yegua Formation had dissolved solids concentrations less than 500 mg/l; whereas, about 70 percent of those from the Fleming Formation had dissolved solids less than 500 mg/l. Although water with less than 500 mg/l dissolved solids may not be available in large quantities in certain places in the county, it is recognized that ground water having dissolved solids in excess of the recommended limit is commonly used without any obvious ill effects.

Irrigation

The suitability of water for irrigation depends on the chemical quality of the water and on other factors such as soil texture and composition, types of crops, topography of the land, the amount of water used and the methods of applying it, and the amount and distribution of rainfall.

Chemical analyses of irrigation water permit classification in terms of suitability and provide some assurance as to the effects of the water on crops and soils.

The most important characteristics in determining the quality of irrigation water, according to the U.S. Salinity Laboratory Staff (1954, p. 69-82), are: (1) Total concentration of soluble salts, an index of the salinity hazard, (2) relative proportion of sodium to other cations, and index of the sodium hazard, (3) concentration of boron or other elements that may be toxic, and (4) the bicarbonate concentration as related to the concentration of calcium plus magnesium.

The U.S. Salinity Laboratory Staff introduced the term "sodium-adsorption-ratio" (SAR) to express the relative activity of sodium ions in exchange reactions with the soil. This ratio is expressed by the equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}},$$

where the concentrations of the ions are expressed in me/l (milliequivalents per liter).

The U.S. Salinity Laboratory Staff has prepared a system for classifying irrigation waters in terms of salinity and sodium hazard. Empirical equations were used in formulating a diagram which uses SAR and specific conductance in classifying irrigation waters. The diagram is reproduced in modified form as Figure 19. With respect to sodium and salinity hazards, waters are divided into four classes—low, medium, high, and very high. The range of this classification extends from those waters which can be used for irrigation of most crops on most soils to those waters which are usually unsuitable for irrigation.

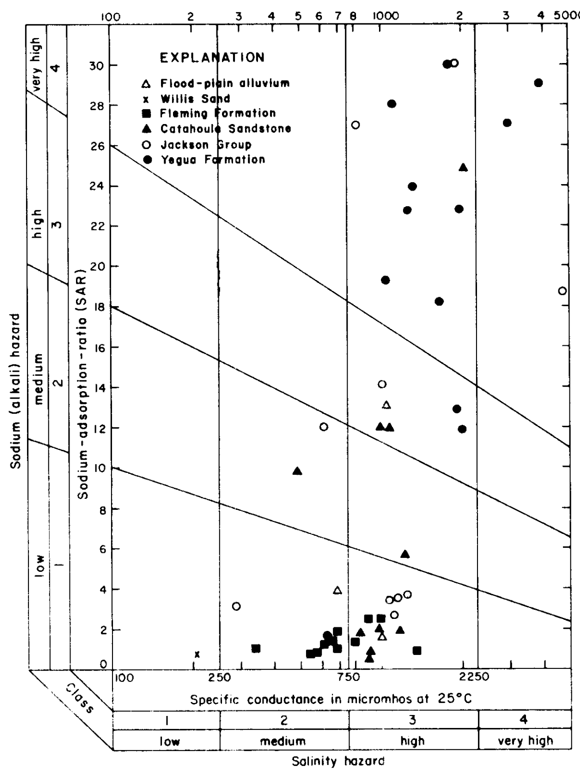


Figure 19.—Classification of Irrigation Waters

Representative water-analysis data from most of the aquifers in Grimes County are plotted on Figure 19. The data show that the water ranges from low to very high with respect to the sodium and salinity hazards. Generally, the better quality water for irrigation is from the younger aquifers. For example, water from the Fleming Formation mostly is low in the sodium hazard and medium in the salinity hazard, whereas water from the Yegua Formation mostly is high to very high in the sodium and salinity hazards. Although water from the Yegua Formation is not known to be used for irrigation in Grimes County, any attempts to irrigate with such water should include special soil-management practices.

An excessive concentration of boron makes water unsuitable for irrigation. Boron in correct amounts is essential to plant growth but is toxic at concentrations only slightly more than optimum. Results of the determinations of boron show that concentrations are low, indicating that the constituent is not a problem in the ground water in Grimes County.

Another factor used in assessing the quality of water for irrigation is the RSC (residual sodium carbonate) in the water. Excessive RSC causes the soil structure to deteriorate, and plant growth diminishes accordingly. Determinations of RSC show that the lower concentrations are generally associated with water from the younger aquifers. Water from the Yegua Formation and Catahoula Sandstone have relatively high RSC.

For supplemental irrigation in areas of relatively high rainfall, as in Grimes County, water-quality requirements are not rigid. Therefore, the overall appraisal of ground water for irrigation in Grimes County with respect to plant growth and soil effects is favorable.

Industrial Use

The quality requirements for industrial water range widely, and almost every industrial application has different standards. For some purposes, such as cooling, water of almost any quality can be used; whereas, in some manufacturing processes and in high-pressure steam boilers, water approaching the quality of distilled water may be required. The quality requirements for many types of industries are given in Table 7.

Hardness, reported as an equivalent quantity of calcium carbonate, is a property of water which receives great attention in evaluating an industrial water supply. Hardness is objectionable, because it contributes to the formation of scale in boilers, pipes, water heaters, and radiators, which results in loss in heat transfer, boiler failure, and reduction of flow. However, calcium carbonate in water sometimes forms protective coatings on pipes and other equipment and reduces corrosion.

In Grimes County, water ranging in hardness from soft (less than 60 mg/l) to very hard (more than 180 mg/l) is available in places. Generally, the softer water is associated with the older aquifers. For example, about half of the water sampled from the Yegua Formation was soft; whereas, almost none of the water samples from the Fleming Formation was soft.

High dissolved-solids concentrations may be closely associated with the corrosive property of a water, particularly if chloride is present in appreciable quantities. Water containing high concentrations of magnesium chloride may be very corrosive, because hydrolysis of this unstable salt yields hydrochloric acid.

In summary, ground water in many places in Grimes County will meet the quality requirements for many industrial uses, and with treatment, it is possible to make the water satisfactory for almost any special use.

Contamination and Protection

Pesticides

To provide information on the presence of pesticides (insecticides and herbicides), samples of ground water from four wells in the report area were analyzed for pesticides by procedures recommended by the Subcommittee on Pesticide Monitoring of the Federal Committee on Pest Control (Green and Love, 1967, p. 13-I 6). The wells that were sampled on February 8, 1971, were KW-59-24-801, KW-59-48-403, KW-60-17-201, and KW-60-33-702, having depths of 35, 64, 21, and 25 feet, respectively. No pesticides were found in the water samples from any of these wells.

Salt-Water Disposal

The disposal of salt water from oil-field operations into unlined open-surface pits is the most hazardous method with respect to contamination of shallow fresh water. The time required for the salt water to affect the quality of water in nearby wells may vary from a few months to several years. Once such a source of contamination is eliminated, flushing and dilution of the contamination may require a considerably longer time than the period of original contamination.

According to a salt-water production and disposal inventory {Texas Water Commission and Texas Water Pollution Control Board, 1963}, only 52 barrels of salt water were reported to have been produced and disposed of in Grimes County in 1961. This production was in the Madisonville South Field (Figure 26), with disposal in an open-surface pit.

Another inventory of salt-water production and disposal was made in 1967. Questionnaires sent to oilfield operators by the Railroad Commission of Texas indicated that the only production reported in 1967 was in the Carlton Speed Field (Figure 26). Here 1,275 barrels were produced and disposed of in an unlined open-surface pit, which was reported to be a temporary method of disposal. During the 1970-71 period of field study in Grimes County, no open-surface pits were observed. The scarcity of pits is attributed to the small amount of oil and gas production in the county and to a no-pit order by the Railroad Commission that went into effect throughout Texas on January 1, 1969.

No evidence of salt-water contamination was found during the current ground-water investigation. This should not be construed, however, to mean that contamination did not occur during previous years when the pits were in use.

Table 7.—Water-Quality Tolerance for Industrial Applications[1]

[Allowable Limits in Milligrams Per Liter Except as Indicated]

INDUSTRY	TURBIDITY	COLOR	COLOR + O_2 CONSUMED	DISSOLVED OXYGEN (ml/l)	ODOR	HARDNESS	ALKALINITY (AS $CaCO_3$)	pH	TOTAL SOLIDS	Ca	Fe	Mn	Fe+ Mn	Al_2O_3	SiO_2	Cu	F	CO_3	HCO_3	OH	$CaSO_4$	Na_2SO_4 TO Na_2SO_3 RATIO	GENERAL[2]
Air Conditioning[3]	--	--	--	--	--	--	--	--	--	--	0.5	0.5	0.5	--	--	--	--	--	--	--	--	--	A,B
Baking	10	10	--	--	--	(4)	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
Boiler feed:																							
0-150 psi	20	80	100	2	--	75	--	8.0+	3,000-1,000	--	--	--	--	5	40	--	--	200	50	50	--	1 to 1	--
150-250 psi	10	40	50	.2	--	40	--	8.5+	2,500-500	--	--	--	--	.5	20	--	--	100	30	40	--	2 to 1	--
250 psi and up	5	5	10	0	--	8	--	9.0+	1,500-100	--	--	--	--	.05	5	--	--	40	5	30	--	3 to 1	--
Brewing:[5]																							
Light	10	--	--	--	Low	--	75	6.5-7.0	500	100-200	.1	.1	.1	--	--	--	1	--	--	--	100-200	--	C,D
Dark	10	--	--	--	Low	--	150	7.0+	1,000	200-500	.1	.1	.1	--	--	--	1	--	--	--	200-500	--	C,D
Canning:																							
Legumes	10	--	--	--	Low	25-75	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
General	10	--	--	--	Low	--	--	--	--	--	.2	.2	.2	--	--	--	1	--	--	--	--	--	C
Carbonated beverages[6]	2	10	10	--	0	250	50	--	850	--	.2	.2	.3	--	--	--	.2	--	--	--	--	--	C
Confectionary	--	--	--	--	Low	--	--	(7)	100	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Cooling[8]	50	--	--	--	--	50	--	--	--	--	.5	.5	.5	--	--	--	--	--	--	--	--	--	A,B
Food, general	10	--	--	--	Low	--	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	C
Ice (raw water)[9]	1-5	5	--	--	--	--	30-50	--	300	--	.2	.2	.2	--	10	--	--	--	--	--	--	--	C
Laundering	--	--	--	--	--	50	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Plastics, clear, undercolored	2	2	--	--	--	--	--	--	200	--	.02	.02	.02	--	--	--	--	--	--	--	--	--	--
Paper and pulp:[10]																							
Groundwood	50	20	--	--	--	180	--	--	--	--	1.0	.5	1.0	--	--	--	--	--	--	--	--	--	A
Kraft pulp	25	15	--	--	--	100	--	--	300	--	.2	.1	.2	--	--	--	--	--	--	--	--	--	--
Soda and sulfite	15	10	--	--	--	100	--	--	200	--	.1	.05	.1	--	--	--	--	--	--	--	--	--	--
Light paper, HL-Grade	5	5	--	--	--	50	--	--	200	--	.1	.05	.1	--	--	--	--	--	--	--	--	--	B
Rayon (viscose) pulp:																							
Production	5	5	--	--	--	8	50	--	100	--	.05	.03	.05	<8.0	<25	<5	--	--	--	--	--	--	--
Manufacture	.3	--	--	--	--	55	--	7.8-8.3	--	--	.0	.0	.0	--	--	--	--	--	--	--	--	--	--
Tanning[11]	20	10-100	--	--	--	50-135	135	8.0	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--
Textiles:																							
General	5	20	--	--	--	20	--	--	--	-	.25	.25	--	--	--	--	--	--	--	--	--	--	--
Dyeing[12]	5	5-20	--	--	--	20	--	--	--	--	.25	.25	.25	--	--	--	--	--	--	--	--	--	--
Wool scouring[13]	--	70	--	--	--	20	--	--	--	--	1.0	1.0	1.0	--	--	--	--	--	--	--	--	--	--
Cotton bandage[13]	5	5	--	--	Low	20	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--

1/ American Water Works Association, 1950.
2/ A—No corrosiveness; B—No slime formation; C—Conformance to Federal drinking water standards necessary; D-NaCl, 275 mg/l.
3/ Waters with algae and hydrogen sulfide odors are most unsuitable for air conditioning.
4/ Some hardness desirable.
5/ Water for distilling must meet the same general requirements as for brewing (gin and spirits mashing water of light-beer quality; whiskey mashing water of dark-beer quality).
6/ Clear, odorless, sterile water for syrup and carbonization. Water consistent in character. Most high quality filtered municipal water not satisfactory for beverages.
7/ Hard candy requires pH of 7.0 or greater, as low value favors inversion of sucrose, causing sticky product.
8/ Control of corrosiveness is necessary as is also control of organisms, such as sulfur and iron bacteria, which tend to form slimes.
9/ $Ca(HCO_3)_2$ particularly troublesome. $Mg(HCO_3)_2$ tends to greenish color. CO_2 assists to prevent cracking. Sulfates and chlorides of Ca, Mg, Na should each be less than 300 mg/l (white butts).
10/ Uniformity of composition and temperature desirable. Iron objectionable as cellulose adsorbs iron from dilute solutions. Manganese very objectionable, clogs pipelines and is oxidized to permanganates by chlorine, causing reddish color.
11/ Excessive iron, manganese, or turbidity creates spots and discoloration in tanning of hides and leather goods.
12/ Constant composition; residual alumina 0.5 mg/l.
13/ Calcium, magnesium, iron, manganese, suspended matter, and soluable organic matter may be objectionable.

Improperly Cased Wells

Aquifers may be contaminated by the invasion of salt water through improperly cased oil or gas wells. These wells usually penetrate not only fresh water, but also salt water before reaching the oil and gas. If the salt water is under greater pressure than the fresh water, the salt water may move up the well bore and invade the sand containing fresh water.

To combat the threat of this source of contamination, the Railroad Commission of Texas requires that fresh-water strata be protected by casing and cement in oil and gas wells drilled in the State. The Oil and Gas Division of the Railroad Commission is responsible for seeing that oil and gas wells are properly constructed, and in the last several years, the Texas Water Development Board has furnished ground-water data to oil operators and to the Railroad Commission so that all sands containing fresh to slightly saline water may be protected.

The oil and gas fields in Grimes County do not have field rules regarding surface casing. Casing requirements in these fields are regulated on an individual-well basis by data supplied to the oil operators and to the Railroad Commission by the Texas Water Development Board. This method provides adequate protection.

AVAILABILITY OF GROUND WATER

Fresh to slightly saline ground water is available everywhere in Grimes County. The Yegua Formation, Jackson Group, Catahoula Sandstone, Fleming Formation, and flood-plain alluvium are the important aquifers that are tapped by wells and are the sources of almost all fresh to slightly saline water presently (1971) being pumped. The Carrizo, Queen City, and Sparta Sands have varying capacities for potential clevelopment, but are not tapped by wells. The Willis Sand and terrace deposits contain only small quantities of water and have a relatively small areal extent.

Quantity of Available Water and Areas Favorable for Devetopment

The quantity of water that can be withdrawn from the aquifers on a long-term basis without depleting the existing supply is equal to the amount of replenishment or recharge that the aquifers receive. Computations of the amount of replenishment can be made, with some assumptions, for some of the aquifers in the county by determining the amount of water that originally moved through these aquifers prior to development. The amount of replenishment can be computed from the equation :

$$Q = 7.48\ T\ I\ L,$$

where

Q = quantity of water in gallons per day moving through the aquifer,
T = transmissivity in feet squared per day,
I = hydraulic gradient of the potentiometric surface (prior to development) in feet per mile, and
L = length of the aquifer, in miles, through which the water moves;
7.48 = gallons per cubic foot.

The hydraulic gradients of the present potentiometric surfaces of the aquifers are believed to closely approximate the original hydraulic gradients (prior to well development), because of the relatively small amount of pumping in the county.

Carrizo and Queen City Sands

The amount of water that can be withdrawn on a long-term basis from the Carrizo and Queen City Sands was not determined. They are not as likely to be tapped by water wells in the future as the more economically accessible overlying aquifers that yield good quality water.

Only slightly saline water is available from the Carrizo Sand, and this water is available only in about 50 square miles of the northwestern part of the county. lola is located at the downdip limit of the slightly saline water, southeast of which the water in the Carrizo becomes more highly saline. Depths to the top of the Carrizo within the area of slightly saline water range from about 1,800 to 2,200 feet below land surface. Any wells tapping this aquifer would be capable of yielding more than 500 gpm and could be expected to flow.

Fresh to slightly saline water is available from the Queen City Sand. This water is available in an area of about 125 square miles in the northwestern part of the county. lola and Cross are the only towns within this area although Bedias is near the downdip limit of slightly saline water. Southeast of this limit, the water in the Queen City becomes more highly saline. Only a small part of the total amount of fresh to slightly saline water is fresh. The fresh water in the Queen City is confined mostly to the lower half of the aquifer (Figure 3) and is available in an area of about 40 square miles in the northwestern part of the county. Depths to the top of the Queen City Sand within the area of fresh to slightly saline water range from about 1,200 to 2,000 feet below land surface. Wells tapping the aquifer would be capable of yielding more than 500 gpm.

Sparta Sand

Fresh to slightly saline water is available from the Sparta Sand in an area of about 275 square miles in about the northern third of the county. Singleton and Carlos are near the downdip limit of slightly saline water. Only a part of the total amount of fresh to slightly saline water is fresh. The fresh water, which is mostly confined to the basal part of the aquifer (Figure 3), is available only in an area of about 125 square miles in the northwestern part of the county (Figures 4 and 20). Wells tapping the aquifer would be capable of yielding more than 500 gpm.

The amount of fresh to slightly saline water that is available from the Sparta Sand can be approximated with some assumptions. The original hydraulic gradient in the Sparta Sand in Grimes County was assumed to be six feet per mile, which was determined to be the hydraulic gradient in Brazos and Burleson Countiles prior to significant well development (Follett, 1973). The average transmissivity of the sand containing fresh to slightly saline water in northern Grimes County is 4,400 feet squared per day. This was derived from an average sand thickness of 200 feet along the Grimes County-Madison County line (Figure 20), and from an average hydraulic conductivity of 22 feet per day. The 22 feet per day is the average of the hydraulic conductivities from seven aquifer tests in Brazos County (Follett, 1973, Table 6).

On the basis of a transmissivity of 4,400 feet squared per day and a hydraulic gradient of 6 feet per mile, the quantity of water that originally moved as recharge through the Sparta Sand across the 18-mile length of the aquifer at the Grimes County-Madison County line was about 3.5 mgd. Of this amount, about 3 mgd is estimated to be presently available for use, as probably not more than 0.5 mgd is being pumped from the Sparta in parts of Madison and Leon Counties, through which water in the Sparta moves enroute to Grimes County.

The areas most favorable for development of fresh to slightly saline ground water from the Sparta are those areas where the sand thicknesses are large. In Grimes County, the largest accumulation of sand is in the northern part of the county where the thickness of sand containing fresh to slightly saline water exceeds 200 feet. About 12 miles south of this area, the thickness of sand containing fresh to slightly saline water diminishes to zero (Figure 20).

Yegua Formation

Fresh to slightly saline water is available from the Yegua Formation in an area of 360 square miles in the northern half of the county. Navasota, Roans Prairie, and Shiro are near the downdip limit of the slightly saline water. Only a part of the total amount of fresh to slightly saline water is fresh. The fresh water in the aquifer is available in an area of about 170 square miles of the outcrop and a few miles downdip (Figures 6 and 21). Although the aquifer presently yields only small to moderate amounts of water to wells, it is capable of yielding more than 500 gpm.

The amount of fresh to slightly saline water that is available from the Yegua can be approximated from the amount of water that originally moved through the aquifer as recharge prior to well development. The original hydraulic gradient in the Yegua in Grimes County was assumed to be 5 feet per mile, which is the same as the present gradient (Figure 13). The average transmissivity of the sand containing fresh to slightly saline water is 3,100 feet squared per day. This was derived from an average sand thickness of 375 feet at the southern limit of the Yegua outcrop (Figure 21) and from a hydraulic conductivity of 8.3 feet per day.

On the basis of a transmissivity of 3,100 feet squared per day and on a hydraulic gradient of 5 feet per mile, the quantity of water that originally moved through the Yegua across the 25-mile length of the aquifer near the southern limit of the Yegua outcrop was about 3 mgd. All of this amount is considered to be available for use in Grimes County, because less than 0.1 mgd is being pumped from the Yegua in Grimes County and from parts of Madison and Brazos Counties through which the water moves enroute to Grimes County.

The area most favorable for development of fresh to slightly saline ground water from the Yegua is between Bedias and lola, where more than 400 feet of sand occurs in an area of 8 to 10 square miles. Favorability decreases south of this area where the thickness of sand gradually diminishes to zero (Figure 21).

Jackson Group

Fresh to slightly saline water is available from the Jackson Group in an area of about 500 square miles in the central part of the county. Most of the towns in the county, except Cross, Courtney, and Plantersville, are within this area. Of the total area of available fresh to slightly saline water, about 350 square miles is underlain by fresh water (Figures 8 and 22). The aquifer is capable of yielding more than 500 gpm of water to wells.

The amount of fresh to slightly saline water that is available from the Jackson can be approximated from the amount of water that originally moved through the aquifer as recharge prior to well development. The original hydraulic gradient in the Jackson Group was assumed to be 5 feet per mile. The average transmissivity of the sand containing fresh to slightly saline water in Grimes County is 2,500 feet squared per day. This was derived from an average sand thickness of 275 feet near the Jackson-Catahoula contact and from a hydraulic conductivity of 9.1 feet per day. The 9.1 feet per day is the average of two hydraulic conductivities estimated from specific capacities that were determined by Winslow (1950, p, 12) in Walker County.

On the basis of a transmissivity of 2,500 feet squared per day and on a hydraulic gradient of 5 feet per mile, the quantity of water that originally moved as recharge through the Jackson across the 24-mile length of the aquifer near the Jackson-Catahoula contact was about 2.2 mgd. All of this amount is considered to be available in Grimes County, because only 0.06 mgd was pumped from the Jackson in 1970.

The areas most favorable for development of fresh to slightly saline water from the Jackson Group are adjacent to the (outcrop of the aquifer on the south, where sand in excess of 250 feet thick is present. Favorability decreases south of this area as the sand thickness gradually diminishes to zero (Figure 22).

Catahoula Sandstone

Fresh to slightly saline water is available from the Catahoula Sandstone in an area of about 450 square miles mostly in the southern half of the county, Of this area, one-half is underlain by fresh water (Figures 10 and 23). The aquifer is capable of yielding more than 500 gpm of water to wells.

The amount of fresh to slightly saline water that is available from the Catahoula can be approximated from the amount of water that originally moved through the aquifer as recharge prior to well development. The original hydraulic gradient in the Catahoula was assumed to be 7 feet per mile, which is about the same as the present gradient. The average transmissivity of the sand containing fresh to slightly saline water is 5,000 feet squared per day. This was derived from an average sand thickness of 225 feet along a northeasterly line 20 miles long and 5 miles south of Navasota, and from an average hydraulic conductivity of 22 feet per day.

On the basis of a transmissivity of 5,000 feet squared per day and on a hydraulic gradient of 7 feet per mile, the quantity of water that originally moved as recharge through the Catahoula across the 20-mile length of the aquifer was about 5.2 mgd. Of this amount, about 4.5 mgd is considered to be available because only 0.71 mgd was pumped from the Catahoula in 1970.

The areas most favorable for the development of fresh to slightly saline ground water from the Catahoula are mostly several miles south of the Catahoula outcrop, where relatively thick deposits of sand occur. The thickest deposit (more than 250 feet) covers an area of about 35 square miles, 5 miles south of Navasota. A large area of thick sand (from 225 to 250 feet thick) surrounds this area and extends from Navasota and Courtney to the Montgomery County line; a small area of sand having a thickness greater than 225 feet, but less than 250 feet occurs in the southeastern corner of the county (Figure 23).

Fleming Formation

Fresh to slightly saline water is available from the Fleming Formation in an area of about 350 square miles mostly in the southern half of the county. All of this area is underlain by fresh water because nearly all of the water in the aquifer in the county is fresh. The aquifer is capable of yielding more than 500 gpm of fresh water to wells.

The amount of fresh water that is available from the Fleming can be approximated from the amount of water that originally moved through the aquifer as recharge prior to well development. The original hydraulic gradient in the Fleming was assumed to be 7 feet per mile, which is the same as the present gradient (Figure 13). The average transmissivity of the sand containing fresh water is 34,500 feet squared per day. This was derived from an average sand thickness of 300 feet along a northeasterly line 20 miles long from the southwestern corner of the county through Plantersville, and from an average hydraulic conductivity of 115 feet per day.

On the basis of a transmissivity of 34,500 feet squared per day and a hydraulic gradient of 7 feet per mile, the quantity of water that originally moved as recharge through the Fleming across the 20-mile length of the aquifer was about 36 mgd. All of this amount is considered to be available in Grimes County, because only 0.46 mgd was pumped from the Fleming in the county in 1970.

The area most favorable for development of fresh ground water from the Fleming is in the southeastern corner of the county where sand in excess of 450 feet thick is present. Favorability decreases north of this area as the sand thickness gradually diminishes to zero at the northern limit of outcrop of the Fleming (Figure 24).

Willis Sand and Terrace Deposits

The amount of water that could be pumped on a long-term basis from the Willis Sand and terrace deposits was not determined, because these aquifers are able to yield water only in a relatively small area of the county. They are not likely to be utilized to a significant extent in the future, because more productive aquifers underlie them at shallow depths.

Fresh water is available from the Willis in about 85 square miles of its outcrop, where sufficient saturated thickness is present to yield water to wells. Maximum potential yields to wells would be less than 50 gpm.

Fresh water is available in places from the terrace deposits. The only known deposit that has sufficient saturated thickness to yield water to wells is in and near Navasota. Although pits dug into the deposit have been reported to yield large quantities of water, drilled wells probably are capable of yielding less than 300 gpm.

Flood-Plain Alluvium

Fresh water is available from the flood-plain alluvium in an area of about 20 square miles south of the town of Navasota along the Brazos River and near the mouth of the Navasota River. Elsewhere in the county, the alluvium is not known to contain water in sufficient amounts for development.

The amount of water that is available from the flood-plain alluvium on a long-term basis without depleting the supply depends upon the rate of recharge or replenishment of the aquifer. Cronin and Wilson (1967, p, 44), in their comprehensive study of ground water in the flood-plain alluvium of the Brazos River, estimated recharge by using the procedure described by Keech and Dreeszen (1959, p. 45-48), in which the difference in ground-water flows estimated between the upstream and downstream sections of saturated alluvium between two successive flow lines is equal to the estimated infiltration by precipitation.

On this basis, the estimated annual recharge at six locations along the Brazos River upstream from Grimes County averaged slightly more than 3.0 inches, or, in general, somewhat less than 10 percent of the annual precipitation. Cronin, Shafer, and Rettman (1963, p. 119), also estimated recharge to the alluvium of the Brazos River upstream and downstream from Grimes County on the basis of water-level fluctuations. The amount of recharge per square mile was computed to be about 177 acre-feet, or a little less than 3 1/2 inches per year. On the basis of an annual recharge rate of 177 acre-feet per square mile, the amount of water that can be pumped frorn the flood-plain alluvium in Grimes County on a long-term basis without clepleting the supply is 3,500 acre-feet per year or about 3 mgd.

Pumping of water in excess of 3 mgd in some years would cause a lowering of the water table in excess of the normal but temporary lowering due to pumping. This excess lowering could be offset if the period of overdraft is followed by periods of above-normal rainfall when recharge would increase and pumpage would decrease. However, continuous withdrawals of ground water in excess of recharge would result in a lowering of the water table accompanied by a decrease in the yield of the wells due to the decrease in thickness of the water-bearing materials.

The areas rnost favorable for the development of large quantities of water from the flood-plain alluvium south of Navasota are mostly in those areas where the saturated thicknesses are large. Sufficient data on saturated thicknesses are not available to define such areas; consequently, test drilling is recommended to locate optimum well sites. Wells located at favorable sites may be expected to yield about 1,500 gpm.

Conclusions

The ground-water resources of Grimes County are almost entirely undeveloped. A total of 52 mgd of fresh to slightly saline water is available from the Sparta Sand, Yegua Formation, Jackson Group, Catahoula Sandstone, Fleming Formation, and flood-plain alluvium on a long-term basis without depleting the supply. In addition, smaller but undetermined amounts of fresh to slightly saline water are available from the Carrizo, Queen City, and Willis Sands and from the terrace deposits. Drilled wells that are properly constructed in any of the aquifers except the Willis Sand and terrace deposits could be expected to yield more than 500 gpm.

NEEDS FOR CONTINUED DATA COLLECTION

The collection of basic data, such as an inventory of pumpage, observation of water levels, and analysis of water samples should be continued in the county. Without these data, inaccurate computations regarding ground-water development could lead to improper well construction, improper spacing of wells, overpumping of aquifers, and excessive interference with existing developments. Whenever accurate computations are made for the development of ground-water supplies, everyone concerned will have a better realization of the relatively large magnitude of the available ground-water supplies and, hence, more confidence in the utilization of the ground water to its fullest extent.

Prior to the time of the field work for this study, Grimes County had not been included in the State-wide observation-well program in which periodic measurements of water levels are made in selected wells. An observation well program is recommended for the future so that trends in water levels will be established prior to any future large scale development. Selected observation wells in the Catahoula Sandstone, Fleming Formation, and flood-plain alluvium would be very useful. Observation wells in the Yegua and Jackson Formations would be of secondary importance.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report was developed by the Texas Water Development Board for use throughout the State. Under this system, each l-degree quadrangle in the State is given a number consisting of two digits. These are the first two digits in the well number. Each l-degree quadrangle is divided into

7½-minute quadrangles that are given two-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7½-minute quadrangle is subdivided into 2½-minute quadrangles and given a single digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2½-minute quadrangle is given a two-digit number in the order in which it is inventoried, starting with 01. These are the last two digits of the well number (Figure 25). Only the last three digits of the well numbers are shown near the well symbols on the well location map (Figure 26); the second two digits are shown in or near the northwest corner of each 7½-minute quadrangle; and the first two digits are shown by the large block numbers 59 and 60. In addition to the seven-digit well number, a two-letter prefix (KW) is used to identify the county.

DEFINITIONS OF TERMS

In this report certain technical terms, including some that are subject to different interpretations, are used. For convenience and clarification, these terms are defined as follows:

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

Acre-foot per year.—One acre-foot per year equals 892.13 gallons per day.

Aquifer.—A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

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 relationships 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, hydraulic conductivity, transmissivity, and storage coefficient.

Artesian aquifer, confined aquifer.—Artesian (confined) water occurs where an aquifer is overlain by rock of lower hydraulic conductivity (e.g., clay) that confines the water under pressure greater than atmospheric. The water level in an artesian well will rise above the level at which it was first encountered in the well. The well may or may not flow.

Brine.—Water containing more than 35,000 mg/l dissolved solids (Winslow and Kister, 1956, p. 5).

Cone of depression.—Depression of the water table or potentiometric surface surrounding a discharging well or group of wells and is more or less shaped as an inverted cone.

Dip or rocks, attitude of beds.—The angle or amount of slope at which a bed is inclined from the horizontal; direction is also expressed (for example 1 degree southeast; or 90 feet per mile southeast).

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

Electric log.—A graph showing the relation of the electrical properties of the rocks and their fluid contents 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.

Fresh water.—Water containing less than 1,000 mg/l dissolved solids (Winslow and Kister, 1956, p. 5).

Ground water.—Water in the ground that is in the saturated zone from which wells, springs, and seeps are supplied.

Head, static.—The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point.

Hydraulic gradient.—The change in static head per unit of distance in a given direction.

Hydraulic conductivity.—The rate of flow of a unit volume of water in unit time at the prevailing kinematic viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head over unit length of flow path. Formerly called field coefficient of permeability.

Moderately saline water.—Water containing 3,000 to 10,000 mg/l dissolved solids (Winslow and Kister, 1956, p. 5).

Potentiometric surface.—A surface which represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface.

Slightly saline water.—Water containing 1,000 to 3,000 mg/l dissolved solids (Winslow and Kister, 1956, p. 5).

Specific capacity.—The rate of discharge of water from a well divided by the drawdown of water level in the well. It is generally expressed in gallons per minute per foot of drawdown.

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

Transmissivity.—The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is the product of the hydraulic conductivity and the saturated thickness of the aquifer. Formerly called coefficient of transmissibility.

Very saline water.—Water containing 10,000 to 35,000 mg/l dissolved solids (Winslow and Kister, 1956, p. 5).

Water level; static level, or hydrostatic level.—In an unconfined aquifer, the distance from the land surface to the water table. In a confined (artesian) aquifer, the level to which the water will rise either above or below land surface.

Water table.—That surface in an unconfined water body at which the pressure is atmospheric.

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.

Yield.—The rate of discharge, commonly expressed as gallons per minute, gallons per day, or gallons per hour. In this report, yields are classified as small, less than 50 gpm (gallons per minute); moderate, 50 to 500 gpm; and large, more than 500 gpm.

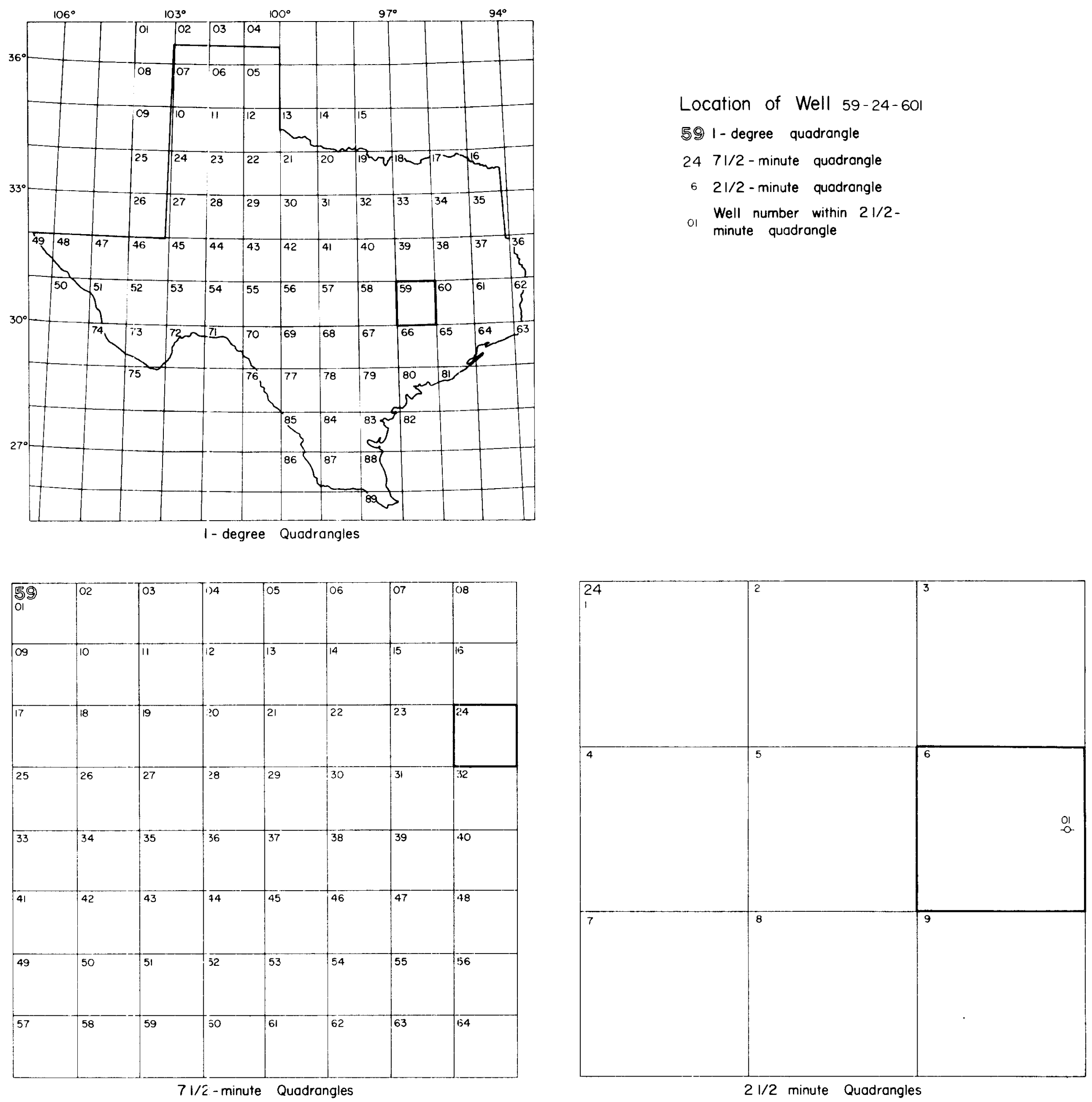


Figure 25

Well-Numbering System

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Table 9.—Drillers' Logs of Wells

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-16-402		
Owner: M. D. Nevill Driller: Carl Ryan Drilling Co.		
Shale	162	162
Sand	13	175
Shale	9	184
No record	1	185
Well KW-59-16-403		
Owner: A. C. Denman Driller: Carl Ryan Drilling Co.		
Shale	189	189
Sand	7	196
Shale	9	205
Shale	215	420
Sand	20	440
Shale, sandy	31	471
Well KW-59-16-502		
Owner: J. D. Akers Driller: Carl Ryan Drilling Co.		
Shale	62	62
Sand	58	120
Shale	18	138
Sand	7	145
Shale	173	318
Sand	20	338
Well KW-59-16-803		
Owner: Iola Water Co. Driller: Baker & Bradford		
Shale	170	170
Sand, iron water	40	210
Shale	350	560
Sand, good water	30	590
Well KW-59-16-901		
Owner: Pete Adams Driller: Carl Ryan Drilling Co.		
Shale	144	144
Sand and shale	18	162

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-16-901—Continued		
Sand	2	164
Shale	136	300
Sand	8	308
No record	10	318
Well KW-59-16-902		
Owner: B. I. Cole Driller: Neal Drilling Co.		
Sand	4	4
Clay	16	20
Sand	15	35
Shale, blue	45	80
Shale, gray	45	125
Sand	12	137
Shale, gray	83	220
Shale, sandy	55	275
Shale, gray	5	280
Sand	15	295
Shale, gray	8	303
Shale, sandy	17	320
Shale, blue	40	360
Sand	5	365
Shale, blue	15	380
Sand	14	394
Shale, gray	8	402
Sand	28	430
Shale, gray	20	450
Sand	3	453
Shale, gray	47	500
Shale, sandy	10	510
Shale, gray	5	515
Shale, sandy	5	520
Shale, gray	40	560
Shale, sandy	10	570
Shale, gray	70	640
Sand	40	680

Well KW-59-24-301

Owner: R. C. Churnsides
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface, clay	33	33
Clay and rock	23	56
Sand	15	71
Clay	230	301
Clay, broken and sand	22	323
Clay	60	383
Broken	7	390
Sand	28	418
Shale	2	420

Well KW-59-24-402

Owner: Ray T. Trant
Driller: Carl Ryan Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Shale	297	297
Sand	3	300
Shale and sand	28	328

Well KW-59-24-501

Owner: A. E. Woods
Driller: Carl Ryan Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	50	50
Sand	10	60
Shale	92	152
Rock	1	153
Shale	27	180
Shale	17	197
Sand	8	205
Shale	207	412
Sand	10	422
Shale	8	430

Well KW-59-24-702

Owner: A. M. Flynt
Driller: Carl Ryan Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	30	30
Sand	5	35
Shale	5	40

Well KW-59-24-702—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Shale, sandy	20	60
Shale	160	220
Sand	30	250
Shale, sandy	10	260
Shale	78	338
Sand	12	350
Shale	35	385
Sand, shaly	20	405
Shale, sandy	10	415
Shale	12	427
Sand	11	438
Shale	11	449

Well KW-59-24-902

Owner: R. S. Butaud
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Surface	0	0
Sand	12	12
Rock	9	21
Lignite	1	22
Rock	14	36
Shale, brown	10	46
Shale, brown, hard	28	74
Shale, gray	26	100
Shale, green	25	125
Lignite	7	132
Rock	3	135
Sand, blue	27	162

Well KW-59-32-201

Owner: William Buchman
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Clay, red	3	3
Shale, brown	15	18
Sand	2	20
Shale, blue	85	105
Shale, brown, and lignite	25	130

Table 9.—Drillers' Logs of Wells—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-32-201—Continued		
Shale, blue	10	140
Sand, blue, water	15	155

Well KW-59-32-202

Owner: Tony Kolbachinski
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Sand	12	12
Shale, blue, rocky	33	45
Shale, brown	29	74
Sand, blue	10	84
Rock	6	90
Shale, hard, blue	38	128
Sand, blue, water	12	140

Well KW-59-32-302

Owner: L. E. Fuller
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	30	30
Rock	2	32
Rock and clay	16	48
Sand	6	54
Clay	24	78
Clay	5	83
Sand	17	100
Clay	37	137
Shale, clay, and lignite	7	144
Clay and lignite	6	150
Sand	7	157
Broken	10	167
Shale	22	189
Shale and sand streaks	22	211
Shale, sandy	23	234
Shale	17	251
Rock	3	254
Sand, broken	3	257
Sand	5	262
Clay	17	279
Shale and rock	19	298

Well KW-59-32-302—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Sand	8	306
Clay	152	458
Clay	22	480
Clay	22	502
Shale	8	510
Sand	14	524
Sand	7	531
Broken	15	546

Well KW-59-32-502

Owner: P. T. Green
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Clay, red	4	4
Shale, gray	12	16
Lignite	4	20
Sand, fine	12	32
Rock	2	34
Shale, blue	34	68
Sand, blue	12	80

Well KW-59-32-706

Owner C. C. Arrington, Jr.
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, rock, clay and sand	34	34
Sand and lignite	22	56
Clay, lignite, and sand	45	101
Clay	22	123
Clay and lignite	15	138
Sand	30	168
Clay and rock	22	190
Sand, broken, clay, and rock	45	235
Clay and rock	23	258
Sand rock, broken—top 6' lignite	23	281
Lignite and clay	22	303
Clay	3	306
Sand	15	321
Clay	4	325
Clay and rock	46	371

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-32-706—Continued		
Clay, rock, hard	45	416
Clay, lignite, blue	23	439
Clay, rock	22	461
Clay	89	550
Clay, rock	44	594
Clay	45	639
Sand, fine and broken	22	661
Sand	9	670
Clay	5	675

Well KW-59-32-707

Owner: Gilbert Husfeld
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, clay and sand	23	23
Sand	7	30
Clay and rock	16	46
Shale, sandy, hard	23	69
Clay with streaks of lignite	22	91
Clay	10	101
Sand	19	120
Clay	9	129
Sand	3	132
Clay and broken sand	25	157
Clay	47	204
Sand	20	224

Well KW-59-32-801

Owner: Sam F. Busa
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Clay	4	4
Shale, gray	18	22
Shale, blue	24	46
Rock, hard	2	48
Shale, hard, blue	16	64
Rock, hard	10	74
Shale, blue	56	130
Sand, hard, blue	12	142

Well KW-59-32-802

Owner: Jeff Moody
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	175	175
Rock	20	195
Clay	80	275
Sand	45	320
Sand	27	347
Clay (rock 347)	33	380
Sand	120	500
Sand	34	534

Well KW-59-32-901

Owner: David O. Dickinson
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Shale, gray, hard	22	22
Shale, blue	10	32
Sand, blue	4	36
Shale, blue, hard	2	38
Rock	3	41
Shale, blue, hard	59	100
Sand, white, water	28	128

Well KW-59-40-102

Owner: Jasper Hughes
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Rock, maral	33	33
Shale and rock	67	100
Shale and clay	23	123
Shale, hard streaks	67	190
Shale and rock	45	235
Clay	15	250
Broken, hard	7	257
Sand	23	280

Well KW-59-40-201

Owner: Eugene Green
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Black land	2	2
Shale, gray	9	11

Table 9.—Drillers' Logs of Wells—Continued

Well KW-59-40-201—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Rock	2	13
Shale, gray	17	30
Rock	9	39
Shale, gray	13	52
Shale, blue	16	68
Shale, blue, brittle	17	85
Shale, blue, rocky	43	128
Sand, water, gray	12	140

Well KW-59-40-202

Owner: Adams and Thomas
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, clay and maral rock	34	34
Clay	22	56
Clay and rock	22	78
Clay	15	93
Sand	7	100
Shale, sandy	45	145
Shale, with streaks of rock	23	168
Shale, with streaks of rock	32	200
Clay	12	212
Broken	6	218
Sand	22	240

Well KW-59-40-301

Owner: Eugene Green
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Shale, hard, gray	24	24
Shale, blue	62	86
Rock, hard	2	88
Shale, blue	8	96
Sand, blue, water	12	108

Well KW-59-40-302
(Partial log)

Owner: Dr. R. H. Hooper
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Old hole—no record		347
Sand, broken	26	373

Well KW-59-40-302—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Rock and clay	122	495
Sand	25	520

Well KW-59-40-303

Owner: Robert Falkenbury
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay and sand	71	71
Sand	22	93
Clay	74	167
Clay, sandy	45	212
Sand, broken	23	235
Shale, sandy	21	256
Shale	88	344
Sand	12	356
Shale and rock	103	459
Clay, sandy	23	482
Clay	15	497
Sand	20	517

Well KW-59-40-404

Owner: L. L. Prause
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay and sand	23	23
Shale	113	136
Clay	45	181
Shale	94	275
Sand	5	280
Shale and clay	112	392
Rock and broken sand	12	404
Clay and rock	112	516
Sand, broken	10	526
Sand	36	562

Well KW-59-40-501

Owner: Ira Floyd Jr.
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and clay and rock	34	34
Shale, blue	45	79

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-40-501—Continued		
Clay	45	124
Sand, broken	6	130
Sand	22	152
Sand, broken and shale	17	169

Well KW-59-40-502

Owner: Jack Baker
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	57	57
Rock, clay streaks	21	78
Clay and rock, bottom sand, gravel	10	88
Sand, bottom sand and gravel	23	111
Clay and rock	5	116
Sand, clay, and rock	7	123
Shale, broken	22	145
Clay and rock	22	167
Clay	33	200
Sand	10	210
Shale	2	212

Well KW-59-40-601

Owner: W. D. Purvis
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay and soil	15	15
Clay	5	20
Rock	18	38
Rock	7	45
Rock	15	60
Clay	7	67
Sand, broken and clay	23	90
Sand, broken	22	112
Sand	23	135

Well KW-59-40-702

Owner: City of Navasota
Driller: Layne Texas Co.

	THICKNESS (FEET)	DEPTH (FEET)
Soil, black	4	4
Clay, yellow	125	129
Sand, hard	6	135
Well KW-59-40-702—Continued		
Shale, sandy, hard	18	153
Shale, soft	19	172
Sand, hard	4	176
Sand and gravel	25	201
Shale	4	205
Packsand, hard, shale, blue	44	249
Shale hard and sand layers	21	270
Shale, hard	9	279
Shale, hard and sand layers	13	292
Shale, hard	20	312
Shale, hard, sandy	10	322
Shale, hard	26	348

Well KW-59-40-705

Owner: City of Navasota
Driller: Layne Texas Co.

	THICKNESS (FEET)	DEPTH (FEET)
Soil and clay	15	15
Lime, sandy, hard	30	45
Shale, hard and gravel	9	54
Rock	7	61
Shale, hard	28	89
Sand with shale breaks	21	110
Shale, hard	29	139
Sand, coarse-grained	30	169
Sand, hard	4	173
Shale, hard	21	194

Well KW-59-40-706
(Partial log)

Owner: City of Navasota
Driller: —

	THICKNESS (FEET)	DEPTH (FEET)
Soil, black, clay, (Fleming) and sandstone (Catahoula)	6	6
Clay, joint	10	16
Sandstone	16	32
Clay, potter's	9	41
Quicksand	80	121
Sandstone	10	131
Sand	8	139

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-40-706—Continued		
Gravel	12	151
Gravel and clay	14	165
Sandstone	10	175
Clay	15	190
Sandstone and sand	120	310
No record	520	830

Well KW-59-40-707

Owner: City of Navasota well 11
Driller: Layne Texas Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	15	15
Sand	20	35
Clay	165	200
Sand	55	255
Shale and sand layers	60	315

Well KW-59-40-708

Owner: City of Navasota well 12
Driller: Layne Texas Co.

	THICKNESS (FEET)	DEPTH (FEET)
Soil and clay	10	10
Caliche and clay	45	55
Shale	35	90
Caliche and shale	51	141
Sand, hard	14	155
Shale	27	182
Sand and shale	20	202
Shale	11	213
Sand	7	220
Shale	2	222
Sand	8	230
Shale	10	240
Sand, fine	16	256
Shale	11	267
Sand and shale	8	275
Shale	22	297
Shale and sand streaks	28	325
Shale	5	330
Shale and sand streaks	15	345
Well KW-59-40-708—Continued		
Sand	9	354
Shale and sandy shale	29	383
Shale, fine and sand streaks	34	417
Shale	18	435
Sand, fine and shale streaks	13	448
Shale and sandy shale	33	481
Shale, sandy	53	534
Shale	11	545
Shale, sandy and shale	113	658
Sand	31	689
Shale and sandy shale	33	722
Shale, sandy	40	762
Shale, and sandy shale	93	855
Shale and sand streaks	13	868
Shale and sandy shale	74	942
Sand, fine, gray	15	957
Shale	27	984
Shale, sandy and shale	51	1,035
Sand, fine	10	1,045
Shale, and sandy shale	111	1,156
Shale, sandy	35	1,191
Sand, fine, white	23	1,214
Shale	12	1,226

Well KW-59-40-709

Owner: City of Navasota
Driller: Layne Texas Co.

	THICKNESS (FEET)	DEPTH (FEET)
Soil	5	5
Clay	11	16
Sand and gravel	18	34
Caliche, clay	19	53
Clay and sand streaks	48	101
Clay	17	118
Clay, sooty	27	145
Clay	3	148
Sand, broken	42	190
Clay	11	201

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-40-709—Continued		
Clay, sandy and sand streaks	16	217
Sand, broken	28	245
Shale, sandy and sand streaks	38	283
Sand, fine	13	296
Shale, sandy	12	308

Well KW-59-40-801

Owner: Don Davis
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and sand	22	22
Clay	11	33
Broken	12	45
Clay and rock	11	56
Clay	45	101
Sand	10	111
Clay	35	146
Sand and rock	15	161
Clay	8	169
Clay, broken last 5 ft.	22	191
Sand	21	212

Well KW-59-40-901

Owner: C. M. Monday
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and clay	70	70
Sand	30	100
Clay and rock	115	215
Sand	16	231

Well KW-59-40-902

Owner: Preston Nobles
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Sand	34	34
Clay and sand	67	101
Clay and rock	76	177
Clay, broken, sand and rock	34	211
Clay	79	290
Sand	8	298

Well KW-59-40-903

Owner: James Evans
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, sand and clay	34	34
Sand and rock and clay	22	56
Sand and rock	10	66
Clay	23	89
Sand, broken	12	101
Clay	44	145
Sand	15	160
Clay and rock	31	191
Shale, sandy (rock 220-223)	45	236
Clay	45	281
Sand with clay streaks	24	305

Well KW-59-47-303

Owner: Moore Brothers
Driller: Rouse Exploration Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Sand, hard	2	2
Clay	12	14
Sand and gravel	31	45
Clay	95	140
Gravel and rock	6	146
Shale, green	14	160
Gravel	8	168
Shale, sandy, green	16	184
Sand, coarse-grained	56	240
Gravel	8	248
Shale, green and limestone	34	282
Sand	8	290
Shale, green	14	304
Sand	12	316
Shale, green	23	339
Sand	1	340
Limestone	5	345
Sand	40	385
Shale	20	405
Sand	18	423

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-47-303—Continued		
Shale	2	425
Sand	13	438
Sand and shale streaks	8	446

Well KW-59-47-309

Owner: Tommie Holidy
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Soil	20	20
Sand and gravel	15	35
Clay, white and hard	30	65
Clay and gravel	21	86
Clay	21	107
Shale, white	108	215
Shale and rock	21	236
Shale, sandy	43	279
Sand	21	300
Shale	87	387
Shale, sandy, broken	128	515
Shale (rock 589-594)	85	600
Clay, sandy, blue	31	631
Sand, fine	11	642
Shale	115	757
Shale, sandy, blue	11	768
Shale	74	842
Sand and shale, broken	11	853
Shale	106	959
Clay	21	980
Shale	21	1,001
Clay	42	1,043
Shale and sand, broken	52	1,095
Shale	95	1,190
Shale and clay	84	1,274
Clay	126	1,400
Sand	17	1,417

Well KW-59-48-106
(Partial log)

Owner: City of Navasota well 15
Driller: Layne Texas Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil	15	15
Sand	17	32
Sand	13	45
Sand	35	80
Shale, sandy and sand streaks	10	90
Shale, hard	32	122
Shale, hard	67	189
Shale	89	278
Sand	20	298
Shale	5	303
Shale	17	320
Sand	20	340
Shale	10	350
No record	8	358

Well KW-59-48-108

Owner: Jimmie Wilson
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and clay	34	34
Sand and gravel	9	43
Clay and rock	12	55
Sand with clay streaks	10	65
Clay and rock	192	257
Clay, sandy, broken	44	301
Clay and rock	88	389
Sand, broken and clay	67	456
Sand, fine	15	471
Clay	5	476
Sand	4	480

Well KW-59-48-109

Owner: Ed Warzon
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and clay	15	15
Sand and gravel	33	48

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-48-109—Continued		
Clay and rock	118	166
Sand, broken	45	211
Sand	15	226
Well KW-59-48-110		
Owner: Gerald McAlexander Driller: Pomykal Drilling Co.		
Sand	5	5
Clay	13	18
Sand	60	78
Rock and clay	6	84
Well KW-59-48-201		
Owner: Hackney Iron and Steel Co. Driller: Falkenbury Drilling Co.		
Clay	18	18
Sand	22	40
Clay	39	79
Sand	16	95
Clay	28	123
Sand, broken	23	146
Sand	31	177
Well KW-59-48-204		
Owner: Johnny Sache Driller: Falkenbury Drilling Co.		
Surface, clay and sand	23	23
Clay, sandy	10	33
Sand	13	46
Sand and gravel	27	73
Well KW-59-48-301		
Owner: Moody & Clary Driller: Falkenbury Drilling Co.		
Surface soil, sand, clay	33	33
Sand and clay	44	77
Clay	19	96
Rock	4	100
Sand with clay streaks	22	122

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-48-301—Continued		
Sand	10	132
Clay	13	145
Sand, clay, broken and rock	22	167
Sand, broken	45	212
Clay	113	325
Well KW-59-48-501		
Owner: Trinston Harris Driller: Falkenbury Drilling Co.		
Soil and rock and clay and sand	34	34
Clay, broken, rock and sand	22	56
Clay and streaks, sand	22	78
Clay, broken, rock, and sand	22	100
Clay and rock	22	122
Clay	6	128
Sand (rock 134)	16	144
Sand, broken and clay	22	166
Sand, broken and rock (176)	23	189
Sand	5	194
Clay, rock (210)	17	211
Broken	14	225
Rock and sand	8	233
Sand	14	247
Well KW-59-48-503		
Owner: Joe Mike Batts Driller: Falkenbury Drilling Co.		
Sand, rock and clay	23	23
Clay and rock	35	58
Rock	20	78
Sand, broken and clay	34	112
Clay	22	134
Sand	6	140
Clay and rock	17	157
Sand	5	162
Clay	32	194
Sand	31	225

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-48-601		
Owner: Albin Finke Driller: Falkenbury Drilling Co.		
Surface, sand and clay	33	33
Clay and rock	95	128
Sand and rock	30	158
Well KW-59-48-602		
Owner: Albin Finke Driller: Falkenbury Drilling Co.		
Surface, sand and clay	23	23
Sand, broken	22	45
Clay	90	135
Sand, broken, clay and rock	25	160
Sand	20	180
Well KW-59-48-603		
Owner: Stone Binford Driller: Falkenbury Drilling Co.		
Clay, surface	18	18
Rock	2	20
Sand	14	34
Sand, broken and rock	34	68
Clay	93	161
Sand	27	188
Well KW-59-48-706		
Owner: James E. Lyon Driller: Falkenbury Drilling Co.		
Clay and silt	38	38
Sand, broken	8	46
Sand and gravel	27	73
Clay and rock	3	76
Sand	14	90
Clay	23	113
Well KW-59-48-804		
Owner: James E. Lyon Driller: Falkenbury Drilling Co.		
Soil	15	15
Sand, fine, red	5	20
Well KW-59-48-804—Continued		
Clay, red	31	51
Gravel, sandy	10	61
Rock and clay	11	72
Clay, sandy	9	81
Sand, red (rock at bottom)	33	114
Clay, sandy	15	129
Rock	5	134
Clay	17	151
Sand	17	168
Clay	26	194
Sand and rock	15	209
Clay	13	222
Sand, blue	16	238
Shale	52	290
Clay	33	323
Shale, sandy	63	386
Clay	64	450
Shale, sandy	12	462
Clay and caliche, hard	39	501
Clay, white	61	562
Clay and shale	23	585
Clay, rocky, hard	75	660
Clay	35	695
Sand, blue	52	747
Clay	64	811
Sand, blue	10	821
Clay and rock	37	858
Rock	3	861
Sand	21	882
Clay	3	885
Well KW-59-48-805		
Owner: Navasota School District Driller: Falkenbury Drilling Co.		
Surface, sand and clay	34	34
Clay	16	50
Sand	4	54

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-48-805—Continued		
Clay and rock	60	114
Sand, broken	9	123
Sand and rock	22	145
Sand	13	158
Well KW-59-48-806		
Owner: James E. Lyon Driller: Falkenbury Drilling Co.		
Clay	53	53
Sand and gravel	15	68
Gravel	3	71
Clay and rock	24	95
Sand	23	118
Clay	17	135
Well KW-59-48-807		
Owner: James E. Lyon Driller: Falkenbury Drilling Co.		
Clay	35	35
Sand	10	45
Gravel	29	74
Rock	2	76
Clay	14	90
Sand	20	110
Clay	3	113
Well KW-59-48-809		
Owner: James E. Lyon Driller: Falkenbury Drilling Co.		
Clay and silt	33	33
Sand and gravel	25	58
Clay	35	93
Sand	27	120
Clay	15	135
Well KW-59-48-901		
Owner: Roy S. Weaver Sr. Driller: Falkenbury Drilling Co.		
Clay and sand rock	37	37
Clay and rock	43	80

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-59-48-901—Continued		
Sand and rock	23	103
Rock and clay	23	126
Clay	22	148
Clay and rock	15	163
Sand and rock	31	194
Sand	8	202
Well KW-59-48-903		
Owner: Binford Weaver Driller: Falkenbury Drilling Co.		
Clay	70	70
Sand, broken	17	87
Clay	73	160
Sand	26	186
Well KW-59-56-301		
Owner: Alfred C. Glassell Jr. Driller: Falkenbury Drilling Co.		
Clay and sand	33	33
Sand	54	87
Clay	58	145
Sand, broken	22	167
Clay	48	215
Sand	49	264
Clay	17	281
Sand	12	293
Well KW-60-09-201		
Owner: Simes Landers Driller: Carl Ryan Drilling Co.		
Shale	171	171
Sand and shale streaks	32	203
Sand streaks	54	257
Sand	7	264
Sand	43	307
Well KW-60-09-301		
Owner: Darl R. Sanders Driller: Neal Drilling Co.		
Shale	78	78
Sand	2	80

Table 9.—Drillers' Logs of Wells—Continued

Well KW-60-09-301—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Shale	40	120
Shale, sandy	20	140
Lignite	5	145
Shale, sandy	18	163
Sand	10	173
Shale	11	184
Sand	11	195
Shale	48	243
Sand	7	250
Shale, sandy	8	258
Sand	4	262
Shale, sandy	20	282
Sand	58	340

Well KW-60-09-401

Owner: N. T. Price
Driller: Bradford Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Sand, surface	4	4
Shale, blue	76	80
Sand	3	83
Shale	87	170
Sand	12	182
Shale, blue	470	652
Sand, blue	20	672

Well KW-60-09-502

Owner: R. L. Upchurch
Driller: Bradford Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Shale	150	150
Sand	5	155
Shale	117	272
Sand	20	292

Well KW-60-09-601

Owner: L. B. Segler
Driller: Neal Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay, brown	40	40
Shale, gray	62	102
Shale, sandy	8	110

Well KW-60-09-601—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Shale, gray	30	140
Shale, sandy	7	147
Shale, blue	10	157
Shale, sandy	3	160
Shale, gray	48	208
Sand	6	214
Lignite	4	218
Sand	2	220
Shale, sandy	80	300
Shale, gray	40	340
Shale, brown	48	388
Sand	32	420
Shale, gray	20	440

Well KW-60-09-702

Owner: W. R. Surface
Driller: Neal Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Topsoil	11	11
Shale	35	46
Sand	6	52
Shale, sandy	18	70
Sand	6	76
Shale, sandy	10	86
Sand	10	96
Shale	48	144
Shale, sandy	42	186
Shale	14	200
Shale, sandy	40	240
Shale	30	270
Sand	24	294

Well KW-60-09-703

Owner: Luther Tyer
Driller: Carl Ryan Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Shale	90	90
Sand	16	106
Shale	134	240
Sand	6	246

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-09-703—Continued		
Shale, sandy	143	389
Shale	51	440
Sand	30	470
Well KW-60-09-704		
Owner: W. R. Surface Driller: Neal Drilling Co.		
Clay	40	40
Shale, blue	140	180
Shale, sandy	15	195
Shale, gray	25	220
Shale, blue	30	250
Sand	10	260
Shale, gray	15	275
Sand	9	284
Shale, gray	16	300
Well KW-60-09-801		
Owner: Bedias Water Co. Driller: Carl Ryan Drilling Co.		
Shale	340	340
Sand	15	355
Shale and sand streaks	25	380
Sand	5	385
Shale	30	415
Sand	77	492
Well KW-60-09-804		
Owner: Mary Barnes Driller: Carl Ryan Drilling Co.		
Shale	246	246
Sand	8	254
Shale	81	335
Sand	14	349
Shale	114	463
Sand	8	471
Shale	35	506
Sand	13	519
Sand and shale	20	539

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-09-805		
Owner: Will D. Smith Driller: Bradford Drilling Co.		
Shale	180	180
Sand	10	190
Shale	297	487
Sand	35	522
Well KW-60-10-401		
Owner: Ted O. Laws Driller: Bradford Drilling Co.		
Shale	175	175
Sand	11	186
Shale	272	458
Sand	25	483
Well KW-60-10-402		
Owner: J. O. Doan Driller: Bradford Drilling Co.		
Shale	180	180
Sand	10	190
Shale	300	490
Sand	25	515
Well KW-60-17-101		
Owner: J. K. Dyer Driller: Bradford Drilling Co.		
Shale	132	132
Sand	10	142
Shale	233	375
Sand	20	395
Well KW-60-17-302		
Owner: Aubrey Solomon Driller: Bradford Drilling Co.		
Shale	140	140
Sand	30	170
Shale	335	505
Sand	33	538

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-17-501		
Owner: E. C. Rigby Driller: Bradford Drilling Co.		
Shale	80	80
Sand	10	90
Shale	181	271
Sand	20	291
Well KW-60-17-801		
Owner: Mary Shook Driller: B. C. Kolbachinski		
Shale, rusty, rocky	40	40
Shale, hard, blue	28	68
Rock	3	71
Shale, brown and lignite	12	83
Shale, blue	55	138
Sand, blue, water	12	150
Well KW-60-17-802		
Owner: Keith E. Gorsuch Driller: Falkenbury Drilling Co.		
Sand, surface	10	10
Shale and clay	90	100
Sand	36	136
Well KW-60-17-803		
Owner: Bill Fulton Driller: B. G. & R. Drilling Co.		
Shale	41	41
Shale, sandy, lignite	20	61
Sand, lignite	31	92
Shale	10	102
Sand	15	117
Shale	26	143
Sand	10	153
Shale	93	246
Sand	4	250
Shale	13	263
Sand	16	279

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-17-803—Continued		
Shale	13	292
Lignite and rock	3	295
Sand	12	307
Well KW-60-18-101		
Owner: Earnest Johnson Driller: B. C. Kolbachinski		
Clay, red	4	4
Shale, sandy, brown	24	28
Shale and lignite	10	38
Shale, blue	30	68
Shale and lignite, dark brown	22	90
Shale, gray	34	124
Rock, hard	2	126
Shale, blue	12	138
Sand, blue, water	2	140
Well KW-60-25-201		
Owner: L. B. Floyd Driller: Falkenbury Drilling Co.		
Surface and sandstone	23	23
Marl, rock, and caliche	22	45
Shale	55	100
Sand	8	108
Rock	27	135
Sand rock	33	168
Clay	10	178
Sand, fine	17	195
Clay	7	202
Well KW-60-25-202		
Owner: Leslie Barber Driller: Falkenbury Drilling Co.		
Surface and maral rock	55	55
Shale	36	91
Sand	19	110

Well KW-60-25-203

Owner: Amelia Bookman
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Shale, gray, hard	45	45
Shale, blue	35	80
Shale, light blue	52	132
Sand, blue-green, water	8	140

Well KW-60-25-303

Owner: J. L. Francklow
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface, soil, clay, maral rock	34	34
Maral rock	22	56
Shale, blue and rock	67	123
Clay and rock	33	156
Sand	22	178

Well KW-60-25-501

Owner: J. S. Bracewell
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Clay	4	4
Shale, gray	34	38
Rock, gray	28	66
Shale, blue, hard	62	128
Rock	2	130
Shale, blue	60	190
Sand, blue, water	10	200

Well KW-60-25-503

Owner: Frank Szymczak
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Clay	3	3
Sand	1	4
Shale, gray	32	36
Sand	4	40
Shale, gray, sticky	20	60
Shale, light blue	36	96
Sand, brown, water	25	121

Well KW-60-25-504

Owner: H. P. Walkoviak
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Clay	3	3
Shale, gray	7	10
Rock	5	15
Shale, gray, sticky	55	70
Rock, sandy, soft	11	81
Shale, blue	39	120
Sand, blue, water	20	140

Well KW-60-25-702

Owner: Harold Huber
Driller: V. R. Bigham

	THICKNESS (FEET)	DEPTH (FEET)
Soil, black	180	180
Sand, water	6	186
Sand and shale, mixed	514	700
Sand, water	46	746

Well KW-60-25-703

Owner: B. L. Sullivan
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface, maral rock	33	33
Maral rock and clay	23	56
Rock	22	78
Shale, hard	89	167
Shale and clay	23	190
Clay	22	212
Clay and rock	22	234
Shale (256-278 hard)	54	288
Sand	4	292
Clay and shale	32	324
Clay and rock	11	335
Sand	33	368
Clay	2	370

Well KW-60-25-704

Owner: Ralph Frank
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Soil, surface clay and sand	33	33
Clay	10	43
Sand and rock	17	60
Clay and rock	50	110
Shale, sandy	12	122
Sand	22	144

Well KW-60-25-801

Owner: Henry Molitor
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, clay and rock	34	34
Clay and rock	22	56
Clay	45	101
Clay and rock	44	145
Clay and rock	23	168
Clay and sand	22	190
Clay	54	244
Broken	13	257
Sand	17	274

Well KW-60-25-802

Owner: Frank Szymczak
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay and sand	34	34
Rock, maral and clay	22	56
Clay and rock	22	78
Clay	15	93
Sand, broken	8	101
Clay and rock	67	168
Clay	11	179
Sand	14	193

Well KW-60-25-805

Owner: H. L. Reitz
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Soil	11	11
Caliche	22	33

Well KW-60-25-805—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Clay and rock, sand (65-66)	46	79
Clay	22	101
Clay, blue	44	145
Clay, rock	22	167
Clay	23	190
Clay and rock	46	236
Shale, blue	22	258
Shale	112	370
Shale, sandy	45	415
Shale and rock	22	437
Clay	23	460
Clay and rock	88	548
Clay and rock	22	570
Shale	23	593
Clay	22	615
Clay	67	682
Clay and rock	90	772
Shale	109	881
Sand	24	905
No record	5	910

Well KW-60-25-902

Owner: Clara Schroeder
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and clay	115	115
Sand	13	128
Shale	38	166
Sand	5	171
Shale	17	188
Sand	12	200

Well KW-60-25-903

Owner: D. C. Whitfield
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and sand	15	15
Clay and rock	112	127
Sand	26	153

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-26-101		
Owner: Oscar Johnson Driller: Falkenbury Drilling Co.		
Surface and clay	30	30
Sand and gravel	26	56
Clay	36	92
Sand	8	100
Shale, sandy	44	144
Sand	14	158
Well KW-60-26-206		
Owner: H. H. Hendrix Driller: Falkenbury Drilling Co.		
Sand, gravel, and clay	105	105
Clay	81	186
Sand	26	212
Well KW-60-26-401		
Owner: Joe S. Kroll Driller: B. C. Kolbachinski		
Clay, red	3	3
Shale, gray	15	18
Sand	3	21
Shale, gray	19	40
Rock	2	42
Shale, gray, sticky	76	118
Shale, blue	32	150
Sand, blue, water	21	171
Well KW-60-26-402		
Owner: Jack Smith Driller: Falkenbury Drilling Co.		
Surface soil, clay and rock	34	34
Sand	8	42
Clay and rock	14	56
Clay	67	123
Sand, broken	22	145
Sand	68	213

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-26-402—Continued		
Sand, broken	9	222
Rock	6	228
Clay	29	257
Sand, broken	5	262
Clay	45	307
Sand	8	315
Clay	15	330
Sand	10	340
Clay	51	391
Well KW-60-26-707		
Owner: Richards Water Co. Driller: Bradford Drilling Co.		
Shale	135	135
Sand, iron water	53	188
Shale	66	254
Sand	26	280
Well KW-60-26-709		
Owner: Lee Podraza Driller: Falkenbury Drilling Co.		
Surface and clay	30	30
Sand	10	40
Broken	15	55
Clay	23	78
Clay, broken and sand	22	100
Rock, broken clay and sand	22	122
Clay	8	130
Sand	15	145
Sand	23	168
No record	1	169
Well KW-60-26-710		
Owner: Theory Bowen Jr. Driller: B. C. Kolbachinski		
Shale, gray, sticky	68	68
Sand, gray	6	74
Shale, gray, sticky	61	135

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-26-710—Continued		
Rock	2	137
Shale, blue	31	168
Sand, blue, water	12	180

Well KW-60-33-102

Owner: Anderson Water Co.
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	70	70
Sand	15	85
Rock and clay	102	187
Sand, broken	7	194
Rock and clay	158	352
Rock	22	374
Clay and rock	213	587
Sand	8	595
Rock and clay	17	612
Sand, broken	20	632
Clay and rock	66	698
Sand, broken	12	710
Clay and rock	33	743
Sand, broken	15	758
Clay	17	775

Well KW-60-33-202

Owner: Clarence Molitor
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Clay	4	4
Shale, pink	19	23
Shale, white	37	60
Shale, blue	16	76
Shale, gray, sticky	42	118
Sand	8	126
Sand rock	11	137
Shale, gray	33	170
Shale, blue	12	182
Sand, blue, water	18	200

Well KW-60-33-203

Owner: Felix Kimick
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Clay, red	24	24
Shale, gray, sticky	91	115
Sand, white	8	123
Rock, sandy	3	126
Shale, gray	50	176
Sand, blue, water	34	210

Well KW-60-33-204

Owner: H. A. McCosky
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and clay	30	30
Sand, broken and rock	26	56
Clay	66	122
Shale	44	166
Clay	104	270
Sand rock and sand	14	284
Shale	61	345
Sand rock	22	367
Clay, sandy	44	411
Sand	44	455

Well KW-60-33-301

Owner: Jim Draper
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	85	85
Sand	22	107
Clay and rock	123	230
Sand	6	236
Clay	90	326
Shale	45	371
Sand, broken	54	425
Sand	28	453

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-33-302		
Owner: Dr. E. W. Roberts Driller: B. C. Kolbachinski		
Clay, red	4	4
Rock	3	7
Shale, pink, sticky	45	52
Rock, hard	2	54
Shale, gray, sticky	26	80
Shale, gray	50	130
Rock	7	137
Shale, gray	8	145
Shale, gray, sandy	15	160
Shale, gray, sticky	34	194
Shale, blue	38	232
Sand, blue, water	18	250
Well KW-60-33-401		
Owner: John Dobyanski Driller: Falkenbury Drilling Co.		
Surface and sand	37	37
Sand and clay	23	60
Clay	68	128
Clay and rock	22	150
Sand	15	165
Clay	8	173
Shale and rock	22	195
Rock and clay	23	218
Clay	22	240
Shale and rock	22	262
Shale	15	277
Rock	18	295
Shale	11	306
Clay and rock	15	321
Sand	14	335
Clay	10	345

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-33-501		
Owner: Frank H. Nelson Driller: Falkenbury Drilling Co.		
Surface, clay and sand	37	37
Sand	45	82
Clay	22	104
Clay and rock	22	126
Clay (break on bottom)	90	216
Sand	27	243
Well KW-60-33-502		
Owner: Frank H. Nelson Driller: Falkenbury Drilling Co.		
Sand, broken and clay	65	65
Clay	105	170
Sand, broken	30	200
Sand	25	225
Clay	111	336
Rock	39	375
Sand, broken	40	415
Sand	47	462
Well KW-60-33-503		
Owner: Frank H. Nelson Driller: Falkenbury Drilling Co.		
Clay	45	45
Sand	55	100
Clay	29	129
Sand	26	155
Clay and rock	84	239
Sand (poor)	7	246
Clay and rock	55	301
Sand, fine-grained, broken	35	336
Clay	22	358
Sand	24	382

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-33-503—Continued		
Rock	43	425
Sand	67	492
Well KW-60-33-601		
Owner: Joe Stafford Driller: B. C. Kolbachinski		
Clay, red	20	20
Shale, gray, sticky	32	52
Sand	3	55
Shale, white, sticky	61	116
Sand, white, water	14	130
Well KW-60-33-701		
Owner: Glen Swietzer Driller: Falkenbury Drilling Co.		
Sand and clay	33	33
Sand	12	45
Clay and rock	111	156
Rock, broken	4	160
Sand, good	18	178
Clay and rock	27	205
Rock, broken	6	211
Sand, broken, fine	36	247
Clay and rock	32	279
Rock	45	324
Sand rock	11	335
Sand	17	352
Clay breaks	2	354
Sand	16	370
Well KW-60-33-703		
Owner: T. H. Law Driller: Falkenbury Drilling Co.		
Surface, sand, clay	23	23
Clay	55	78
Sand	17	95
Sand, broken	17	112

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-33-703—Continued		
Sand	33	145
Clay	22	167
Sand, broken	30	197
Sand	5	202
Clay	15	217
Sand	10	227
Well KW-60-33-801		
Owner: Doyle Cobler Driller: Falkenbury Drilling Co.		
Surface, clay and sand	78	78
Clay and rock, broken sand	45	123
Clay	140	263
Sand	24	287
Well KW-60-33-802		
Owner: Mike Busa Driller: Pomykal Drilling Co.		
Clay	10	10
Rock and sand	40	50
Shale	35	85
Sand, fine	30	115
Shale	5	120
Shale, sandy	10	130
Shale	15	145
Sand, fine	8	153
Shale	27	180
Sand	123	303
Well KW-60-33-803		
Owner: A. D. Werner Driller: Falkenbury Drilling Co.		
Soil, surface	34	34
Clay	22	56
Sand	22	78
Sand and clay streaks	40	118
Clay	4	122
Clay, sandy	23	145

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-33-803—Continued		
Clay and rock	22	167
Clay	8	175
Sand, hard and tight	15	190
Clay	44	234
Sand	15	249
Clay and rock	52	301
Sand, broken	22	323
Sand	20	343
Rock	2	345

Well KW-60-34-102

Owner: Mrs. Jane G. Marechal
Driller: Layne Texas Co.

	THICKNESS (FEET)	DEPTH (FEET)
Soil	3	3
Clay and sandy clay	92	95
Sand, white	17	112
Clay, sandy	21	133
Sandy and sandy clay	32	165
Clay and sandy clay	90	255
Clay and sandy clay	18	273
Sand, broken	36	309
Shale	11	320
Sand	23	343
Shale	3	346
Sand	15	361
Shale, sandy	10	371
Sand, broken	30	401
Shale	5	406

Well KW-60-34-401

Owner: L. S. Drapela
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil and sand	34	34
Clay and rock	51	85
Sand	2	87
Clay and rock	58	145
Shale, sandy	32	177

Well KW-60-34-401—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Clay	35	212
Shale and rock	44	256
Clay and rock	45	301
Rock	22	323
Sand	2	325
Clay	43	368
Sand	36	404

Well KW-60-34-701

Owner: Dr. Felix Rutledge
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and sand	34	34
Clay	91	125
Sand	34	159
Clay and rock	188	347
Shale	45	392
Sand, broken	10	402
Sand	35	437

Well KW-60-34-702

Owner: Steve Pavalock
Driller: B. C. Kolbachinski

	THICKNESS (FEET)	DEPTH (FEET)
Shale, gray, sticky	10	10
Rock	8	18
Shale, gray, sticky	67	85
Rock	7	92
Shale, gray, sticky	30	122
Sand, gray, water	8	130

Well KW-60-34-703

Owner: Harold Webster
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface, clay and sand	34	34
Clay	22	56
Sand	23	79
Clay	88	167
Sand	37	204

Well KW-60-34-704

Owner: Will Klovenski
Driller: A. E. Newcomb

	THICKNESS (FEET)	DEPTH (FEET)
Surface	1	1
Shale	10	11
Sand	15	26
Shale	53	79
Sand	28	107
Shale	73	180
Sand	25	205

Well KW-60-41-104

Owner: Jack McGirty
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, sand and clay	34	34
Clay, rock at 35′	37	71
Sand	17	88
Clay	12	100
Sand rock, clay	23	123
Sand	8	131
Clay	14	145
Clay and sand	22	167
Clay, rock (50 ft)	44	211
Clay	23	234
Sand	12	246
No record	324	570

Well KW-60-41-105

Owner: T. H. Law
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface, clay and sand	65	65
Sand	15	80
Clay	31	111
Sand	15	126
Clay and sand streaks	108	234
Sand	26	260
Clay	18	278
Sand	22	300
Shale and rock	145	445

Well KW-60-41-202

Owner: T. H. Law
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	34	34
Sand and clay	12	46
Clay and rock	151	197
Sand, broken and rock	43	240
Rock and clay	77	317
Sand	8	325
Clay	10	335
Sand with clay break at 357-369	65	400
Shale	63	463
Sand	18	481
Clay	44	525
Rock	40	565
Clay and rock	177	742
Sand	33	775

Well KW-60-41-301

Owner: Charlie Brooks
Driller: Borgstedt Well Service

	THICKNESS (FEET)	DEPTH (FEET)
Clay, light	16	16
Dark	10	26
Rock	11	37
Clay	7	44
Rock and yellow clay	32	76
Shale	20	96
Rock	10	106
Shale and rock	30	136
Rock	33	169
Sand rock	11	180

Well KW-60-41-302

Owner: St. Joseph Church
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, clay and sand	56	56
Clay, broken, rock and sand	66	122

	THICKNESS (FEET)	DEPTH (FEET)
Well KW-60-41-302—Continued		
Sand (hard, fine, red sand)	43	165
Clay and rock	173	338
Sand	22	360

Well KW-60-42-104

Owner: Charles A. Phillips
Driller: Beaumier Iron Works

	THICKNESS (FEET)	DEPTH (FEET)
Shale	110	110
Rock	22	132
Sand	22	154
Rock	21	175
Shale	22	197
Sand	33	230

Well KW-60-42-105

Owner: John Phillips
Driller: Con-Tex Water Well Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay and rock	30	30
Sand	4	34
Clay and rock	32	66
Sand	6	72
Clay	2	74
Sand	2	76
Sand and hard streaks	2	78
Clay	16	94
Sand	5	99
Clay	74	173
Sand	11	184
Rock and lime	3	187
Sand	16	203

Well KW-60-42-106

Owner: St. Mary Church
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil and clay	34	34
Clay	108	142
Sand, broken and clay	26	168
Clay	5	173
Sand	27	200

Well KW-60-42-201

Owner: John Sebastian
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil and sand	34	34
Clay	44	78
Clay, sandy	15	93
Sand	11	104
Clay and rock	113	217
Sand	10	227
Rock	3	230
Sand	26	256

Well KW-60-42-401

Owner: Shadow Lake Estates
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil and clay	20	20
Sand	24	44
Clay	12	56
Clay, broken and sand	23	79
Sand	7	86
Rock and clay	15	101
Clay	22	123
Clay and rock	107	230
Sand, broken and rock	19	249
Sand and rock	7	256
Clay	11	267
Sand	27	294

Well KW-60-42-405

Owner: Father T. W. Kappe
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, clay and sand	34	34
Sand	10	44
Clay	34	78
Clay and rock	45	123
Clay, rock at 173	97	220
Broken	15	235
Sand	20	255

Well KW-60-42-406

Owner: Charles Thompson
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil and clay	34	34
Sand and clay	22	56
Clay and rock	68	124
Clay	44	168
Clay and rock	23	191
Clay, broken on top	37	228
Sand	22	250

Well KW-60-42-407

Owner: Tony Phillips
Driller: Con-Tex Water Well Co.

	THICKNESS (FEET)	DEPTH (FEET)
Clay	125	125
Sand with hard streaks	20	145
Clay	19	164
Sand	3	167
Clay	12	179
Rock	1	180
Clay with hard streaks	10	190
Sand	15	205
Sand with clay	4	209
Sand	17	226

Well KW-60-42-503

Owner: John R. Smith
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface sand	37	37
Sand and clay	22	59
Clay	22	81
Clay and rock	23	104
Rock and clay	88	192
Sand, broken and rock	23	215
Rock, broken	44	259
Sand	11	270
Sand, broken	12	282

Well KW-60-42-802

Owner: Unknown
Driller: Seismograph Crew

	THICKNESS (FEET)	DEPTH (FEET)
Sand, fine-grained	18	18
Clay, sandy, non-calcareous	39	57
Sand, fine-grained	13	70
Clay, calcareous, containing lime	265	335
Silt, fine-grained sand, some lime	32	367
Clay, calcareous, containing lime	40	407
Sand, some lime	21	428
Clay, calcareous, containing lime	10	438
Sand, some lime, clay breaks	34	472
Clay, calcareous, containing lime	21	493
Sand, silty, some lime	12	505
Clay, calcareous, containing lime	100	605
Sand, silty, some lime	20	625

Well KW-60-42-803

Owner: Falkenbury Drilling Co.
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil, clay and sand	34	34
Sand with clay	22	56
Sand	10	66
Clay	10	76
Sand	10	86
Clay	37	123
Clay with hard streaks	22	145
Clay	10	155
Sand	22	177
Clay	13	190
Clay with hard streaks	44	234

Well KW-60-42-803—Continued

	THICKNESS (FEET)	DEPTH (FEET)
Sand with hard streaks	22	256
Sand	11	267

Well KW-60-42-804

Owner: Falkenbury Drilling Co.
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface and clay	33	33
Clay	23	56
Sand	18	74
Clay	38	112
Rock and sand	11	123
Sand	10	133
Clay	35	168
Clay and rock	89	257
Clay	100	357
Sand, broken	8	365
Sand	18	383
Rock and clay	2	385

Well KW-60-42-805

Owner: Mrs. E. Carraway
Driller: Falkenbury Drilling Co.

	THICKNESS (FEET)	DEPTH (FEET)
Surface soil and clay and sand	33	33
Sand	10	43
Clay	13	56
Clay with rock	22	78
Clay	67	145
Clay and rock	45	190
Clay	22	212
Clay, broken and sand	23	235
Clay, sandy, broken	21	256
Shale, sandy	22	278
Sand	8	286
Clay	13	299
Sand	17	316