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BULLETIN 6105

GROUND-WATER GEOLOGY OF LIVE OAK COUNTY, TEXAS

Prepared in cooperation with the Geological Survey
United States Department of the Interior
and
Live Oak County

April 1961

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TEXAS BOARD OF WATER ENGINEERS

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GROUND-WATER GEOLOGY OF

LIVE OAK COUNTY, TEXAS

By

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United States Geological Survey

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GROUND-WATER GEOLOGY OF LIVE OAK COUNTY, TEXAS

ABSTRACT

Live Oak County is on the Gulf Coastal Plain in southern Texas. Most of the 1,072 square miles of the county are devoted to farming and ranching which provide the principal income for the 9,000 inhabitants. The production of oil is also an important industry.

The principal water-bearing formations underlying the county are the Carrizo sand, Oakville sandstone, Lagarto clay, and Goliad sand, and range in age from Eocene to Pliocene. The formations dip toward the coast at rates ranging from less than 20 to about 140 feet to the mile. A map showing the surface geology and four geologic sections made from electric logs of oil wells are included in the report.

About 2,150,000 gallons per day of ground water was withdrawn in 1957 from approximately 1,000 wells in the county. Some irrigation, municipal, and stock supplies were obtained from surface-water sources. In Live Oak County the water-bearing sands above a depth of 2,000 feet contain approximately 20 million acre-feet of fresh and slightly saline water. Even though it may be impractical to recover much of the stored water, the rate of withdrawal could be increased several times more than the 1957 rate without appreciably depleting the water available from storage for many decades. A large but unestimated amount of fresh to slightly saline water occurs in the Carrizo sand in the northern and northwestern parts of the county at depths as much as 6,000 feet. Most of the water in the Carrizo sand in Live Oak County is more than 4,000 feet below land surface and therefore is too deeply buried to be economically developed for most uses.

Most of the ground water in Live Oak County is substandard in quality for municipal, industrial, and irrigational uses. However, because better water is not available in most areas in the county, substandard water has been used successfully by users of all three categories Generally the Goliad sand contains water of better quality than that in any formation except the Carrizo sand. In favorable areas properly constructed wells in the Carrizo, Oakville, Lagarto, and Goliad may yield 1,000 gallons per minute or more. Yields from wells tapping the other water-bearing formations generally are small and the water commonly is suitable only for stock.

GROUND-WATER GEOLOGY OF LIVE OAK COUNTY, TEXAS

INTRODUCTION

Purpose and Scope of Investigation

Live Oak County, lying near the boundary between the dry subhumid and semi-arid regions of Texas (Thornthwaite, 1941), is subject to periods of moderate to severe drought which alternate with periods of more or less adequate rainfall. In most areas of the county, during periods of severe drought, the only water available is from wells.

The investigation of the geology and ground-water resources of Live Oak County by the U. S. Geological Survey in cooperation with the Texas Board of Water Engineers and Live Oak County was begun in the summer of 1956. The specific objectives were: (1) to study the occurrence of ground water; (2) to determine the chemical quality of the water contained in each aquifer; (3) to study the geology as it pertains to the occurrence, depth, thickness, and water-bearing properties of the geologic formations and the quality of the water in these formations; (4) to determine the sources and areas of the recharge; and (5) to determine the present and to estimate the potential future development of ground water.

The report is based on data for 684 wells (Table 3) and 42 drillers' logs (Table 4) collected from the summer of 1956 through the summer of 1957; and on 405 chemical analyses (Table 5) made by the U. S. Geological Survey.

Four geologic sections prepared from electric logs and a geologic map based on a compilation of current studies and previously published data are included in the report. The report also includes a map based upon the interpretation of electric logs which shows the approximate thickness of the fresh and slightly saline water-bearing strata. The water-yielding properties of the formations which were determined at three different sites are shown in Table 1.

The investigation was made under the immediate supervision of R. W. Sundstrom, district engineer of the U. S. Geological Survey in charge of ground-water investigations in Texas, and under the administrative direction of S. W. Lohman, branch area chief, and A. N. Sayre, former chief of the Ground Water Branch of the Geological Survey.

Location and Physical Features

Live Oak County is in south-central Texas (Figure 1) on the Gulf Coastal Plain. George West, the county seat, is 65 miles northwest of Corpus Christi,

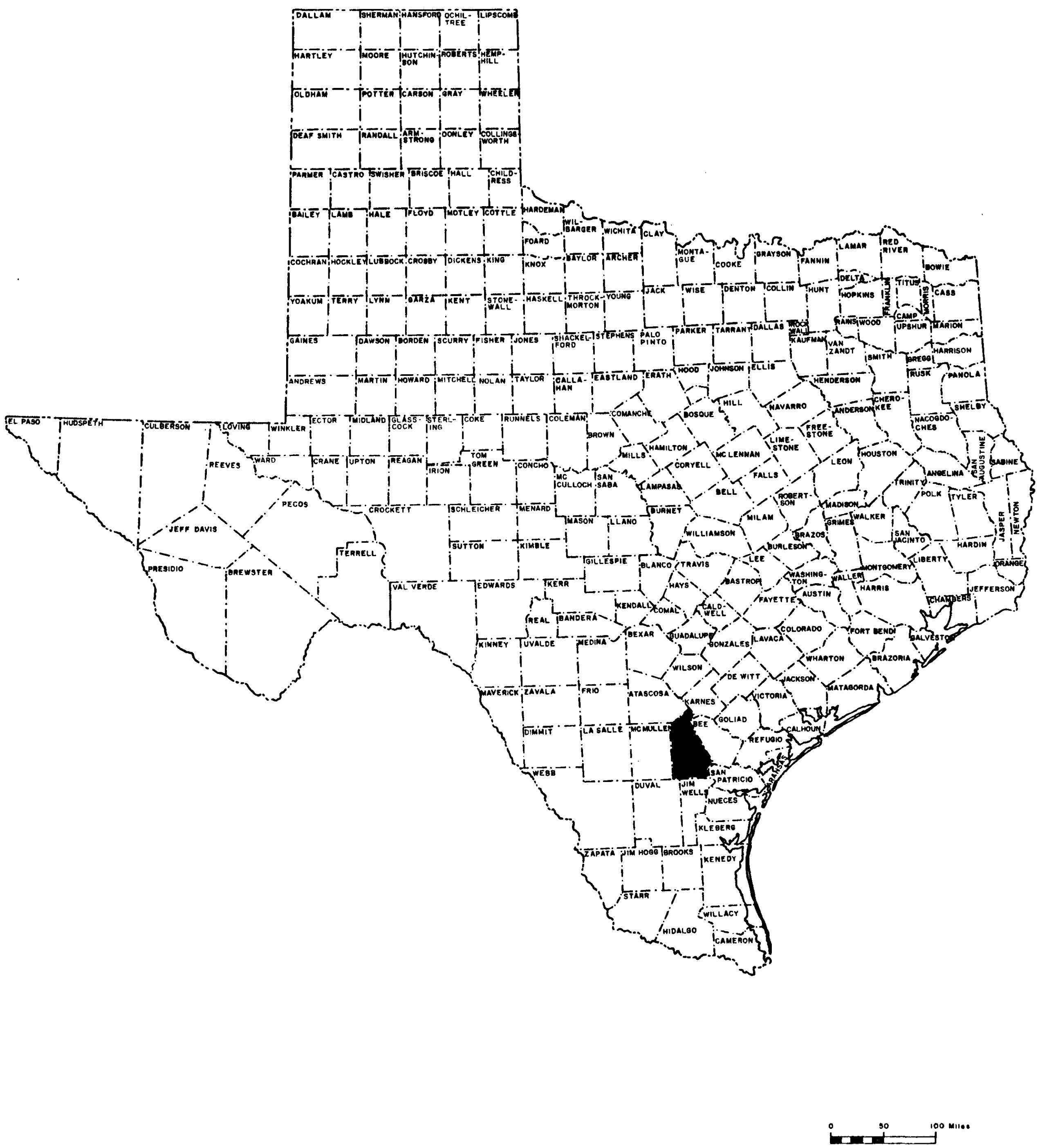


FIGURE 1. Index map of Texas showing location of Live Oak County

and 83 miles south-southeast of San Antonio. The area of the county is 1,072 square miles.

Most of Live Oak County is rolling to moderately hilly, although some areas are nearly flat. The altitude ranges from about 460 feet in the southwestern part of the county to about 90 feet near Lake Corpus Christi. The county is drained by the Nueces River and its tributaries, the Frio and Atascosa Rivers, with the exception of a small, elongated area near the Bee County line which is drained by tributaries of the Aransas River.

The two largest towns in Live Oak County-Three Rivers and George West-had estimated populations in 1957 of 2,800 and 1,800, respectively. The total population of the county in 1950 was 9,054. Other communities in Live Oak County are: Oakville, Whitsett, Simmons, Clegg, Dinero, Karon, and Mikeska.

Economic Development

The economy of Live Oak County is based largely on livestock,production, dryland farming, and a few thousand irrigated acres. The principal farm crops are grain sorghums, cotton, forage, and small grains. Less important are flax, broom corn, corn, peanuts, truck crops, dairy products, and honey. Ordinarilly about a third of the county is cultivated. Ranching is practiced in most of the remaining area. The county contains two refineries and an oil-well cementing industry. About 15 oil fields produced 1,712,705 barrels of oil and a small amount of gas in 1956.

Previous Investigations

A report by Lynch (1940) contains records of 69 wells, 61 partial and 13 complete chemical analyses of water samples, and a map showing the well locations. Descriptions of the geology at numerous locations in Live Oak and adjacent counties have been published in reports by Deussen (1924), Sellards, Adkins, and Plummer (1932), Bailey (1926), Anders (1957), Weeks (1945), Ellisor (1933), Sayre (1937), Lonsdale (1935), and Deussen and Dole (1916). A report by Eargle and Snider (1957) contains a description and geologic sections of the Jackson group in the western corner of Karnes County and descriptions of the Frio clay, Catahoula tuff, and Oakville sandstone, and the more important uranium deposits in Karnes, Atascosa, and Live Oak Counties. The public water supplies of George West and Three Rivers were briefly described by Broadhurst, Sundstrom, and Rowley in 1950 (pages 7-8, 75-79).

Acknowledgments

The authors wish to express their appreciation to the city officials of George West and Three Rivers and to the farmers and ranchers of the county for their cooperation in permitting access to their properties and supplying information about their wells. Considerable help was received also from D. Hoye Eargle of the U. S. Geological Survey, and officials of the Stanolind, Magnolia, Lee, and Humble Oil Companies. Well drillers J. E. Hutchins of Three Rivers, W. D. Miller of George West, and W. E. Eads and R. R. Lawson of Beeville contributed freely of their time and records.

Climate

Live Oak County lies in the dry subhumid region within 20 miles of the boundary between the dry subhumid and semiarid regions of Texas (Thornthwaite, 1941). The county is subject to periods of climatic extremes which range from arid to wet subhumid. Figure 2 shows graphically the annual precipitation at George West, the station having the longest period of continuous record in Live Oak County (1916-58). The average annual precipitation at George West is 26.90 inches. Precipitation was below normal for the 7-year period 1950 through 1956, although drought conditions were eased locally in 1952 when Beeville in Bee County (Figure 3) and Whitsett in Live Oak County recorded above normal rainfall.

The average monthly precipitation at George West also is shown graphically in Figure 2. May, June, and September are the wettest months; January, February, and November are the driest months. The range in average monthly precipitation at George West is about 2.65 inches between February and September.

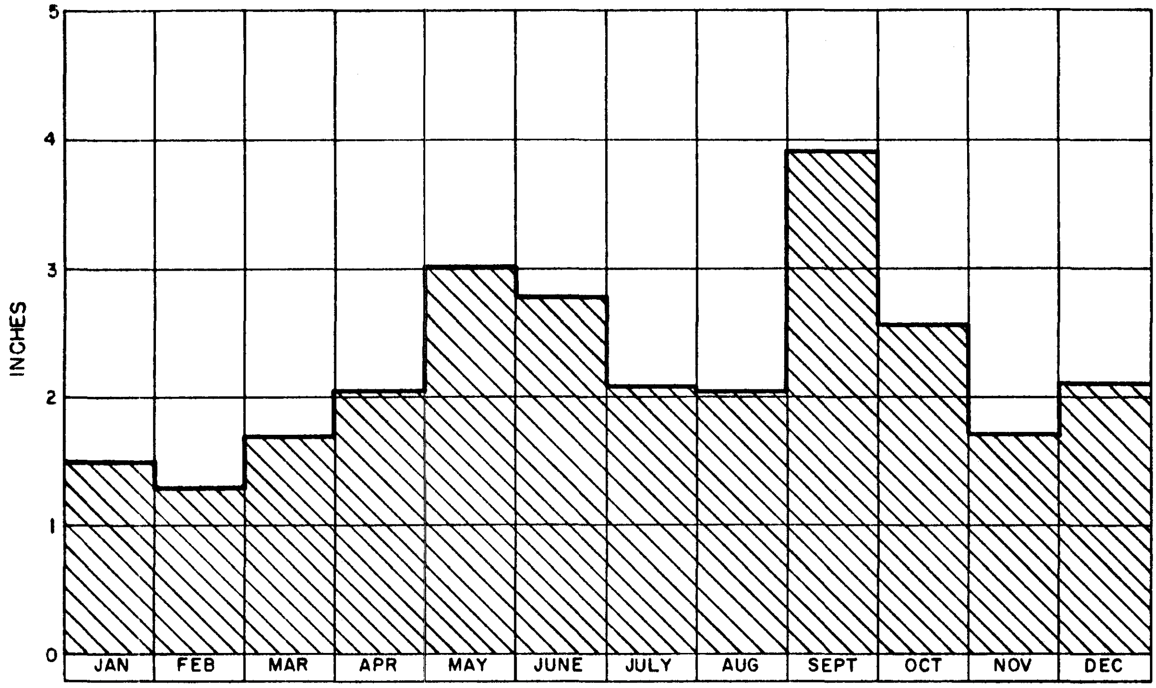
Records of temperature and evaporation are not kept in Live Oak County. However, records from the slightly more humid Beeville station, located about 25 miles east-northeast of George West, are available for the period 1915-58. The mean daily temperature at Beeville was 52.2°F. in January, 83.8°F in July, and the mean annual temperature for the period of record was 70.9°F. The maximum recorded temperature was 111°F; the minimum was 5°F. Records for the station at Beeville show that the adjusted average annual rate of evaporation for the period 1915-58 was 57.12 inches.

GENERAL GEOLOGY

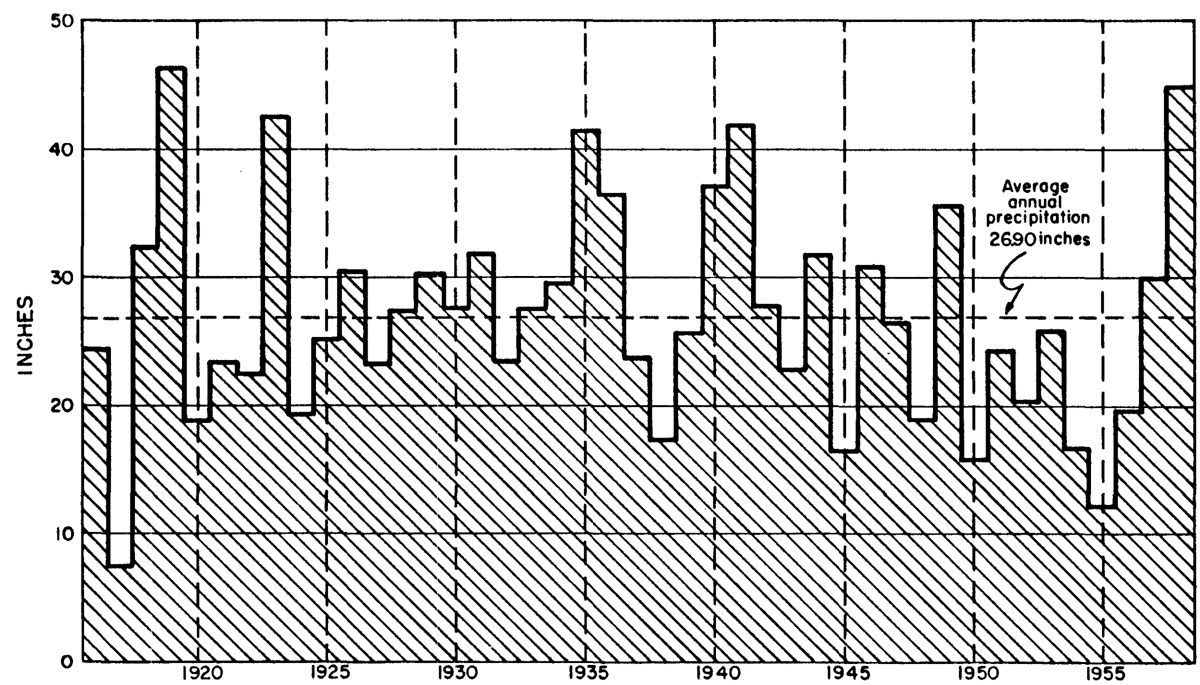
The geologic formations described in this report crop out in Live Oak County or adjacent counties and range in age from Eocene to Recent. They are listed in Table 1, with their lithologic characteristics, approximate range in thickness, and water-bearing properties. Plate 1 shows the area of outcrop of the various formations in the county and the location of selected wells. Four geologic sections based on electric logs (Plates 2, 3, 4, and 5) show the structural relationship and thickness, and indicate the lithologic character of the formations. All the rocks are of sedimentary origin and consist primarily of alternating beds of sand, silt, and clay that normally strike approximately north-northeast, and dip toward the coast at rates ranging from about 20 feet to the mile for the younger formations to more than 140 feet per mile for the older.

Many normal faults cut the rocks in Live Oak County. The faults dip steeply and the displacements range from a few feet to several hundred feet. The strike of most of the faults is nearly parallel to the strike of the formations, although a few faults have oblique strikes. Only a few of the faults are shown on Plate 1; others were not shown either because their position was not accurately known or because actual faulting could not be proven conclusively.

The depositional environment of the outcropping formations in the Gulf Coastal Plain was at or near an oscillating shoreline. Thus terrestially deposited strata alternate with marine or brackish-water deposits. Downdip the terrestial deposits grade into marine sands, silts, and clays, and where deeply buried into only marine clays. During late Tertiary time the sea withdrew toward the present coastline, leaving portions of the Tertiary rocks above sea level where they are now exposed. The upper Eocene and lowermost Miocene



Annual monthly precipitation



Annual precipitation

FIGURE 2. Precipitation at George West, 1916-58

(from records of the U.S. Weather Bureau)

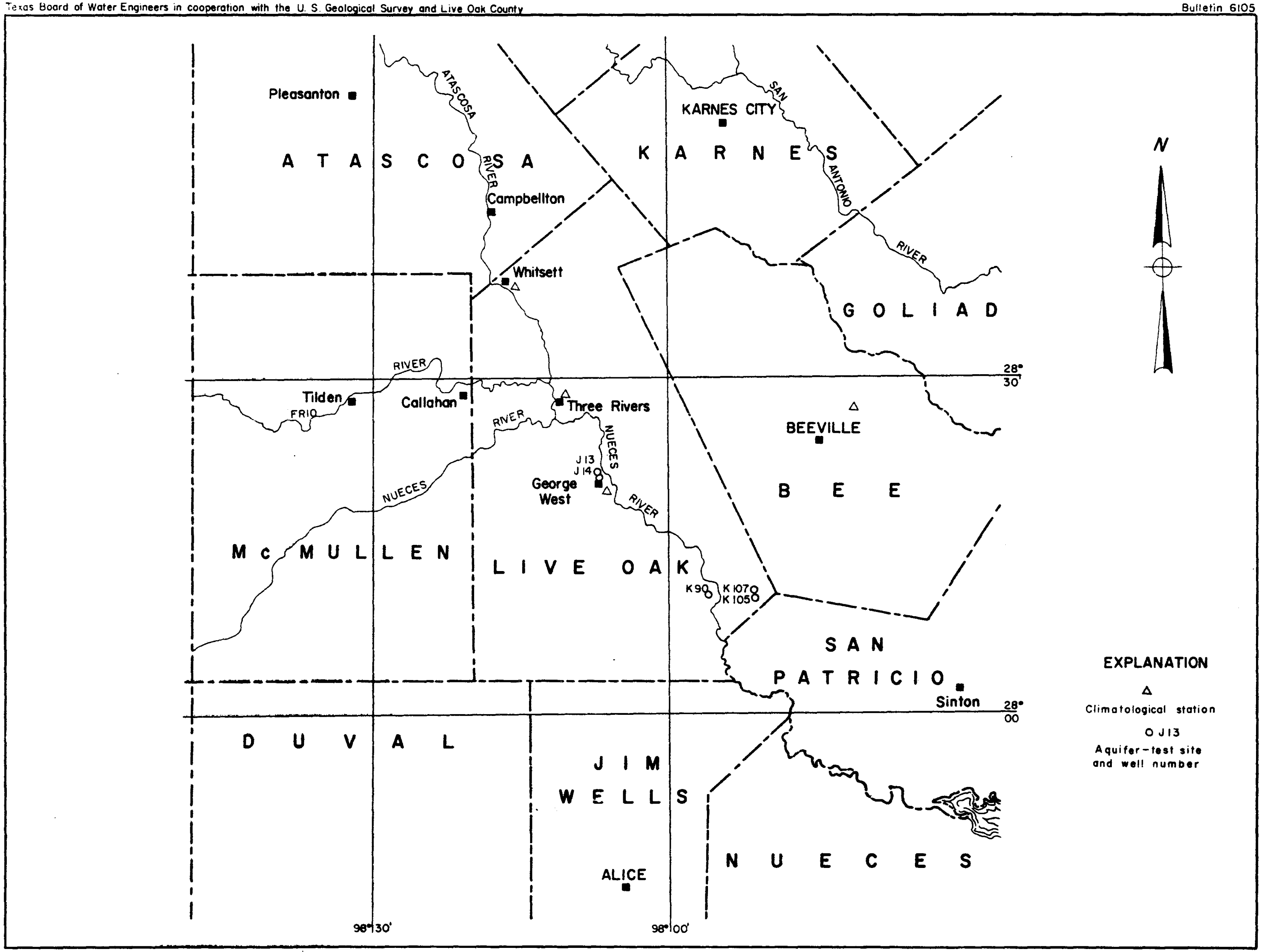


FIGURE 3.— Location of climatological stations and aquifer-test sites in Live Oak and adjacent counties

Table 1.--Stratigraphic units and their water-bearing properties in Live Oak County

System	Series	Group	Stratigraphic unit	Approximate thickness (feet)	Character of rocks	Water-bearing properties
Quaternary	Recent and Pleistocene		Alluvium	0 - 70	Terrace deposits composed of clay, silt, sand, and gravel.	Not an important aquifer in Live Oak County.
Quaternary(?) and Tertiary	Pleistocene(?) and Pliocene		—Unconformity— Rocks of Goliad and younger age	0 -500	Sand and sandstone interbedded with silt, clay and gravel. Contains large quantities of caliche on the outcrop.	Yields from very small to large quantities of fresh to moderately saline water.
Tertiary(?)	Pliocene(?)		—Unconformity— Interstream sand and gravel deposits	?	Predominantly sand and gravel	Not an aquifer in Live Oak County.
Tertiary	Miocene(?)		—Unconformity— Lagarto clay	0-1,000	Clay, sandy and silty clay; and calcaseous clay interbedded with sand.	Yields from very small to large quantities of fresh to slightly saline water.
	Miocene		Oakville sandstone	0 -400+	Medium to fine-grained sand and sandstone, clay, bentonitic clay, and small amounts of ash.	Yields range from very small to large quantities of fresh to slightly saline water.
	Miocene(?)		—Unconformity— Catahoula tuff	0 -700?	Predominantly tuffaceous clay and tuff; locally sandy clay, bentonitic clay, and thin beds of sand and conglomerate.	Yields very small to small quantities of slightly to very saline water.
	Oligocene(?)		—Unconformity— Frio clay	0 -200+	Clay, silty clay, and sand.	Not an aquifer in Live Oak County.
	Eocene	Jackson	—Unconformity— Undifferentiated	650±-1,300+	Clay, sand, silt, bentonitic clay, volcanic ash, and tuff and bedded deposits containing mixtures of these materials. Some beds are fossiliferous.	Yields very small to small quantities of slightly to moderately saline water.
		Claiborne	Yegua formation	1,050 - ?	Sand and clay containing some selenite and thin beds of lignite, limestone and bentonite.	Will yield small to moderate amounts of moderately saline water.
			—Unconformity— Cook Mountain formation	650 -1,000+	Fossiliferous clay and shale containing lenses of sandstone and limestone, glauconite and small amounts of selenite.	Not an aquifer in Live Oak County.
			—Unconformity— Sparta sand	50 - 150	Fine-grained sand, silt, and clay.	do.
			Mount Selman formation: Weches greensand member	130 - ?	Fossiliferous shale, sand and glauconite.	do.
			Mount Selman formation: —Unconformity(?)— Queen City sand member	1,050 - ?	Medium to find-grained sand interbedded with clay and silt.	do.
			Mount Selman formation: Reklaw member	350 - ?	Primarily marine clay and shale and one rather thin sand bed.	do.
			Carrizo sand	950-1,200	Medium to fine-grained sand, silt, and clay.	Will yield large quantities of slightly saline water where encountered above a depth of 6,000 feet.

formations contain large volumes of volcanic ash, apparently explosively ejected from volcanoes whose location has not been determined. In late Pliocene or early Pleistocene time, gravel, sand, and silt were spread over much of the existing Coastal Plain south and east of the Balcones fault zone (Figure 1). Erosion has lowered most of the land surface leaving a few hills capped with ancient stream gravels. The lower and broader terraces are underlain by gravel, sand, silt, and clay of Quaternary age.

GEOLOGIC FORMATIONS AND THE OCCURRENCE OF GROUND WATER

The rocks that crop out in Live Oak County were deposited in fresh water, with the exception of part of the Jackson group and possibly all or part of the Frio clay. However, a short distance downdip several of the formations grade into material that was deposited in brackish or salt water. Most of the sand beds in Live Oak County contain fresh or slightly saline water downdip from the outcrop, indicating that some flushing of brackish or salt water has taken place. Farther downdip the water becomes progressively more mineralized until the beds contain connate water—that is, water of approximately the composition of that in which the sediments were originally deposited (Winslow and others, 1957, page 387). The water-bearing formations in Live Oak County are continually recharged by the infiltration of a small part of the precipitation, which falls on the more permeable strata. However, most of the precipitation that falls in the county runs off in streams, evaporates, or is transpired by plants. The remaining water, probably less than five percent, may reach the zone of saturation where it moves slowly toward an area of discharge such as a well, natural outlet, or, under artesian pressure, it may seep or percolate slowly upward into overlying beds.

In this report water is classified according to its dissolved-solids content, as follows (Winslow and Kister, 1956, page 5):

Description	Dissolved-solids content (parts per million)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

Water for public supply, irrigation, stock, and domestic supplies in Live Oak County is generally either in the fresh or slightly saline range. Slightly saline water, although undesirable, generally may be used for drinking with no apparent ill effects. Water containing in excess of 3,000 ppm (parts per million) dissolved solids has been used for supplemental irrigation. Experiments have indicated that 10,000 ppm is the upper limit of salinity that can be tolerated by livestock (Smith and others, 1942, page 15).

The following ratings apply for general discussions of the yield of wells in Live Oak County:

Description	Yield (gallons per minute)
Very small	Less than 10
Small	10 to 50
Moderate	50 to 500
Large	More than 500

The rocks of Tertiary and Quaternary age (Table 1), which underlie Live Oak County, are composed mainly of sand and silt interbedded with clay and silty or sandy clay. The position of water table ranges from, at, or near the surface in the valleys of the Atascosa, Frio, and Nueces Rivers to more than 100 feet along the divides. Although all the deposits below the water table are saturated, only the sandy beds yield water freely to wells.

In areas where the sands crop out, water generally is unconfined—that is, the surface of the ground-water body (water table) occurs in permeable materials and is subject only to atmospheric pressure. Downdip from the outcrop ground water in sandy formations is confined by relatively impermeable overlying clays and is under artesian pressure or pressure head, and the water is called artesian water. Confined water is under sufficient pressure to rise in a tightly cased well above the level at which it is encountered. If the pressure head is large enough to cause the water in a well to rise to an altitude greater than that of the land surface, the well will flow.

Although the confining clay beds are usually regarded as impermeable, they actually have very low permeability; and as they underlie an extensive area, large quantities of water may move upward very slowly through them (Winslow and others, 1957, page 387). The very slow upward movement of ground water through the confining clay beds which underlie Live Oak County and its replacement with water from the outcrop area probably accounts for most of the aquifer flushing that has taken place.

Tertiary System

Eocene Series

Claiborne Group

The Claiborne group, which does not crop out in Live Oak County, comprises the Carrizo sand, Mount Selman formation, Sparta sand, Cook Mountain formation, and Yegua formation. The rocks of the Claiborne group consist of an alternating series of continental and marine strata. The sands generally represent intervals of terrestial deposition; the fossiliferous strata indicate marine deposition; and the lignite strata indicate palustrine deposition (Sellards and others, 1932, page 610).

Carrizo Sand

The Carrizo sand unconformably overlies the Wilcox group in the north and northwestern parts of Live Oak County, where the Carrizo is about 1,100 feet thick and buried at a depth of about 3,950 feet. The formation dips toward the southeast at a rate of about 140 feet to the mile. Electric logs and core tests indicate that where the top of the Carrizo is less than about 6,500 feet deep, it consists predominately of medium- and fine-grained sand interbedded with relatively small amounts of silt and clay. Downdip the clays become progressively thicker, the sands become finer, and the formation contains more carbonaceous material.

The Carrizo sand contains the deepest fresh to slightly saline water known in Texas. All of the water in the formation in Live Oak County is under artesian pressure, the pressure being sufficient to cause wells in many low areas to flow. Electric logs and chemical analyses of water from Carrizo wells in Karnes (Anders, in press), Bee, and Live Oak Counties indicate that the greatest depth of fresh to slightly saline water in the Carrizo sand is more than 6,000 feet below the land surface in some areas. The heavy dotted line in Figure 4 shows the approximate contact between slightly saline and moderately saline water in the Carrizo sand.

Mount Selman Formation

The Mount Selman formation, which does not crop out in Live Oak County, has been subdivided in central and northeastern Texas into three members, the Reklaw, Queen City sand, and the Weches greensand all of which can be recognized in the subsurface of Live Oak County.

Reklaw Member

The Reklaw member, which conformably overlies the Carrizo sand, underlies the northwestern corner of the county at a depth of about 3,600 feet where it is 350 feet thick. The member consists mainly of a somewhat fossiliferous and glauconitic marine clay or shale. A thin-bedded glauconitic sand and shale zone about 50 to 75 feet thick occurs at or near the base. Where it occurs at relatively shallow depths, the Reklaw is distinguishable on electric logs as a predominantly clay stratum between two prominent sand zones. Downdip toward the southeast where the formation thickens, the sand zones above and below the Reklaw member merge into clays and the true thicknesss cannot be determined. Electric logs indicate that the Reklaw will not yield potable water to wells in Live Oak County.

Queen City Sand Member

The Queen City sand member of the Mount Selman formation conformably overlies the Reklaw member. In the northwestern corner of Live Oak County, where the Queen City is found at depths of about 2,550 feet, it consists primarily of relatively thin medium- and fine-grained sands interbedded with silts and clays. The Queen City sand member is about 1,050 feet thick in this area. Several miles downdip from the northwest corner of Live Oak County, where the top of

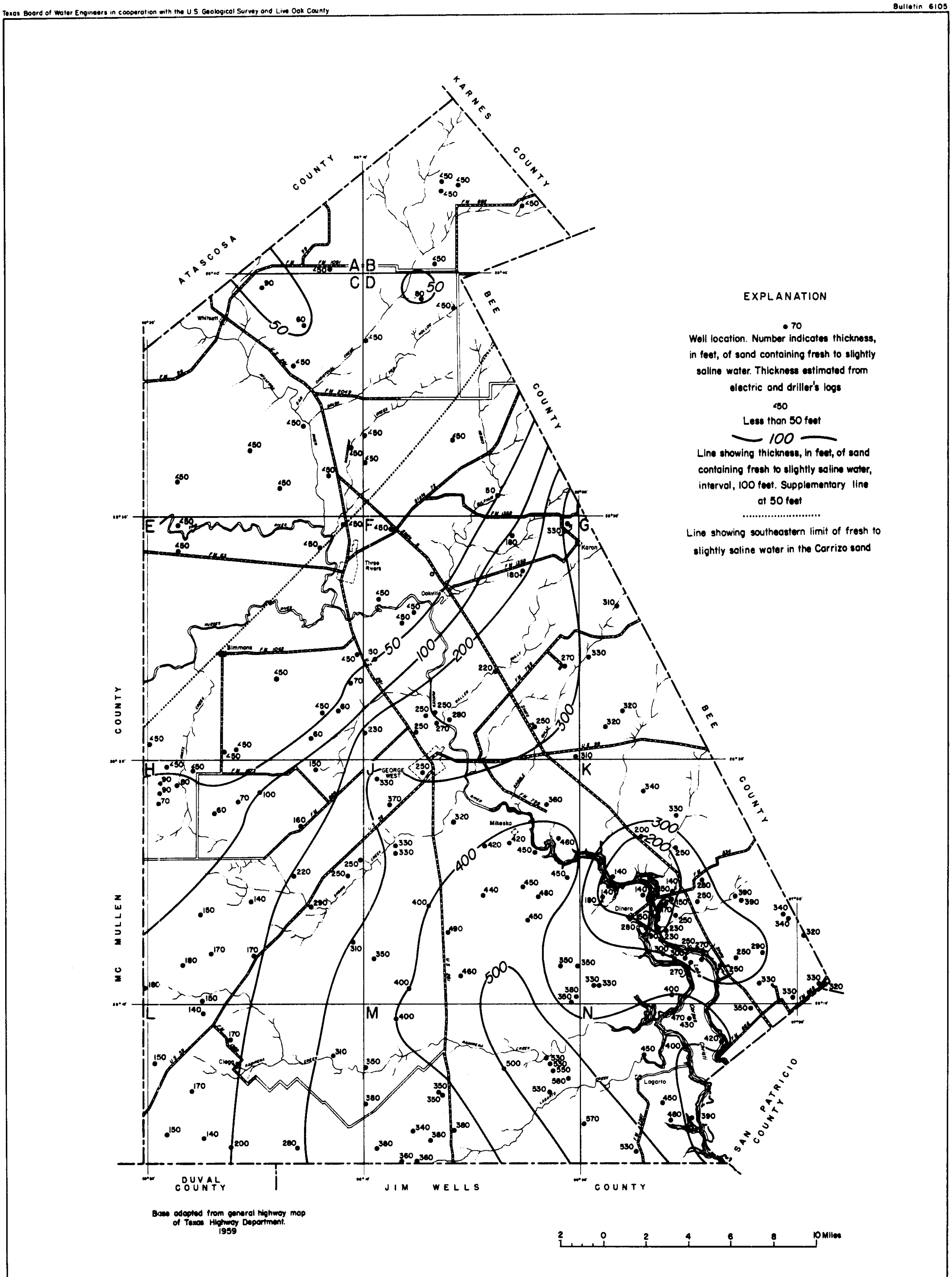


FIGURE 4.- Approximate thickness of sand containing fresh to slightly saline ground water, exclusive of the Carrizo sand, Live Oak County

the Queen City is about 3,000 feet deep, marine fossils are found in at least one zone in the member. Downdip where the top of the Queen City is below 6,500 feet, electric logs indicate that it is more than 90 percent fine sand, silt, and clay. The Queen City seems to thicken somewhat downdip but the thickness cannot be determined accurately because the increased clay content impairs the definition of the contact between the Queen City and the adjacent clays. Electric logs indicate that the Queen City sand member does not contain fresh or slightly saline water in Live Oak County,

Weches Greensand Member

The Weches greensand member is the uppermost member of the Mount Selman formation. The Weches, which conformably overlies the Queen City sand member, does not crop out in Live Oak County, but is present in the subsurface at a depth of about 2,400 feet in the northwestern corner of the county. At the outcrop in Wilson and Atascosa Counties the unweathered Weches is a fossiliferous, glauconitic sand and shale or clay. In Live Oak County electric logs indicate that the member is composed of clay and is about 130 feet thick in the northwestern corner of the county. The Weches probably thickens somewhat downdip but the large quantities of clay contained in the adjacent strata impair the definition of the contact on electric logs. Electric logs indicate that the Weches greensand member of the Mount Selman formation consists chiefly of clay and, therefore, will not yield water to wells in Live Oak County,

Sparta Sand

The Sparta sand, which conformably overlies the Weches greensand member of the Mount Selman formation, does not crop out in Live Oak County. However, the Sparta is encountered in the subsurface in the northwestern corner of the county at a depth of about 2,250 feet. Electric logs indicate that the Sparta consists of fine-grained sand, silt, and clay, and ranges in thickness from 50 to 150 feet, Downdip the formation grades into silt and clay and the Sparta cannot be separated from the adjoining clay strata. The Sparta sand contains no fresh or slightly saline water in Live Oak County.

Cook Mountain Formation

The Cook Mountain formation is primarily a fossiliferous clay or shale containing very thin sandstone and limestone lenses, substantial amounts of glauconite, and some selinite. The formation unconformably overlies the Sparta sand. The Cook Mountain does not crop out in Live Oak County but is found at depths of about 1,600 feet in the northwest corner of the county, where it is about 650 feet thick. Downdip, the formation exceeds 1,000 feet in thickness. Electric logs indicate that the Cook Mountain formation is not an aquifer in Live Oak County.

Yegua Formation

The Yegua formation, often referred to as the "Cockfield" (Sellards and others, 1932, page 666) is the youngest formation in the Claiborne group. The

Yegua unconformably overlies the Cook Mountain formation and is reached in wells at a depth of about 550 feet in the northwestern corner of Live Oak County where it is approximately 1,050 feet thick. Where exposed, the Yegua is composed primarily of nonmarine sand and clay but contains minor amounts of selenite, and beds of lignite and limestone (Lonsdale, 1935, page 41). Thin beds of bentonite and some volcanic ash have also been reported from the Yegua (Sellards and others, 1932, pages 669 and 673, and Renick, 1936, page 13). The volcanic material probably represents material from the opening phase of a period of volcanism, which may have been followed later by enormous quantities of volcanic ash and other debris ejected from a volcano or volcanoes whose location is unknown. Downdip from the outcrop the Yegua formation becomes progressively finer-grained and contains a much greater percentage of marine deposits. Its contacts, especially with the Cook Mountain, are not readily distinguishable on electric logs. The logs also show that throughout the part of Live Oak County in which the upper and lower contacts can be determined, the thickness of the Yegua formation is relatively constant.

Interpretation of electric logs and one water sample (well D-17) indicate that the Yegua formation contains moderately saline water in the northern and northwestern parts of the county where the formation is relatively close to the surface. Downdip, where the formation is deeply buried, the water is highly mineralized.

Jackson Group, Undifferentiated

The rocks of the Jackson group, the uppermost Eocene rocks in Texas, have not been subdivided into formational units in this report. The Jackson conformably overlies the Yegua formation (Sellards and others, 1932, page 682) and crops out along the Live Oak-McMullen county line north of the Frio River; it also crops out along the entire Live Oak-Atascosa county line except in the extreme northern corner where it is overlapped by the Catahoula tuff (Plate 1). In Live Oak County the thickness of the Jackson group at its contact with the Frio clay ranges from about 1,000 feet in the northeastern part of the county near the Atascosa county line, to more than 1,200 feet where the contact crosses the Live Oak-McMullen county line. In the northeastern part of the county where part of the formation is missing the thickness is about 650 feet. The Jackson dips gulfward at a rate of about 120 feet to the mile and thickens to more than 1,300 feet downdip.

Owing to similar depositional environments, the sediments of the Yegua formation and the Jackson group in Live Oak County area are similar in many ways. Where they crop out in Live Oak and Atascosa Counties, both rock units record one or more advances and retreats of the sea, and both consist primarily of sand, silt, and clay that were deposited in shallow marine, bay, littoral, and continental environments. Lignite is also relatively common in both rock units. The Jackson group, however, contains thicker and more fossiliferous marine beds and larger amounts of volcanic ash.

The lower part of the Jackson group is composed of clay, bentonitic clay, sandy or silty clay, silt, thin sand beds, and a small amount of lignite. Electric logs indicate that at depths of less than 1,000 feet in the northwestern part of the county, the lower part of the Jackson group is composed primarily of fine-grained material interstratified with several thin sand beds and containing one bed of sand 30 to 50 feet thick near the base. The base of the Jackson group in Live Oak County is a persistent clay that ranges in thickness from about 30 feet near the outcrop to more than 200 feet at depths greater than 4,000 feet. The sand beds in the lower part of the Jackson become thicker and more numerous toward the northeast corner of the county. The sand content of the lower part of the Jackson increases from the point where the Jackson group is below a depth of about 1,000 feet below land surface, to the area where it is about 3,000 to 3,500 feet below land surface. Downdip from this area the sands are thinner and at great depths they are absent. The lower part of the Jackson group probably does not yield fresh or slightly saline water to wells in the northwestern part of the county; however, interpretation of electric logs from the northeastern part of Live Oak County indicates that several sands in the lower part of the Jackson probably contain slightly saline water (Figure 4).

The upper part of the Jackson group is composed chiefly of tuffaceous sands interbedded with bentonitic clays and a small amount of lignite. Locally some of the sand and clay beds are fossiliferous. Volcanic ash is an important ingredient in the upper part of the Jackson group. Some of the ash consists of medium-grained glass shards which are large enough to be seen with the naked eye. In a few places the interstices between the sand and silt grains and the clay particles are partially filled by uranium, vanadium, molybdenum, and other minerals (Eargle and Snider, 1957, pages 17-26).

In some places on the outcrop the contact between the Jackson group and the Frio clay is defined at the top of a bed of sand 10 to 15 feet thick (Eargle and Snider, 1957, page 10, and Sellards and others, 1932, page 6841. In well sections the contact between the Jackson and Frio is drawn at the top of a persistent sand that overlies the Textularia hockleyensis Cushman and Applin zone (Sellards and others, 1932, page 684).

Wells in the upper part of the Jackson group in Live Oak County yield very small to small amounts of slightly to moderately saline water, although some thin strata that contain highly saline water are present. In general, the Jackson group is a poor aquifer in Live Oak County.

Oligocene(?) Series

Frio Clay

In Live Oak County the Frio clay unconformably overlies the Jackson group and is unconformably overlain by the Catahoula tuff (Ellisor, 1933, page 1332). The Catahoula almost completely overlaps the Frio in the northeastern corner of the county. Where exposed in Live Oak County the Frio clay occupies a zone between the Jackson group and the Catahoula tuff, which ranges in width from 0 in the northeastern part of the county to slightly less than 4 miles where the Frio and Atascosa Rivers cross the outcrop.

Where It outcrops the Frio is composed of clay and silty clay, small amounts of sand, and selenite. The clay is bentonitic and slightly calcareous, resembling some of the clays in the upper part of the Jackson and lower part of the Catahoula. This resemblance has caused considerable confusion in the literature concerning the thickness, composition, and fossil content of the Frio clay, and has, at least locally, made surface and subsurface mapping difficult and subject to error. As used in this report the Frio clay is essentially the same as Bailey's restricted Frio formation (Bailey, 1926, pages 44-52 and

Sellards and others, 1932, page 703), although at least locally, Dailey included similar clays on the upper part of the Jackson.

At the outcrop and for several miles downdip, the sand contained in the Frio occurs more or less evenly distributed in some of the clay beds or as thin lenses generally less than a few feet thick. The sand lenses are mostly disconnected, hence there is little opportunity for percolating meteoric water to flush out the salty connate water which they contain.

The Frio clay ranges in thickness from 0 to more than 200 feet near the outcrop in western Live Oak County. It thickens greatly downdip where the sand beds thicken and become more numerous until they constitute a substantial part of the formation. Large quantities of oil and gas are produced from these deeper sands.

The Frio is not known to yield water to wells in Live Oak County.

Miocene(?) Series

Catahoula Tuff

In Live Oak County the Catahoula tuff overlaps the Frio clay and part of the upper part of the Jackson group, where it has not been removed by erosion. The formation crops out in a broad, irregular belt which ranges in width from about 5 to 11 miles. It is composed predominantly of tuffaceous clay and tuff. Locally the formation contains sandy clay, ashy sand and clay, bentonitic clay, and thin sand and conglomerate beds. The tuff is interbedded with bentonitic clay, clay, and irregularly distributed lenticular sand and conglomerate. The conglomerate consists of chunks of scoriaceous lava and pumice, pebbles of other types of igneous material, opalized wood, irregular masses of chalcedony, quartz, and chert. Drillers' logs and electric logs indicate that sand and gravel beds are present many miles downdip. Coarse-grained sand usually accompanies the gravel. Most of the gravel deposits contain also large quantities of tuff and, locally, clay which fills all or most of the interstices. The tuff restricts the movement of water through many of the gravel and sand zones so that downdip, they either do not yield water or yield only small quantities of highly mineralized water to wells. The exact thickness of the Catahoula tuff could not be determined, however calculations using the width of the Catahoula outcrop and the dips of the base of the Oakville sandstone, which uniformly overlies the Catahoula, indicate the thickness of the Catahoula tuff at its surface contact with the Oakville sandstone is between 500 and 700 feet.

In Live Oak County the Catahoula tuff is a poor aquifer. It generally yields very small to small amounts of water that range in quality from slightly to very saline. Most of the water pumped from the Catahoula is used for stock; although locally, where the water is of relatively good quality, it is used for domestic purposes

Miocene Series

Oakville Sandstone

In Live Oak County the oakville sandstone and Lagarto clay can be separated from each other only with considerable difficulty and the expenditure of an undue amount of time, as good exposures are rare, and because the contact in the west-central part of the county is covered by outliers of the Goliad sand, and the soils and topography of the two formations are similar. An attempt was made to separate the Oakville sandstone and Lagarto clay in the subsurface and the approximate contact between them is shown in Plates 2, 3, 4, and 5. The width of the Oakville and Lagarto outcrop ranges from about one-half mile where the formations are covered by outliers of the Goliad sand to more than 16 miles along the Nueces River. The Oakville dips gulfward at an average rate of 80 feet to the mile.

The type locality of the Oakville sand is at the town of Oakville where the formation consists of medium to slightly coarse-grained, crossbedded sand which is interbedded with bluish clay. In other areas the Oakville is a crossbedded, medium- to fine-grained sand or sandstone interbedded with sandy clay some of which is silty and bentonitic. Electric logs indicate that the formation, where it underlies the Lagarto clay in Live Oak County, ranges in thickness from less than 200 to more than 400 feet. This variation in thickness is in part caused by lithologic variations near the upper or lower contact where, if the Oakville contains large amounts of clay, it cannot be distinguished on electric logs from the underlying clayey Catahoula or the overlying clayey Lagarto. Conversely, if sands are present near the contact with the Lagarto clay or Catahoula tuff, they erroneously might be included in the Oakville sandstone. The variations in the thickness of the Oakville also may have been caused by faulting or other structural deformation which apparently occurred locally following the deposition of most or all of the Oakville sandstone. Structural deformation or faulting is illustrated by the reversal of dip of the Oakville sandstone between wells K-50 and K-69 in cross section B-B' (Plate 3). The Oakville appears to be somewhat thinner in the southwestern part of the county where it probably was eroded prior to the deposition of the Lagarto.

The quality of water in the Oakville sandstone in Karnes County ranges from fresh to slightly saline although the water generally is slightly saline. Fresh water from wells on or near the outcrop is not uncommon; however, water from the Oakville generally is hard or very hard. Locally the water is soft or only moderately hard. In places the water has a rather high chloride content, which ranges from 52 to over 1,500 ppm (parts per million), but is usually between 150 and 500 ppm. Relatively few samples were analyzed for boron and sodium content, however the analyses suggest that these constituents have a rather wide range in concentration and should be considered when water from the Oakville is to be used for irrigation. Locally, water from the Oakville may contain excessive amounts of Fluoride.

The water in the Oakville in Live Oak County generally is more mineralized and somewhat harder toward the southwest. The quality also differs from bed to bed within the formation and with depth of burial. Electric logs indicate that water in the Oakville is progressively more mineralized with depth. However, water in the Oakville appears to be only slightly saline at a depth of 1,900 feet near the community of Lagarto in the southeastern part of the county (Figure 4).

Properly constructed wells will yield moderate to large amounts of fresh to slightly saline water where 100 feet or more of the Oakville sands are saturated. The city of George West, a refinery, a few irrigation wells, and many stock and domestic wells obtain all or part of their water from this formation.

Miocene(?) Series

Lagarto Clay

The Lagarto clay unconformably overlies the Oakville sandstone and in turn is overlain unconformably by rocks of Goliad and younger age which completely overlap it in some parts of the county. The Lagarto clay is poorly exposed in Live Oak County. The soils resemble those of the Oakville sand although in some areas they are slightly darker, have more of a brownish tint, and appear to contain more clay. Generally the soils derived from the Lagarto are sandier in Live Oak County than they are to the northeast in Karnes County. The sand beds in the Lagarto are finer-grained and more thinly bedded than are the sands in either the Oakville or Goliad. Locally thick sand zones, which may comprise more than 50 percent of the Lagarto clay, make it difficult to distinguish it on electric logs from the Oakville sandstone and the Goliad sand. Ordinarily, however, the Lagarto consists primarily of clay, sandy and silty clay, and calcareous clay interbedded with somewhat thinner zones of thin-bedded sand. In general the clay zones in the Lagarto are thicker and more persistent than the clay zones in the Oakville or Goliad.

The Lagarto ranges in thickness from 0 to possibly more than 1,000 feet. In the areas where the Goliad sand is thin or is present as outliers, electric log correlation of individual sand and clay beds shows that the decrease in thickness of the updip Lagarto may be the result of both pre-Goliad erosion and of thinning of individual sand and clay beds within the formation.

The quality of water in the Lagarto at relatively shallow depths in Live Oak County is more variable than in either the Oakville or Goliad. The sand beds in the updip Lagarto, however, will normally yield water that is only slightly more mineralized than that produced from the Oakville sandstone. Commonly the water from the Lagarto has a somewhat higher chloride content and is harder than the water obtained from the Oakville or Goliad. Although water in the Lagarto normally contains more mineral matter than water in the Oakville, the average boron and fluoride concentrations and sodium hazards are probably less.

The sands in the Lagarto contain moderately to slightly saline water at shallower depths than does the Oakville sandstone; the sands in the Lagarto have not been flushed as far downdip. However, the Lagarto yields very small amounts of water to many domestic and stock wells in Live Oak County. The formation yields moderate to large amounts of water to a few irrigation wells. In most areas of the county where the Lagarto is present and contains fresh or slightly saline water, moderate to large amounts may be obtained from saturated sands of the Lagarto if they have an aggregate thickness of 100 feet or more.

Tertiary(?) System

Pliocene(?) Series

Interstream Sand and Gravel Deposits

Some of the higher interstream divides in parts of the Gulf Coastal Plain are capped by remnants of ancient stream deposits. The name Uvalde gravel has been applied to these deposits of coarse sand and gravel. The deposits lie unconformably on beds ranging in age from Late Cretaceous through Miocene and possibly Pliocene. In Wilson, Karnes, Gonzales, and Dewitt Counties the interstream sand and gravel deposits have a coastward linearity and lack continuity along the strike of the older formations.

The interstream sand and gravel deposits dip gently gulfward, occurring at progressively lower altitudes toward the coast. Field observations suggest that the high-level sand and gravel deposits are updip equivalents of the Goliad sand. Proof of Uvalde and Goliad contemporaniety, however, is difficult to obtain in the four-county area mentioned partly because of inadequate topographic maps and partly because of uncertainty regarding the relationship between the Goliad sand and the Willis sand, which crops out northeast of the Colorado River and overlaps the Goliad. The occurrence of the Willis sand has not been proved in central and south Texas because it resembles the Goliad so strongly that the two formations cannot be separated. The Uvalde gravel in Live Oak County, was not differentiated from the underlying deposits on PlLate 1; but where present, it probably is too thin to yield water to wells or is above the water table.

Tertiary and Quaternary Systems

Pliocene and Pleistocene(?) Series

Rocks of Goliad and Younger Age, Undifferentiated

The Lagarto clay is overlain by the Goliad sand in southern Live Oak County. The Goliad sand is not differentiated from younger rocks which may overlie it in the southeastern part of the county. The geologic map of Texas (Darton and others, 1937) shows the Pleistocene Lissie formation and Beaumont clay cropping out in southeastern Live Oak County, east of State Highway 9 and south of U. S. Highway 59. More recent studies (Weeks, 1945a, page 1695, and Doering, 1956, page 1845) show rocks older than the Lissie Eormation cropping out in the area although the writers believe the rocks to be younger than the Goliad sand. The term "rocks of Goliad and younger age" refers to Goliad sand in the area west of State Highway 9 and north of U. S. Highway 59 and to both the Goliad sand and the overlying younger rocks in the remainder of the area.

The contact between the Goliad and the underlying Lagarto clay is unconformable. The Goliad is composed of fine- to coarse-grained sand and sandstone, which in many areas contain gravel interbedded with silty and sandy clay and clay. Where exposed the sand and gravel, and locally the clay, generally are cemented with caliche. Some sand and clay beds contain only a small amount of calcareous material; but other beds, especially near the surface where considerable solution and redeposition of the calcium carbonate has taken place, may contain from 70 to 90 percent caliche by volume. The Goliad sand is distinguished from the Lagarto clay on the surface by the brilliant white of the caliche, the coarse sand and gravel, and the prominent scarp which separates the formation from the more easily eroded Lagarto.

The rocks younger(?) than Goliad age consist of beds of sand, silt, and clay which generally are impregnated with caliche. The sand beds are somewhat finer-grained and less well sorted than those in the Goliad. The land surface formed by the younger rocks is a flat, featureless plain underlain by a dark-gray to black, carbonaceous, slightly silty and sandy, clay soil.

The rocks of Goliad and younger age crop out in a very irregular belt which in Live Oak County ranges in width from about 10 to 20 miles, excluding outliers. In general the rocks dip toward the coast at a rate that ranges from 20 to 45 feet per mile. The somewhat variable rate of dip may be attributed to faulting between the wells used in the dip calculations and other local structural changes, the unconformity between the Goliad sand and Lagarto clay, and differences in the original dip. Although adequate topographic control is lacking, a few altitudes obtained from oil tests and bench marks indicate that the Goliad has a gentler dip where it is thin or exists as outliers than further downdip where it thickens to about 500 feet.

Generally the Goliad sand contains the best quality water of any formation in Live Oak County except the Carrizo sand. Water from the Goliad is fresh to moderately saline, is commonly rather hard, contains appreciable quantities of sodium, and has a relatively high concentration of chloride. The concentration of dissolved minerals in water produced from the rocks of Goliad and younger age differs considerably from place to place.

The rocks of Goliad and younger age yield very small amounts of water to a large number of domestic and stock wells. The formation also yields large volumes of water to a few irrigation wells. In general the Goliad is capable of yielding 500 to more than 1,000 gpm (gallons per minute) to properly constructed wells where 100 feet or more of the formation is saturated.

Quaternary System

Pleistocene and Recent Series, Undifferentiated

Alluvium

Deposits of alluvium consisting of clay, silt, sand, and gravel are found in some stream valleys, principally those of the major rivers. These deposits are heterogeneous in composition and their thickness ranges from 0 to perhaps more than 70 feet locally. Several analyses of water from two municipal supply wells at Three Rivers which are now abandoned and from one presently-used well about one-half mile north of Three Rivers and information supplied by local residents indicate that the yields and quality of water from wells in the alluvial deposits are extremely variable. Also, the quality of water from wells that are close to streams varies depending upon rainfall and stage of the stream, but usually the changes in the ground water lag behind those of the stream. The alluvium, even where it contains considerable saturated sand or gravel, generally yields only very small or small amounts of slightly to moderately saline water to wells.

GROUND WATER

Aquifer Tests

Five aquifer tests were made in Live Oak County (Figure 3) to estimate the ability of some of the fresh and slightly saline water-bearing sand zones to transmit and store water. The data from the tests were analyzed by the Theis nonequilibrium method as modified by Cooper and Jackob (1946, pages 526-534) and the Theis recovery method (Wenzel, 1942, pages 94-97). The results of the tests are shown in Table 2 (page 24).

The ability of an aquifer to transmit water is expressed as its coefficient of transmissibility. The coefficient of transmissibility is defined as the amount of water in gallons per day that will pass through a vertical strip of aquifer having a width of 1 foot and a height equal to the saturated thickness of the aquifer under a hydraulic gradient of 1 foot per foot at the prevailing aquifer temperature. The coefficient of storage of an aquifer is defined as the volume of water it releases or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. The coefficients from the tests represent only the sand zones that were tested in the immediate area of the well. They should not be used to predict yield or drawdown in other areas, although the order of magnitude of the coefficients are about what may be normally expected in a particular formation, assuming approximately equal screened thicknesses.

The aquifer tests (Table 2) were only a few hours in duration and all were in confined aquifers. The coefficients of storage determined in wells J-13 and K-105 were .0012 and .00057, respectively. Coefficients of storage in unconfined aquifers are generally 100 or more times as large; however, most of the moderate- to large-capacity wells in Live Oak County tap confined aquifers.

No tests were made of wells tapping the Carrizo sand in Live Oak County, but a test near Campbellton in southern Atascosa County indicated a coefficient of transmissibility of 40,000 gallons per day per foot for the Carrizo and a coefficient of storage of about .0001.

Present Development

Withdrawals

About 2,150,000 gpd (gallons per day) were withdrawn in 1957 from the approximately 1,000 water wells in Live Oak County. Most of the wells derive their water from the Oakville sandstone, Lagarto clay, or the Goliad sand. Ground water was the only source of municipal and domestic supply for about 6,000 persons and was the source for most of the irrigation and stock supply. The amount of ground water used for municipal, domestic, irrigation, industrial, and stock supply is shown in the following table:

Average daily use of water from wells in
Live Oak County, Texas, 1957, in gallons per day

Use	Withdrawals
Municipal	100,000
Domestic	100,000
Irrigation	1,500,000
Industrial	200,000
Stock	150,000

At least 100,000 gpd of ground water, most of which was moderately saline, was wasted from uncontrolled flowing wells.

Changes in Water Levels

The water levels in wells in Live Oak County respond mainly to changes in withdrawal rates and changes in ground-water storage. However, a change in the physical condition of a well such as damage to the casing, deepening, or partial plugging also may cause a change in the water level in the well. These changes in water level occur because the well bore has gained or lost hydraulic connection with one or more sand zones containing water under different artesian pressure head. A change in chemical quality may occur in such wells because the quality of water is frequently somewhat different in each sand bed or sand zone.

Relatively rapid changes in water levels which occur in a few hours or several days are commonly due to local changes in the withdrawal rates of nearby wells and generally affect a rather small area. Substantial long-term changes in water levels which occur over a period of weeks, months, or years may be caused by changes in the withdrawal rates of wells or by changes in ground-water recharge. Long-term changes in water levels generally affect a large area.

Although few large wells in Live Oak or adjacent counties produce large long-term changes in water levels, moderate changes that are assumed to be more or less local were observed in two areas. A water-level decline of about 8 feet occurred between 1945 and 1957 in well J-14, one of the George West municipal wells. The decline probably can be attributed to drought conditions and increased withdrawals from the city's two wells, although withdrawals from nearby irrigation wells also may have contributed to the decline.

A relatively sharp rise in water levels was observed in some of the wells near Lake Corpus Christi following its enlargement and elevation of stage in 1958 (Plate 1). The altitude of the spillway of the dam forming the larger Lake Corpus Christi is about 13.5 feet higher than the spillway of the old dam which is submerged by the present lake. The rise in the water levels in the wells near the lake is attributed to an increase in ground-water recharge caused by the higher stage of Lake Corpus Christi and to recharge by the drought-breaking rains which started in 1957. However, water levels in some wells near the smaller lake were approximately the same altitude as the lake and the altitude of water levels in wells a short distance from the lake were somewhat lower.

Table 2.--Results of aquifer tests in Live Oak County

Well numbers	Owner	Depth of pumped well (feet)	Length of well screen or slotted casing in pumped well (feet)	Formation opposite screen	Coefficient of transmissibility (gpd/ft)	Coefficient of storage
J-13 and J-14	City of George West	537	153	Oakville sandstone	55,000	1.2×10^{-3}
J-14	do	500	--	do	28,000	--
K-90	Holman Cartwright	425	225	Rocks of Goliad and younger age	32,500	--
K-105 and K-107	L. T. Porter, Jr. & H. F. Meyers	460	160	do	24,000	5.7×10^{-4}
K-107	H. F Meyers	460	160	do	10,000	--

The slope of the water table away from the lake indicated recharge from the lake to the surrounding rocks. The altitude of water levels in wells farther from the lake was higher than the lake, indicating that ground-water flow prior to the construction of the first lake was toward the valley of the Nueces River. In 1958 the situation was similar; that is, the regional slope of the water table was toward the Nueces River valley and Lake Corpus Christi, but the slope of the water table within a mile or two of the lake was away from the lake, resulting in a trough in the water table on both sides of the lake. Sufficient data are not available to determine if the trough is an area of discharge by evapotranspiration, by underflow around the dam creating the lake, or is evidence that the water table was not yet adjusted to the rise in stage of the river due to the building of the dams.

Potential Development

The potential supply of fresh and slightly saline ground water in Live Oak County is large compared to the development in 1957. However, in some parts of the county such as the northern part where the Catahoula tuff and older formations crop out, the potential supply is very small from all formations except the Carrizo sand. This is illustrated in Figure 4 which shows only two areas that have more than 50 feet of aggregate thickness of fresh or slightly saline water-bearing sand. Other similar small areas may be present, but data were not sufficient to map them. Stock supplies generally can be obtained in northern Live Oak County, but the water in several places is too saline for domestic use. In the southern and southeastern parts of the county, where the Oakville sandstone and younger formations crop out, the potential for development is much larger. Locally wells less than 600 feet deep will yield as much as 1,000 gpm. Still larger yields could be obtained in some areas by tapping deeper sands, but the composite water would probably be more mineralized. The quality of water differs from place to place, but may be estimated for many places by referring to Tables 3 and 5.

The part of the Carrizo sand that contains slightly saline water has a much greater potential than all other formations in northern and northwestern Live Oak County. Unfortunately in this area the Carrizo is deeply buried, the concentrations of minerals in the water is too large for many purposes, and its temperature exceeds 140°F.

The potential for development of ground water in a given area is limited by the relationship between the cost and value of the water. If the unit cost exceeds the unit value, it is not economically feasible to develop the water supply. Two of the most important factors which effect the unit cost of water are the initial cost of the well and the cost of pumping. The cost of the well is related to its depth, diameter, and the type of material in which the well is drilled and completed. The cost of pumping depends upon the pumping lift and the cost of power. Although wells tapping the Carrizo sand are capable of yielding large quantities of water in Live Oak County, the cost of constructing wells 4,000 to 6,000 feet deep is too great for most uses. Moderate to large supplies of water are available in other areas in the county, but local pumping lifts may be too great for most uses under present economic conditions.

Pumping lifts are related to the hydraulic properties of an aquifer, the number and spacing of wells, and the rates of withdrawal. Figure 5 shows that for a given pumping rate the drawdown of water levels is greater for smaller values of transmissibility and the drawdown decreases as the distance from the

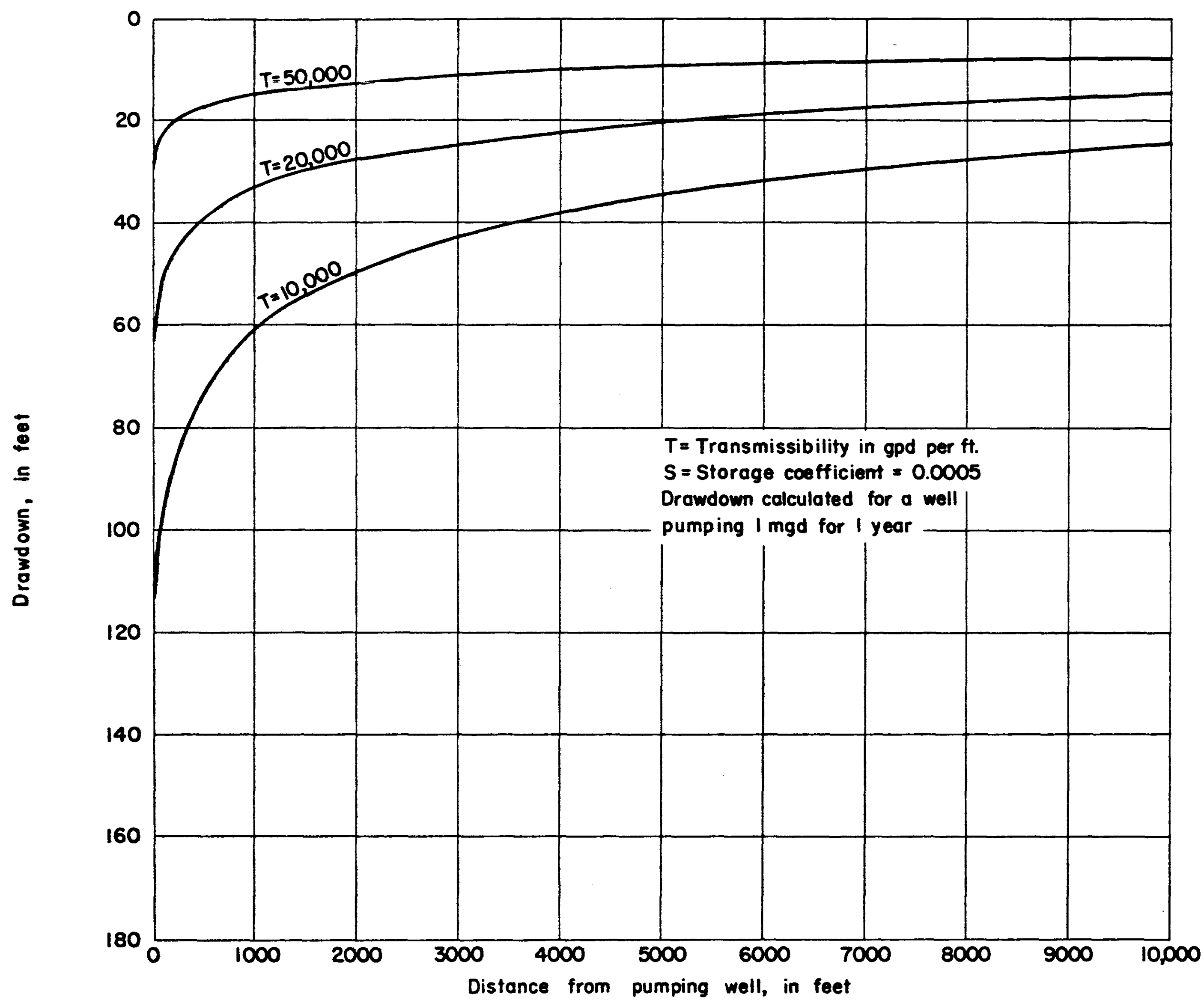


FIGURE 5.— Relation between drawdown and transmissibility in an infinite aquifer

point of withdrawal increases. The drawdown for a particular well is approximately proportional to the pumping rate. Pumping from additional wells increases the pumping lift of each nearby well.

The decline of water levels in artesian wells in Live Oak County caused by pumping will be less than indicated on Figure 5 when the effects of pumping reach the outcrop of the aquifer. There water is intercepted that otherwise would be discharged by evapotranspiration, principally where the formations crop out in stream valleys (Guyton, 1942, page 47, and Theis, 1941, pages 734-737). Some water also will be drained from the interbedded clays throughout the aquifer wherever the artesian pressure is lowered (Winslow and Doyel, 1954, page 421) causing compaction of the clay beds. If withdrawals exceed the amount of water intercepted in the outcrop areas and drained from the clay beds, water levels will decline in the artesian wells at the same slow rate as they do in the outcrop. Figure 6 shows, for example, that at 1,000 feet from a well pumping 1 mgd (million gallons per day) in a formation which has a transmissibility of 50,000 gallons per day per foot and a storage coefficient of 5.0×10^{-4}, the drawdown would be about 17.0 feet when equilibrium was established if the well were 20 miles from the outcrop. The drawdown in an infinite aquifer having the same characteristics would be 18.2 feet after 10 years of pumping and 20.9 feet after 50 years of pumping. Wells nearer to the outcrop would have less drawdown, other things being equal, than wells farther from the outcrop. Figure 6 assumes that no water of compaction will be obtained from the clay beds; this will tend to make the actual drawdowns smaller than those shown.

The amount of water that can be produced by wells in different areas is mainly a function of transmissibility which, in turn, is a function of the thickness and permeability of the aquifer. Pumping tests and geologic data in Karnes and Live Oak Counties suggest that materials in the Carrizo, Oakville, Lagarto, and Goliad formations are more permeable than those in the Yegua, Jackson, or Catahoula. Thus, the geologic map (Plate 1) and the map showing the aggregate thickness of sands containing fresh and slightly saline water (Figure 4) are useful in determining the relative productivity of different areas in Live Oak County. The interpretation of chemical quality of water from electric logs gives only an approximation of the degree of salinity of the water and tells little about the kind of chemical components which the water contains. The interpretations are based on changes in both the resistivity and self-potential curves and, where possible, by comparison of the analyses of water from a sand or sand zone with an electric log of the well from which the sample was taken, or with the electric log of a nearby well. In general, the interpretations are largely a matter of judgment and experience (Jones and Buford, 1951, pages 115-139). The sand-thickness map should be used with caution as it is based largely on the interpretation of widely scattered electric logs of oil wells and drillers' logs of water wells. However, Figure 4, which excludes the Carrizo sand, shows that the most promising area for ground-water development is the southeastern third of the county.

The development of ground water in the county on a long-term basis is dependent upon the quantity of fresh to slightly saline water in storage and the potential rate of replenishment. The fresh and slightly saline water-bearing sands in Live Oak County above a depth of 2,000 feet contain approximately 20 million acre-feet of water, assuming a sand porosity of 30 percent. However, the effective porosity is only about 10 to 15 percent and a large percentage of the water is so deeply buried that its recovery is impractical because pumping lifts would be uneconomical.

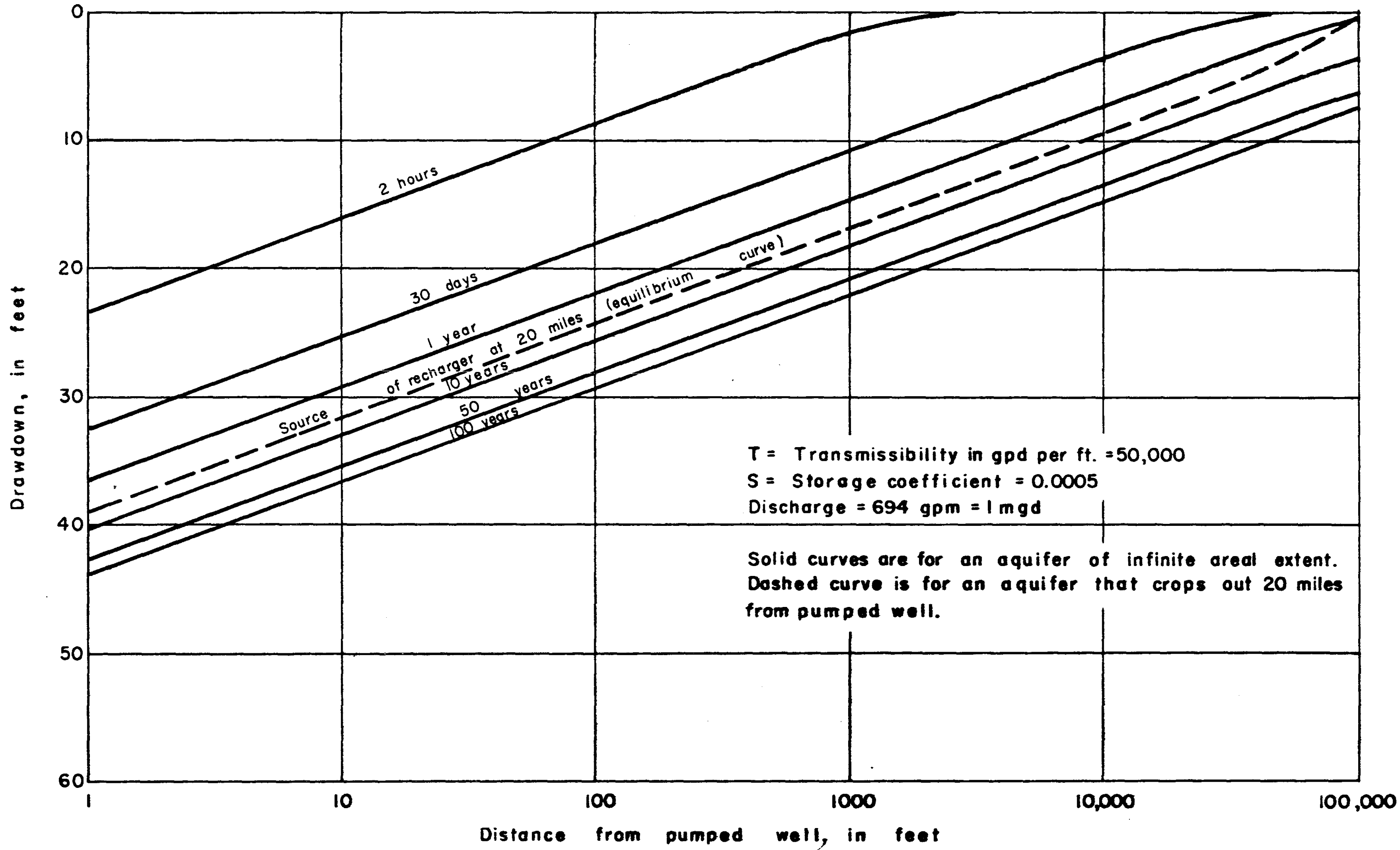


FIGURE 6.—Graph showing relation between drawdown and time

Streamflow records on the Nueces River and its tributaries (Texas Board of Water Engineers, 1958, pages 393-410) indicate that no rejected recharge enters the river while flowing across the outcrops of the Jackson group, the Frio clay, or the Catahoula tuff above the gaging station near Three Rivers. However, a seepage run made by the U. S. Geological Survey in January 1951 (Holland, 1951) indicated a gain of about 2 cubic feet per second between the gaging station near Three Rivers and a point near Mikeska while flowing across the outcrop of the Oakville sandstone and the Lagarto clay. No data are available on gains or losses to the river between Mikeska and the Nueces County line where the river is flowing mostly on the outcrop of rocks of Goliad and younger age although, as has been noted, the gradient of the water table near Lake Corpus Christi indicated ground-water movement from the lake in 1958.

Under equilibrium conditions, the amount of recharge to the aquifers was equal to the amount of discharge from the aquifers. Natural discharge from Live Oak County was by seepage into streams, evaporation, transpiration by plants where the water table was near the surface, and by underflow into adjacent counties. At the present time, a relatively small amount of water is discharge by wells in Live Oak County or to the Nueces River as rejected recharge, evapotranspiration and underflow to adjacent counties probably discharges several times as much. Although data are not available to evaluate the amount, it is believed that total discharge is in the order of a few tens of thousands of acre-feet each year.

The geology and hydrology of the fresh and slightly saline water-bearing formations in Live Oak County are fairly complex, at least locally, and a detailed investigation should precede any large-scale development of ground water. The study should include the collection and analysis of data leading to more accurate quantitative evaluations and the solution of quality-of-water problems to supplement this report. In lieu of a detailed investigation, it may be concluded at this time that the rate of withdrawal from widely spaced wells could be increased several times the 1957 rate (about 2,400 acre-feet a year) without seriously lowering water levels for many decades.,

QUALITY OF WATER

Analyses of 405 samples of water from 354 wells in Live Oak County were made in the Geological Survey laboratory and are included in Table 5. The dissolved solids contents of the samples ranged from about 330 to 12,000 ppm (parts per million).

Classification by the concentration of dissolved constituents as shown on page 10 is only one of several criteria for judging the suitability of water for various uses. The following discussion of other criteria pertains to the most common uses of water in Live Oak County.

The quality tolerance of water for drinking varies with individuals although few people in Texas are known to continually use water containing more than 3,000 ppm dissolved solids. Some types of livestock, however, have been known to survive on water containing as much as 10,000 ppm, although water of considerably better quality is necessary for maximum growth and reproduction (Smith and others, 1942, page 15). The standards for constituents considered most important by the U. S. Public Health Service (1946, pages 12-13) for drinking water used by common carriers are as follows:

Magnesium (Mg) should not exceed 125 ppm.

Chloride (Cl) should not exceed 250 ppm.

Sulfate (SO_4) should not exceed 250 ppm.

Fluoride (F) must not exceed 1.5 ppm.

Dissolved solids should not exceed 500 ppm. However, if such water is not available, a dissolved solids content of 1,000 ppm may be permitted.

These tolerances were set primarily to protect travelers from digestive disturbances. However, most people can become accustomed to water containing considerably higher mineral concentrations; although some new users may suffer ill effects from the water until their digestive systems become accustomed to the change.

Water having a chloride content exceeding 300 ppm may have a salty taste; water having a magnesium and sulfate content exceeding the standards may have a laxative effect; and water having a fluoride content exceeding 1.5 ppm may cause the teeth of children to become mottled (Dean and others, 1935, pages k-24-442). However, fluoride concentrations of about 1.0 ppm appear to reduce the incidence of tooth decay. Water which contains more than 44 ppm nitrate has been related to the incidence of infant cyanosis (methemoglobinemia or "blue baby" disease) by Maxcy (1950, page 271) and may be dangerous for infant feeding. A high nitrate content of water also may be an indication of pollution from organic matter. If the water is to be used for domestic purposes, a well yielding water containing more nitrate than other nearby wells should be tested for bacterial content. Organic matter from privies and barnyards is frequently the source of pollution and will cause an increased nitrate content in water which is in contact with or passes through such wastes. Of the 49 samples of water from Live Oak County that were analyzed for nitrate, 12 samples had no measurable nitrate, 33 samples had 0.1 to 10 ppm, 3 samples had 11 to 30 ppm, and 1 sample (D-27) had 129 ppm.

The chloride content of water of the municipal supply at George West slightly exceeds the Public Health Service standards, each well having a chloride concentration of 285 ppm on July 19, 1956. The standards for sulfate are exceeded by about 100 ppm but the magnesium content falls within the recommended limits. The fluoride content of both wells was within the recommended maximum of 1.5 ppm.

Of the 28 samples that were tested for fluoride in Live Oak County the amounts ranged from .1 to 2.5 ppm and only 3 exceeded the recommended maximum of 1.5 ppm.

Calcium and magnesium are the principal constituents in water that give it the property called hardness. Hard water increases soap consumption by causing a wasteful precipitate to form before a lather can be obtained. The greater the hardness the more rapidly incrustations (boiler scale) will accumulate in boilers, pipes, and hot water heaters. The hardness which is equivalent to the carbonate and bicarbonate content is called carbonate hardness;

the remaining hardness is called noncarbonate hardness. The hardness of water samples from wells in Live Oak County ranges from 8 ppm in a sample from the Carrizo sand to 4,080 ppm in a sample from the Largarto clay. The hardness of water samples from 354 of the wells in the county is given in Table 5 and may be compared with the commonly accepted standard of hardness for public and industrial supplies given in the following table:

Hardness range (ppm)	Classification
60 or less	Soft
61 - 120	Moderately hard
121 - 200	Hard
More than 200	Very hard

Water from many wells in Live Oak County contains appreciable quantities of silica. Although the presence of moderate amounts of silica in water is not harmful for many purposes, its presence in boiler feed water is deleterious because it forms a hard scale; the scale-forming process increases with the pressure in the boiler. The following table shows the maximum allowable concentrations of silica for water used in boilers:

Concentration (ppm)	Boiler pressure (pounds per square inch)
40	Less than 150
20	150 - 250
5	251 - 400
1	More than 400

The silica concentration in the ground water in Live Oak County that was tested ranged between 7 and 96 ppm.

Iron and manganese form reddish or dark gray precipitates which stain clothes and plumbing fixtures. The staining properties of water containing these elements are especially objectionable in some manufacturing processes. Water containing more than 0.3 ppm of iron and manganese combined will probably cause noticeable staining. Ten of 19 determinations of ground-water samples showed an iron content in excess of 0.3 ppm. Manganese was not an important constituent in the small number of samples analyzed for this element, having a concentration of 0.01 ppm or less.

Water becomes less suitable for irrigation as the salinity, sodium, bicarbonate ion, and boron hazards increase. The salinity normally is measured by the specific conductance of the water which is an index of the dissolved solids content. The specific conductance in micromhos per centimeter at 25°C. is about $1\frac{1}{2}$ times the dissolved solids content in parts per million although the relationship is somewhat variable. Percent sodium is used to express sodium hazard. The adverse effect of sodium on soil is more dependent upon the ratio of sodium in irrigation water to the total cations than to the absolute concentration of sodium. The ratio is expressed as a percent and the higher the percent sodium the greater the sodium hazard, although the hazard is somewhat less at low dissolved solids content. Percent sodium is determined by the following equation:

$$\text{Percent sodium} = \frac{\text{Na X } 100}{\text{Na} + \text{Ca} + \text{Mg} + \text{K}}$$

In this equation the concentrations are expressed in epm (equivalents per million). Parts per million values may be converted to equivalents per million by multiplying ppm by the reciprocals of combining weights of the appropriate ions. The sodium adsorption ration (SAR) is also an index of sodium hazard and expresses the relative proportions of sodium to calcium and magnesium according to the equation:

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

In this equation the concentrations are also expressed in epm. The diagram for the classification of irrigation waters based on the specific conductance and the sodium-adsorption ratio is shown in Figure 7 (page 34).

The excess of the carbonate and bicarbonate concentration over the concentration of calcium and magnesium is called the residual sodium carbonate (RSC) which is a measure of the bicarbonate ion hazard. The U. S. Salinity Laboratory Staff (1954, page 81) concluded that waters containing more than 2.5 epm residual sodium carbonate are not suitable for irrigation purposes. Waters containing 1.25 to 2.5 epm are marginal, and those containing less than 1.25 epm are probably safe. These conclusions are based on limited data and are therefore tentative. RSC is determined as follows:

$$\text{RSC} = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$$

in which the concentrations are expressed in epm.

A high boron concentration may make water unsuitable for irrigating some crops. The boron hazard is measured by the concentration of boron in the water. The limiting value for boron for arid and semiarid climates for sensitive, semitolerant, and tolerant crops is shown in the following table (Scofield, 1936):

Permissible limits of boron for several classes of irrigation waters.

Boron class	Sensitive crops (ppm)	Semitolerant crops (ppm)	Tolerant crops (ppm)
1	0.33	0.67	1.00
2	0.33 to .67	0.67 to 1.33	1.00 to 2.00

(Continued on next page)

Permissible limits of boron for several classes of irrigation waters--Continued

Boron class	Sensitive crops (ppm)	Semitolerant crops (ppm)	Tolerant crops (ppm)
3	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	1.25	2.50	3.75

Of the 28 samples analyzed for boron in Live Oak County, none contained less than 0.33 ppm, 17 contained 0.33 to 1.00 ppm, and 7 contained 1.00 to 2.00 ppm. Samples from wells L-10, B-8, H-5, and D-17 contained 2.2, 3.3, 4.3, and 5.8 ppm of boron, respectively.

The effects which the quality of irrigation water has on crops and soils in arid and semiarid climates are discussed in detail by the Staff of the U. S. Salinity Laboratory (1954). In a later report, a member of the Staff (Wilcox, 1955, page 16) states that with respect to salinity and sodium hazards water may be safely used for supplemental irrigation if its conductivity is less than 2,250 micromhos per centimeter at 25°C. and its SAR is less than 14. The maximum safe values for percent sodium, SAR, RSC, and boron have not been determined for humid or subhumid climates, but the limiting values for arid climates represent safe values for the normally subhumid climate of Live Oak County.

Other factors are also important in determining whether water is suitable to irrigate a specific piece of land. Among the more important of these factors are the permeability of the soil and subsoil, the slope of the land, the quantity of water used, the type of crop, and the amount and frequency of rainfall.

The quality of ground water in Live Oak County may differ greatly between formations and from area to area in a single aquifer. Within a single formation the quality in one strata may be considerably different from the quality in another strata; accordingly, deepening or partially plugging a well may appreciably alter the quality of water which it produces. The chemical characteristics of the ground water are not discussed by areas, formations, or depths except in very general terms in previous sections of this report because the variations are too common, too irregular, and the data far too scanty. The best prediction of the quality of water that may be obtained at a specific location can be obtained by examining data from the nearby wells.

SUMMARY OF CONCLUSIONS

A large proportion of the ground water used in 1950 in Live Oak County was of marginal or substandard quality, although large quantities of fair to excellent quality water are available locally. Most of the public, domestic, irrigation, industrial, and stock supplies are obtained from ground water. However, the municipal supply for the town of Three Rivers and some irrigation and stock supplies are obtained from surface sources. Ground-water withdrawals during 1957 from the 1,000 wells in Live Oak County averaged about 2,150,000 gpd. About 75 percent of this water was withdrawn from approximately 23 municipal and

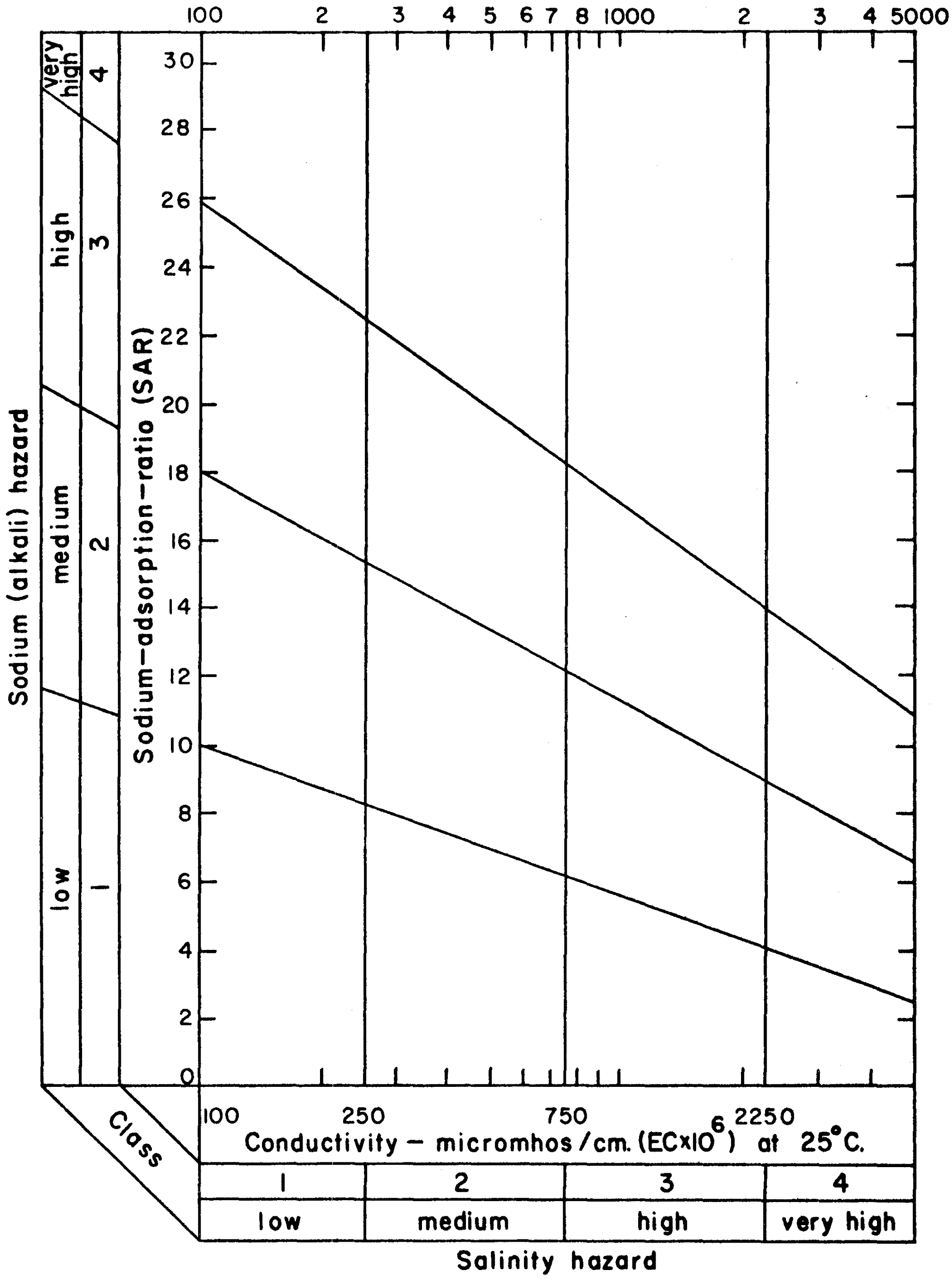


FIGURE 7.—Diagram for the classification of irrigation waters
(After United States Salinity Laboratory Staff, 1954, p. 80)

irrigation wells. Several million acre-feet of fresh and slightly saline water is available from wells less than 2,000 feet deep. The rate of withdrawal of ground water could be increased several times the 1957 rate without causing serious lowering of water levels because of the comparatively large amount of storage and because the potential rate of recharge to the principal water-bearing formations exceeds the rate of withdrawals.

Well yields range from a few gallons per minute in areas where the deposits have low permeabilities or the saturated water-bearing sand is thin to 1,000 gpm or more in areas having appreciable thicknesses of highly permeable sands. The principal water-bearing formations in the county are, in order of their importance, the Goliad sand, the Oakville sand, the Lagarto clay, and the Carrizo sand, In areas where fresh or slightly saline water is not available, wells yielding moderately saline water of satisfactory quality for livestock can probably be developed. However, very little information is available for these areas on the chemical quality of water from sands which occur at depths that exceed 500 feet. Much of the water, even in the most promising areas, contains sufficient concentrations of certain chemical components, especially calcium, sodium, boron, and silica, to limit its use for some industrial applications and to suggest that it be used with caution for long-term irrigation projects.

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Table 4.--Drillers' logs of wells in Live Oak County

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)

Well D-6

Owner: Walter E. Woelful. Driller: J. E. Hutchins.

Surface soil------------	3	3	Sand, hard--------------	33	328
Caliche-----------------	23	26	Shale and hard streaks--	395	723
Shale-------------------	269	295	Sand (water)------------	35	758

Well D-31

Owner: J. Gerald Schulz. Driller: W. E. Eads.

No record---------------	258	258	Shale, gray, hard-------	14	315
Shale and gravel--------	20	278	Shale, blue-------------	22	337
Shale, blue-------------	16	294	Sand, shale streaks-----	32	369
Sand--------------------	7	301	Shale, blue, hard-------	6	375

Well D-35

Owner: A. J. Liska. Driller: J. E. Hutchins.

Surface soil------------	10	10	Sand (water)------------	53	125
Caliche and shale-------	62	72			

Well E-23

Owner: W. A. Smith. Driller: R. R. Lawson.

Topsoil-----------------	6	6	Sand--------------------	21	86
Sand--------------------	9	15	Rock--------------------	11	97
Sand, hard--------------	12	27	Shale and rock----------	18	115
Sand--------------------	11	38	Shale, sandy------------	28	143
Sand, hard--------------	27	65	Rock--------------------	27	170

(Continued on next page)

Well E-23--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Rock and sand, hard-----	10	180	Shale, sandy------------	5	290
Shale, sandy------------	10	190	Rock--------------------	3	293
Sand (water)------------	3	193	Sand (water)------------	5	298
Shale, sandy------------	10	203	Sand, hard--------------	7	305
Shale, sticky-----------	82	285	Sand (water)------------	12	317

Well E-26

Owner: C. S. & W. H. Herring. Driller: J. E. Hutchins.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil------------	5	5	Shale, sandy------------	57	265
Caliche-----------------	30	35	Shale, sticky-----------	280	545
Sand and clay-----------	60	95	Shale, hard-------------	147	692
Shale-------------------	113	208	Sand (water)------------	30	722

Well E-27

Owner: Harold D. House. Driller: J. E. Hutchins.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil------------	5	5	Shale, red--------------	186	226
Clay--------------------	10	15	Shale, hard streaks-----	103	329
Gravel------------------	8	23	Sand (water)------------	57	386
Caliche-----------------	17	40			

Well E-30

Owner: C. S. & O. L. Herring. Driller: J. E. Hutchins.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil------------	3	3	Caliche-----------------	35	70
Clay, red---------------	32	35	Sand (water)------------	61	131

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)

Well E-38

Owner: C. S. & W. H. Herring. Driller: J. E. Hutchins.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil------------	5	5	Shale-------------------	32	155
Shale-------------------	113	118	Sand--------------------	15	170
Sand--------------------	5	123			

Well F-5

Owner: Stanolind Oil and Gas Co. Driller: W. E Eads.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil------------	4	4	Sand--------------------	30	168
Sand and caliche--------	68	72	Shale, blue-------------	27	195
Shale, blue-------------	66	138	Sand, shale streaks-----	135	330

Well F-19

Owner: Flournoy Reagan. Driller: W. E. Eads.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil------------	2	2	Clay, white, sandy------	27	92
Clay, sandy-------------	14	16	Shale, blue, sandy------	22	114
Sand and sandrock-------	49	65	Sand, blue--------------	15	129

Well F-69

Owner: Lela E. Wilson. Driller: G. R. Miller.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Topsoil-----------------	6	6	Shale, blue-------------	214	264
Sand--------------------	14	20	Sand (water)------------	20	284
Shale, gray-------------	30	50			

Well F-76

Owner: Goliad Corp. Driller: Patterson Well Service.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and clay-----------	19	19	Clay--------------------	2	21

(Continued on next page)

Well F-76--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Rock	3	24	Sand	25	185
Sand	62	86	Rock	1	186
Rock	2	88	Sand	37	223
Sand and clay	49	137	Shale	7	230
Rock	1	138	Shale and sand	32	262
Shale	22	160			

Well F-77

Owner: Goliad Corp. Driller: Patterson Well Service.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil	4	4	Rock	1	84
Sand and clay	44	48	Sand and clay	101	185
Clay	3	51	Sand	45	230
Clay, sandy	32	83	Sand and shale	32	262

Well F-78

Owner: Goliad Corp. Driller: Patterson Well Service.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil	4	4	Shale, sand streaks	70	198
Clay, sand streaks	60	64	Sand	58	256
Shale, sandy, hard streaks	64	128	Shale	4	260

Well G-14

Owner: R. E Sallee. Driller: W. E. Eads.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil	2	2	Sand	14	46
Sand	12	14	Clay, white	38	84
Clay, red	18	32	Sand	22	106

(Continued on next page)

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Well G-14--Continued					
Clay, white	49	155	Shale, blue	2	210
Sand	7	162	Sand, blue	22	232
Clay, white	46	208	Shale	3	235

Well G-15

Owner: R. E. Sallee. Driller: W. E. Eads.

Surface soil	2	2	Clay, white	15	112
Sand	54	56	Sand	34	146
Clay, white, and sand streaks	32	88	Clay, white	32	178
Sand, brown	9	97	Sand	22	200

Well H-18

Owner: Gus Houdmann. Driller: Charlie Miller.

Surface soil	4	4	Sand	20	170
Clay	16	20	Clay	130	300
Sand	30	50	Sand	85	385
Clay	100	150			

Well H-22

Owner: Humble Oil & Refining Co. Driller: Carl Vickers.

Soil	5	5	Sand	17	111
Clay	16	21	Shale	123	234
Sand	52	73	Sand	40	274
Shale	21	94			

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)

Well J-13

Owner: City of George West, well 4. Driller: R. W. Hudson.

Surface soil------------	6	6	Clay, sandy---------------	55	253
Sand and caliche--------	34	40	Clay, sticky--------------	23	276
Sand, broken, and caliche	45	85	Sand----------------------	59	335
Clay, sandy-------------	56	141	Gravel, hard, and sand----	13	348
Sand--------------------	24	165	Sand----------------------	153	501
Sand and gravel---------	33	198	Gravel, hard, and sand----	36	537

Well J-21

Owner: William Gregorcyk. Driller: W. D. Walton.

Topsoil, sandy----------	12	12	Sand (water)--------------	36	56
Clay and caliche--------	8	20			

Well J-35

Owner: Perkins & West. Driller: W. E. Eads.

Surface soil------------	3	3	Shale, red----------------	45	123
Clay, sandy-------------	5	8	Sand----------------------	19	142
Sand--------------------	14	22	Shale, hard, sandy--------	23	165
Shale, gray-------------	33	55	Shale, red----------------	29	194
Sand--------------------	23	78	Sand----------------------	78	272

Well J-36

Owner: Perkins & West. Driller: R. R. Lawson.

Topsoil and clay--------	6	6	Sand and sandrock---------	20	96
Sand and sandrock-------	16	22	Clay and shale------------	24	120
Shale, sandy------------	54	76	Sand and sandrock---------	22	142

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)

Well J-41

Owner: Buck West. Driller: C. O. E. Drilling Co.

Surface soil	5	5	Sand and gravel	8	140
Sand	15	20	Shale	20	160
Clay	90	110	Sand (water)	28	188
Shale	22	132			

Well J-73

Owner: W. M. Crocker. Driller: B. T. Sikes.

Topsoil	3	3	Clay	54	174
Clay	87	90	Sand	15	189
Sand	30	120			

Well K-23

Owner: Merle West. Driller: W. E. Eads.

Sand and caliche	15	15	Clay, sandy	36	122
Sand	7	22	Shale, red	14	136
Sand and caliche	22	44	Sand	5	141
Sand and gravel	42	86			

Well K-30

Owner: Walter H. Range. Driller: R. R. Lawson.

Clay	15	15	Sand	5	85
Clay and gravel	20	35	Shale and rock	75	160
Shale, sandy, and sandrock	45	80	Sand	10	170

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Well K-30--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand, hard	45	215	Shale, sandy, and sandrock	20	350
Sand	20	235	Sand (good)	20	370
Shale	10	245	Rock and shale	15	385
Sand	10	255	Sandrock	10	395
Shale	60	315	Shale	5	400
Sand (good)	15	330			

Well K-33

Owner: Walter H. Range. Driller: R. R. Lawson.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Topsoil and clay	4	4	Sand and sandrock	15	96
Caliche and gravel	26	30	Clay	37	133
Sand, hard	32	62	Sand and sandrock	17	150
Shale, sandy	19	81			

Well K-40

Owner: C. N. Freeman. Driller: Patterson Bros.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand and caliche	17	17	Shale	19	201
Caliche	34	51	Sand, hard streaks	14	215
Sand, caliche streaks	20	71	Shale	32	247
Caliche	6	77	Sand	15	262
Sand, caliche streaks	86	163	Shale	4	266
Shale and caliche	19	182			

Well K-85

Owner: Houston Pipeline Co. Driller: Henry Cleveland.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil	4	4	Caliche and shale streaks	111	115

(Continued on next page)

Well K-85--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Sand, soft	5	120	Sand	18	376
Caliche	30	150	Shale and lime	24	400
Shale	10	160	Sand	5	405
Sand	15	175	Lime	7	412
Shale, sticky	20	195	Shale	13	425
Sand	10	205	Sand	10	435
Sand and rock	21	226	Sand and rock	25	460
Shale	14	240	Sand, hard, and shale	38	498
Sand	14	254	Shale	46	544
Shale, sand streaks	56	310	Sand	10	554
Shale	20	330	Shale	36	590
Lime, sandy streaks	28	358	Sand	10	600

Well L-2

Owner: J. R. Dougherty Estate. Driller: W. E. Eads.

Sand	32	32	Rock, hard	4	204
Clay, sandy, rock streaks	71	103	Shale, brown, sandy	27	231
Sand	16	119	Rock, hard, sand streaks	6	237
Shale, brown, hard	81	200			

Well L-26

Owner: J. R. Dougherty Estate. Driller: W. E. Eads.

Sand	6	6	Shale, brown, sandy	57	128
Shale, brown, sandy	60	66	Shale, brown, sticky	27	155
Sand	5	71	Sand, shale streaks	18	173

Table 4.--Drillers' logs of wells in Live Oak County--Continued

Well M-9

Owner: Louis Rouch. Driller: Benny Welty.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Topsoil	3	3	Sand (good)	5	326
Sand and clay	14	17	Shale	3	329
Caliche	26	43	Sand and shale, broken	5	334
Sand	7	50	Shale	2	336
Shale	4	54	Sand, hard	4	340
Sand	14	68	Shale, hard	1	341
Shale, hard, and caliche	72	140	Sand	9	350
Sand, very fine	6	146	Shale	9	359
Shale, hard	144	290	Sand	1	360
Sand and shale	3	293	Shale	2	362
Sand and little shale	5	298	Sand	3	365
Sand	21	319	Shale	40	405
Shale	2	321			

Well M-12

Owner: W. D. Stevens. Driller: J. E. Hutchins.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface sand	3	3	Shale	86	171
Caliche	82	85	Sand (water)	61	232

Well M-17

Owner: Henry Reeves. Driller: W. L. Callaway.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil	10	10	Sand	12	152
Caliche, hard	50	60	Shale, sticky	93	245
Shale	80	140	Sand	28	273

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)

Well M-22

Owner: Humble Oil & Refining Co. Driller: Carl Vickers.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil-------------------	4	4	Shale--------------------	158	196
Clay-------------------	14	18	Sand---------------------	12	208
Caliche----------------	14	32	Shale--------------------	84	292
Sand-------------------	6	38	Sand---------------------	45	337

Well M-23

Owner: Humble Oil & Refining Co. Driller: Carl Vickers.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Surface soil-----------	4	4	Sand---------------------	14	204
Caliche----------------	61	65	Shale--------------------	46	250
Shale------------------	71	136	Sand---------------------	22	272
Sand-------------------	21	157	Shale--------------------	23	295
Shale------------------	33	190	Sand---------------------	22	317

Well M-26

Owner: Humble Oil & Refining Co. Driller: Carl Vickers.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Soil-------------------	2	2	Shale--------------------	16	257
Clay-------------------	12	14	Sand---------------------	15	272
Caliche, brown, and clay	22	36	Shale--------------------	4	276
Shale------------------	125	161	Sand---------------------	6	282
Sand, firm-------------	26	187	Shale--------------------	86	368
Sand-------------------	15	202	Sand---------------------	37	405
Shale------------------	8	210	Shale--------------------	1	406
Sand and shale streaks--	31	241			

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)

Well M-28

Owner: Humble Oil & Refining Co. Driller: Carl Vickers.

Sand-------------------	2	2	Shale and sand------------	46	290
Shale------------------	2	4	Shale, hard---------------	10	300
Caliche----------------	18	22	Shale, sandy--------------	36	336
Caliche and sand--------	61	83	Shale, hard---------------	52	388
Shale------------------	102	185	Sand----------------------	37	425
Sand-------------------	59	244			

Well M-30

Owner: William Hinnant. Driller: B. F. Sikes.

Surface soil------------	3	3	Clay----------------------	35	74
Clay-------------------	27	30	Sand (water)--------------	10	84
Sand-------------------	9	39	Clay----------------------	1	85

Well M-40

Owner: William Hinnant. Driller: Doss Well Service.

Surface sand------------	10	10	Shale, gray---------------	30	125
Sand, gray and yellow---	20	30	Sand, gray, and sandrock--	17	142
Sand, pink, and caliche-	35	65	Sand, gray (water)--------	20	162
Shale, gray, sandy------	30	95	Sand, gray and white------	11	173

Well N-1

Owner: H R. Smith Co. Driller: W E. Eads

Surface soil------------	2	2	Sand----------------------	17	142
Sand and caliche--------	61	63	Shale---------------------	28	170
Clay, sandy-------------	62	125	Sand----------------------	21	191

Table 4.--Drillers' logs of wells in Live Oak County--Continued

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)

Well N-20

Owner: Holman Cartwright. Driller: R. R. Lawson.

	Thickness (feet)	Depth (feet)		Thickness (feet)	Depth (feet)
Topsoil and clay--------	15	15	Shale, sandy--------------	3	109
Caliche, soft, and clay-	63	78	Sand (water)--------------	3	112
Sand, dry, and shale----	26	104	Shale, sandy--------------	18	130
Sand (water)------------	2	106	Sand and rock, (water)----	22	152