TEXAS
WATER
DEVELOPMENT
BOARD

REPORT 20

# GROUND-WATER RESOURCES OF LEE COUNTY, TEXAS

MARCH 1966

TEXAS WATER DEVELOPMENT BOARD

REPORT 20

# GROUND-WATER RESOURCES OF
# LEE COUNTY, TEXAS

BY

Gerald L. Thompson, Geologist
United States Geological Survey

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

March 1966

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# TABLE OF CONTENTS

Page

## TABLE OF CONTENTS (Cont'd.)

Page

## TABLE OF CONTENTS (Cont'd.)

## TABLES

## ILLUSTRATIONS

### Figures

TABLE OF CONTENTS (Cont'd.)

Page

## TABLE OF CONTENTS (Cont'd.)

## Plates

# GROUND-WATER RESOURCES OF LEE COUNTY, TEXAS

## ABSTRACT

Lee County has an area of 644 square miles in the north-central part of the West Gulf Coastal Plain of Texas. The 1960 census gave a population of 8,949. The climate is dry subhumid; the annual potential evapotranspiration exceeds the local precipitation. The economy chiefly depends on farm income from livestock and livestock products. Irrigation and petroleum are of minor economic importance.

About 6,000 feet of alternating beds of friable sandstone, highly indurated sandstone, silt, siltstone, clay, shale, and some thin local limestone lenses form the entire geologic section which contains the aquifers in the county. The water-bearing units, ranging in age from oldest to youngest (Eocene to Recent), are the: Wilcox Group, including the Simsboro Sand Member of the Rockdale Formation of Plummer (1933); Carrizo Sand; Reklaw Formation; Queen City Sand; Sparta Sand; Cook Mountain Formation; Yegua Formation; Jackson Group, including the Wellborn Sandstone; and some surficial deposits. The Simsboro Sand Member, and the Carrizo, Queen City, and Sparta Sands are the principal aquifers. All aquifers except tne surficial deposits dip southeastward at a rate of about 100 to 200 feet per mile, except in areas of faulting. An intricate fault system of en echelon grabens (the Mexia-Talco system) trends northeastward across the county and greatly complicates the geologic structure. The relation of coefficients of transmissibility, based on pumping tests in and near Lee County, to average saturated sand thicknesses would be: 150,000 gpd (gallons per day) per foot for 500 feet of the Simsboro Sand Member; 40,000 gpd per foot for 250 feet of the Carrizo Sand; 10,000 gpd per foot for 260 feet of the Queen City Sand; and 20,000 gpd per foot for 120 feet of the Sparta Sand.

In 1963 about 1.5 mgd (million gallons per day) or 1,700 acre-feet of ground water was used for public supply, irrigation, rural domestic, and livestock needs. More than 365 acre-feet of water issues annually from uncontrolled flowing wells. This amount, much of which flows to waste, is 21 percent of the combined annual quantity used by the county in 1963. The excess flow could be stopped by the installation and use of control valves on the wells.

All principal aquifers in the county possess water suitable for most uses. The Cook Mountain Formation, Yegua Formation, and Jackson Group contain water of relatively poor quality. Iron, localized sulfate concentrations (especially in the minor aquifers), and hardness of water are the chief quality problems. Shallow water in and near the outcrop generally is less mineralized, except for iron, than water at greater depths. Near the base of fresh to slightly saline water the dissolved-solids content rises sharply.

Iron is a problem in most wells. The iron problem can be largely avoided by finishing wells only in certain zones of the aquifers. Relatively low-iron water in the zone of oxidation occurs from the surface to about 80 feet in depth; high-iron water in the intermediate zone occurs between about 80 and 300 to 350 feet in depth; and relatively low-iron water in the zone of reduction occurs below 300 to 350 feet in depth.

The aquifers in the county are practically untapped. Estimates indicate that the Carrizo, Queen City, and Sparta Sands are capable of supporting a total perennial ground-water development of at least 12 mgd, and possibly as much as 40 mgd with pumping levels not exceeding 200 or 400 feet along assumed lines of discharge. Because the quantity of water available from the Simsboro Sand Member was not computed, the total of 12 mgd and 40 mgd is a conservative estimate for all of Lee County. The estimated perennial yield of each of the principal aquifers ranges from about 6 to possibly 19 mgd for the Carrizo Sand; from about 2 to possibly 12 mgd for the Queen City Sand; and from about 4 to possibly 9 mgd for the Sparta Sand.

# GROUND-WATER RESOURCES OF LEE COUNTY, TEXAS

## INTRODUCTION

### Purpose and Scope of Investigation

Information on the ground-water resources of Lee County, and on the means of deriving maximum benefits from available supplies, is presented in detail in this report. The material is the result of a ground-water investigation, begun in October 1963, by the Water Resources Division of the U.S. Geological Survey in cooperation with the Texas Water Development Board.

The scope of the investigation includes: a determination of the location and extent of important fresh-water-bearing formations; the chemical quality of the water; the quantity of ground water being withdrawn, and the effects of these withdrawals upon water levels and water quality; the hydraulic characteristics of the important water-bearing units; an estimate of the quantity of ground water available for development from each of the important aquifers; and a consideration of all significant ground-water problems in Lee County.

To accomplish these objectives, records of 329 water wells and springs (Table 4), including 62 electric logs of oil tests and water wells, and 31 drillers' logs (Table 5) were collected and studied; water samples from 180 wells were collected and analyzed, Moreover, present and past pumpage of ground water was inventoried, and aquifer tests were made on three wells to determine the hydraulic characteristics of the aquifers,

The technical terms used in discussing the ground-water resources of the county are defined and listed alphabetically in the section entitled "Definitions of Terms."

### Location and Extent of Area

Lee County, an area of 644 square miles, is in east-central Texas (Figure 1) between latitude 30°01' and 30°34' N and longitude 96°38' and 97°21' W. It is bordered on the northwest by Williamson and Milam Counties, on the northeast by Burleson County, on the southeast by Washington and Fayette Counties, and on the southwest by Bastrop and Fayette Counties. Giddings, the county seat, is in the southern part of the county and is about 56 miles east-southeast of Austin.

## Climate

Lee County has a dry subhumid climate (Thornthwaite, 1952, fig. 30) in which the annual potential evapotranspiration exceeds the annual precipitation. Hot summers and mild winters are common. The long growing season, averaging 261 days, and the usually adequate rainfall make Lee County a favorable agricultural area.

The average monthly precipitation in Lee County (Figure 2) attains a primary peak of about 4.5 inches in April, slightly lesser amounts in May and June, and a secondary peak of about 4.2 inches in September. Minimum precipitation of approximately 2 inches occurs in July.

The average annual precipitation at Giddings (from 1941-63) is 37.45 inches. Average annual rainfall decreases from about 38 inches at the southeast corner of Lee County to about 34 inches at the northwest corner of the county.

Figure 3 shows the relation between average monthly temperature, average monthly evaporation, and average monthly relative humidity at College Station. This monthly pattern reveals a corresponding increase in average monthly evaporation with increasing average monthly temperature and a decreasing average monthly relative humidity. During the hot summer months when soil moisture demand by vegetation is high, low relative humidity and high evaporation also contribute to a reduction in available soil moisture and thereby reduce the potential recharge to the aquifers.

The center of Lee County is 40 miles southwest of College Station. The average annual gross lake-surface evaporation for Lee County is about 59 inches (Lowry, 1960).

## Physiography and Drainage

Lee County is in the north-central part of the West Gulf Coastal Plain of Texas (Fenneman, 1938, p. 102, 105; Deussen, 1924, fig. 2). More specifically the county is in the western part of the East Texas timber belt (Fenneman, 1938, pl. VII), locally termed the "post-oak belt." Topographically the altitude of the county ranges from slightly less than 230 feet at the confluence of Yegua and Cedar Creeks, in the southeastern part, to slightly more than 775 feet in the Yegua Knobs area 12 miles west-southwest of Lexington.

Several physiographic features trend northeastward across Lee County. These features, related to the geological outcrops, are manifest in prairies and hills. The land surface of the principal outcropping aquifers in the northern half of the county is mostly forested and gently rolling. In the southern part of the county where aquifers of lesser importance crop out, the land surface is irregularly dissected, forming low-lying hills and abrupt escarpments.

Most of Lee County is in the drainage area of the Brazos River (Cronin and others, 1963, fig. 1). A small area south of Giddings is in the Colorado River Basin. The principal streams of Lee County that drain into the Brazos River are East Yegua, Middle Yegua, West Yegua, and Yegua Creeks, Brushy Creek, Elm Creek, Nails Creek: and Cedar Creek. A part of East Yegua and Yegua Creeks marks the county line separating Lee and Burleson Counties, and a part of Cedar Creek separates southeastern Lee County from Washington County. Pin Oak, Rabbs, and

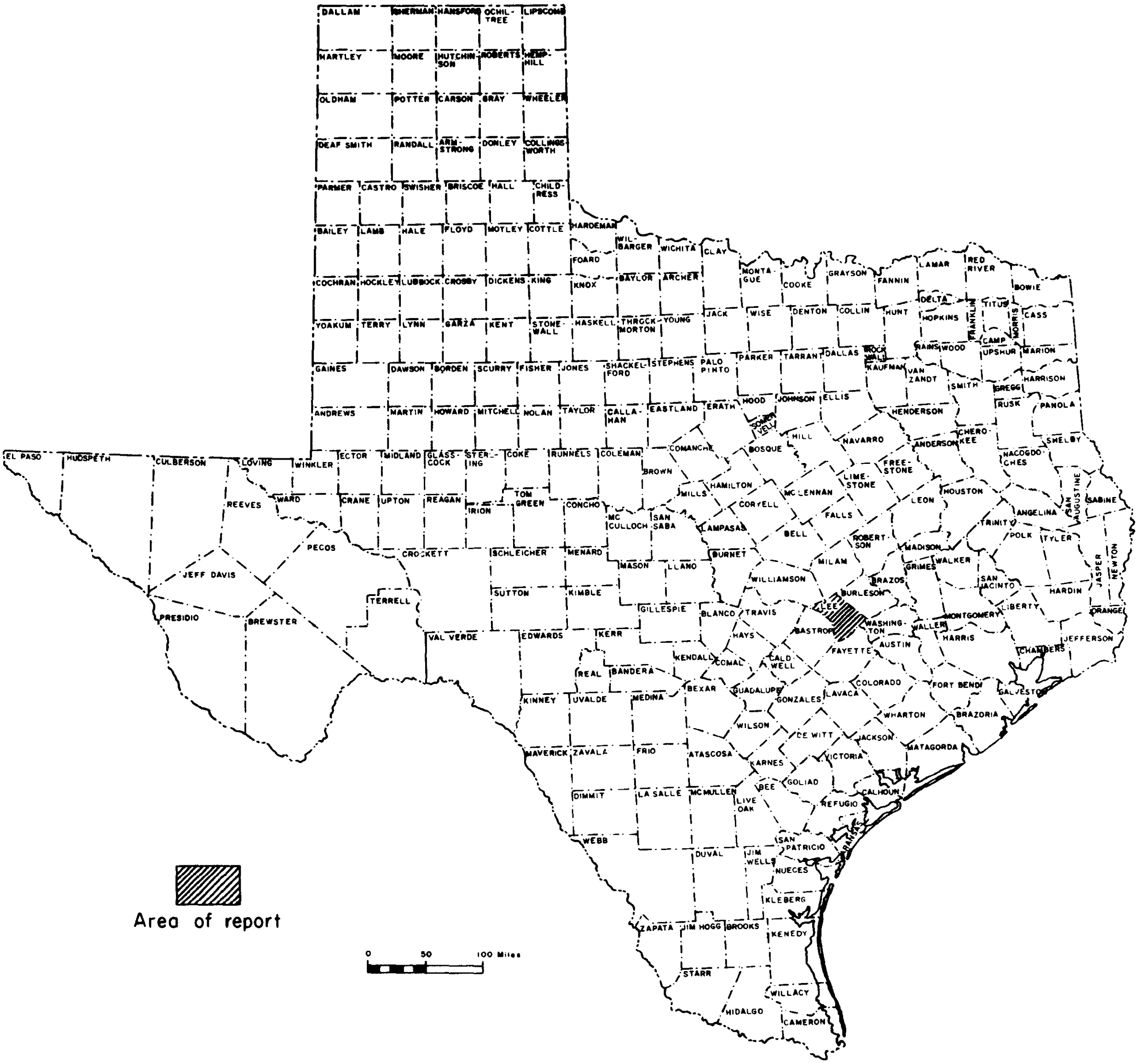
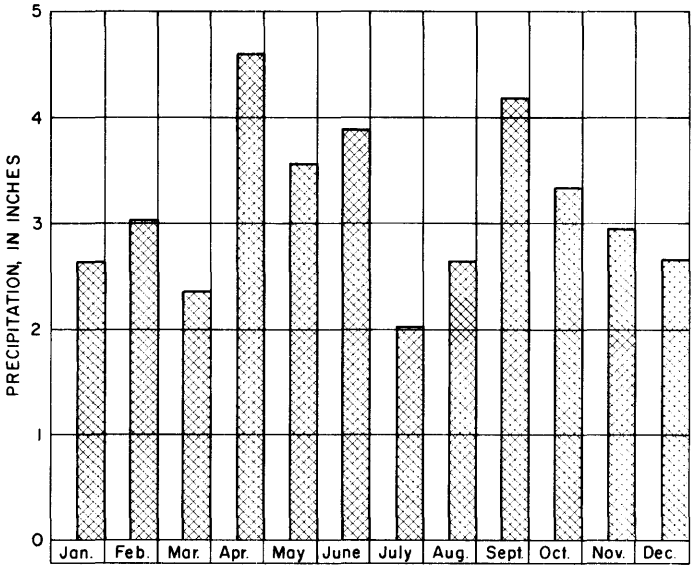


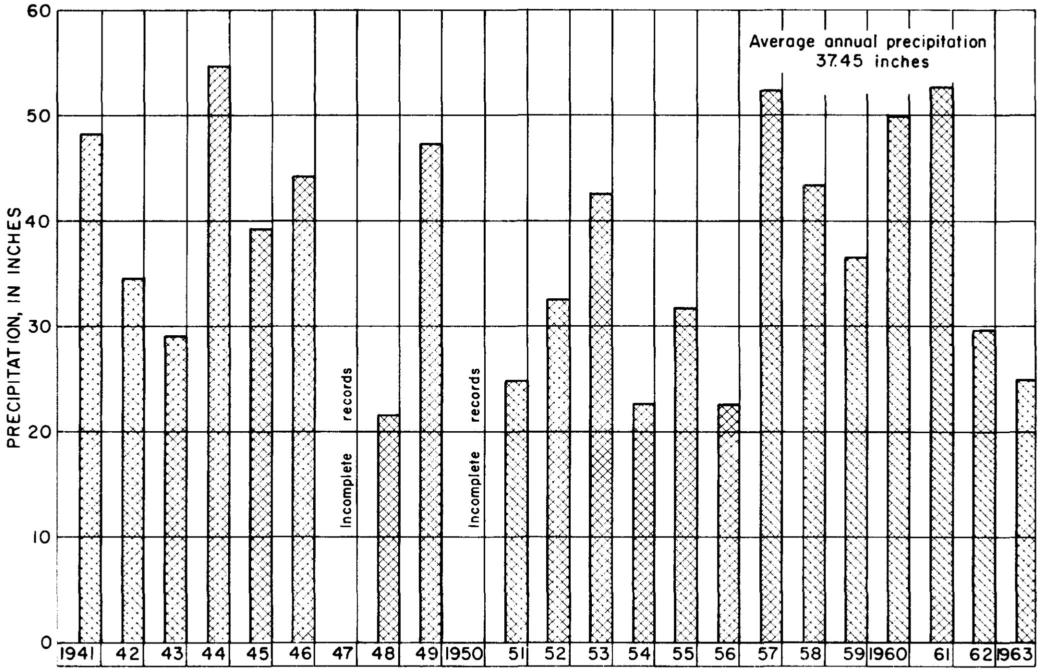
Figure I

Map of Texas Showing Location of Lee County

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



Average monthly precipitation at Giddings, 1941-63



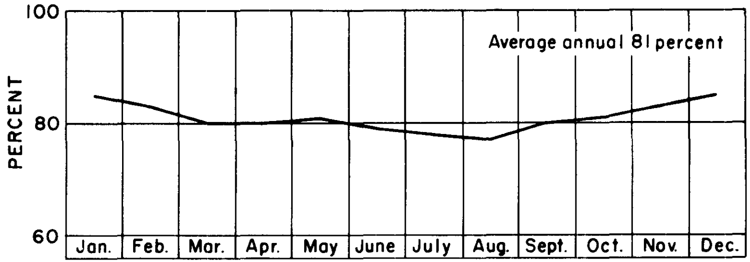
Average annual precipitation at Giddings, 1941-63

Figure 2

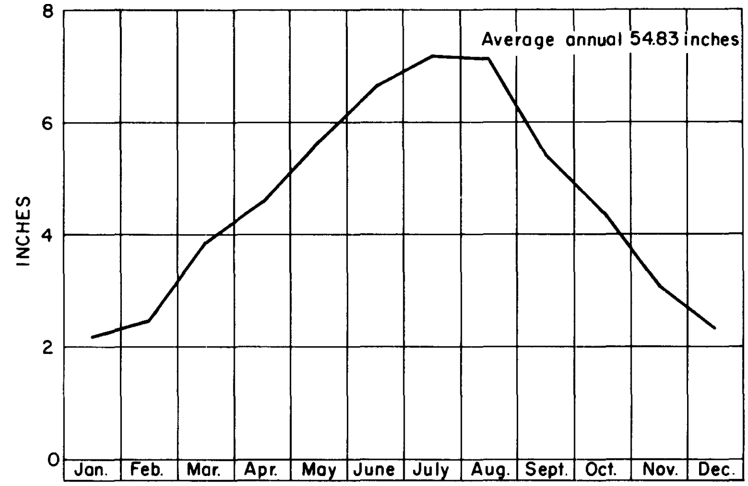
Average Monthly and Annual Precipitation at Giddings, 1941-63

(From records of U. S. Weather Bureau)

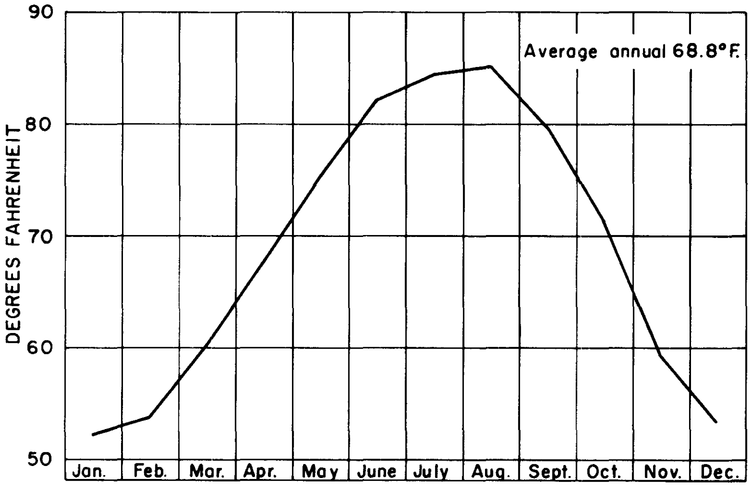
U. S. Geological Survey in cooperation with the Texas Water Development Board



Average monthly relative humidity, 1915–53



Average monthly evaporation, 1916–51 (Gross evaporation from a sunken pan 96 inches in diameter and 24 inches deep)



Average monthly temperature, 1931-60

Figure 3

Average Monthly Temperature, Evaporation, and Relative Humidity at College Station

(From records of U.S. Weather Bureau; and Bloodgood, Patterson, and Smith, 1954)

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

Cummins Creeks south of Giddings are the principal streams that drain into the Colorado River. During a large part of each year most streams in the county flow intermittently, except in local sections where they are fed by springs or uncontrolled flowing wells.

## Economic Development

State records show that Lee County was organized in 1874. The U.S. Census Bureau lists a county population of 8,937 in 1880, a maximum of 14,595 in 1900, and a steady decline from about 14,000 in 1920 to 8,949 in 1960. The population estimate for 1962 is 8,702. The cities and villages were populated in 1960 as follows: Giddings, 2,821; Lexington, 711; Dime Box, 400; Lincoln, 350; Northrup, 100; Fedor, 86; Old Dime Box, 50; Tanglewood, 40; and Mannheim, 30. In 1960 the remaining 4,361 people (49 percent) lived elsewhere in the county.

The total income in the county during 1962 was about $9,130,000, farm income amounting to 46 percent of the total. Two-thirds of the farm income came from livestock and livestock products; in fact, the county is among the most productive hog- and poultry-raising counties in Texas. Leading crops in the county are corn, peanuts, cotton, sorghum, and hay, plus minor amounts of oats and wheat. In 1964 an estimated 200 acres was irrigated by ground and surface water for growing crops. Only two irrigation wells RZ-58-39-504 and RZ-59-33-701 were located in the county, but some landowners irrigate from earthen storage tanks.

Local deposits of fuller's earth, clay, sand, gravel, and lignite are near the surface throughout the county. Of these deposits, lignite in the Wilcox Group has received the most attention. Two mine shafts about 50 feet deep exposed a 4-foot lignite seam near Hicks 2.8 miles north of Tanglewood. The lignite seams here were uneconomically thin and mining operations stopped in 1930 after only 5 years duration (Fisher, 1963, p. 50). Later, hundreds of test holes were drilled in northern Lee County and southern Milam County by the Aluminum Co. of America (Alcoa) to evaluate the economic distribution of the lignite. Alcoa has mined lignite by open pit in Milam County since 1952 for fuel in its aluminum plant about 6 miles northwest of Tanglewood.

Test drilling for petroleum in the county dates from before 1930. Hundreds of oil and seismic test holes have been drilled. The first significant oil production came from Tanglewood field, discovered in December 1948 at 6,316 feet in the Lower Cretaceous Edwards Limestone. Some natural gas is also produced from this field. Another discovery area (McDade field) in the west-central part of the county began production in October 1953. Total oil production here was 334 barrels from sands in the Wilcox Group at a depth of 2,877 feet. The most important discovery area was the Giddings field which began producing in October 1960. The oil comes from the Upper Cretaceous Austin Chalk at a depth of 7,480 feet.

The accumulative oil production to January 1, 1964 in Lee County was 99,365 barrels

## Previous Investigations

Prior to this investigation, little detailed study had been made of the ground-water resources of Lee County. The first investigation (Taylor, 1907), which summarized the well development in Lee County, stated that most wells ranged from 40 to 50 feet in depth and that the county had only one flowing well (800 feet deep), owned by M. G. York near Leobau about 7 miles north-northeast of Giddings.

Clark (1937) inventoried more than 175 wells and included chemical analyses and drillers' logs in his report on Lee County.

A summary of public water supplies in eastern Texas by Sundstrom, Hastings, and Broadhurst (1948) included an inventory of municipal wells, well logs, chemical analyses of water samples, and estimates of water consumption and storage capacity for Giddings, Lexington, and Dime Box. A recently published report related to Lee County is a reconnaissance ground-water investigation of the Brazos River Basin by Cronin and others (1963).

Various reports on regional geology in eastern and southeastern Texas describe the geologic formations common to Lee County. For discussions of the county geology, the reader is referred to Deussen (1914, 1924), Dumble (1918), Renick and Stenzel (1931), Renick (1936), Stenzel (1939), and Harris (1941). With the exception of unpublished work by oil companies, a detailed geologic study of the county has never before been done.

## Well-Numbering System

The well-numbering system used in this report is one adopted by the Texas Water Development Board for use throughout the State and is based on latitude and longitude. Under this system, each l-degree quadrangle in the State is given a number consisting of two digits. These are the first two digits appearing in the well number and may number from 01 to 89. Each l-degree quadrangle is divided into 7 1/2-minute quadrangles which also are given 2-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7 1/2-minute quadrangle is subdivided into 2 1/2-minute quadrangles and given a single digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2 1/2-minute quadrangle is given a 2-digit number in the order in which it is inventoried, starting with 01. These are the last two digits of the well number. In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefix for Lee County is RZ. Thus, well RZ-59-49-505 (which supplies water for the city of Giddings) is in Lee County (RZ), in the l-degree quadrangle 59 (the numbers of all the wells in Lee County begin with either 58 or 59), in the 7 1/2-minute quadrangle 49, in the 2 1/2-minute quadrangle 5, and was the fifth well (05) inventoried in that 2 1/2-minute quadrangle (Figure 4). The letter prefixes for those counties adjacent to Lee County that are used in this report are: Bastrop County, AT; Burleson County, BS; Fayette County, JT; and Milam County, TK.

On the well-location map in this report (Plate 1), the l-degree quadrangles are numbered in large bold numbers. The 7 1/2-minute quadrangles are numbered in their northwest corners. The 3-digit number shown with the well symbol contains the number of the 2 1/2-minute quadrangle in which the well is located and the number of the well within that quadrangle. For example, the city of Giddings well is numbered 505 in the quadrangle numbered 49.

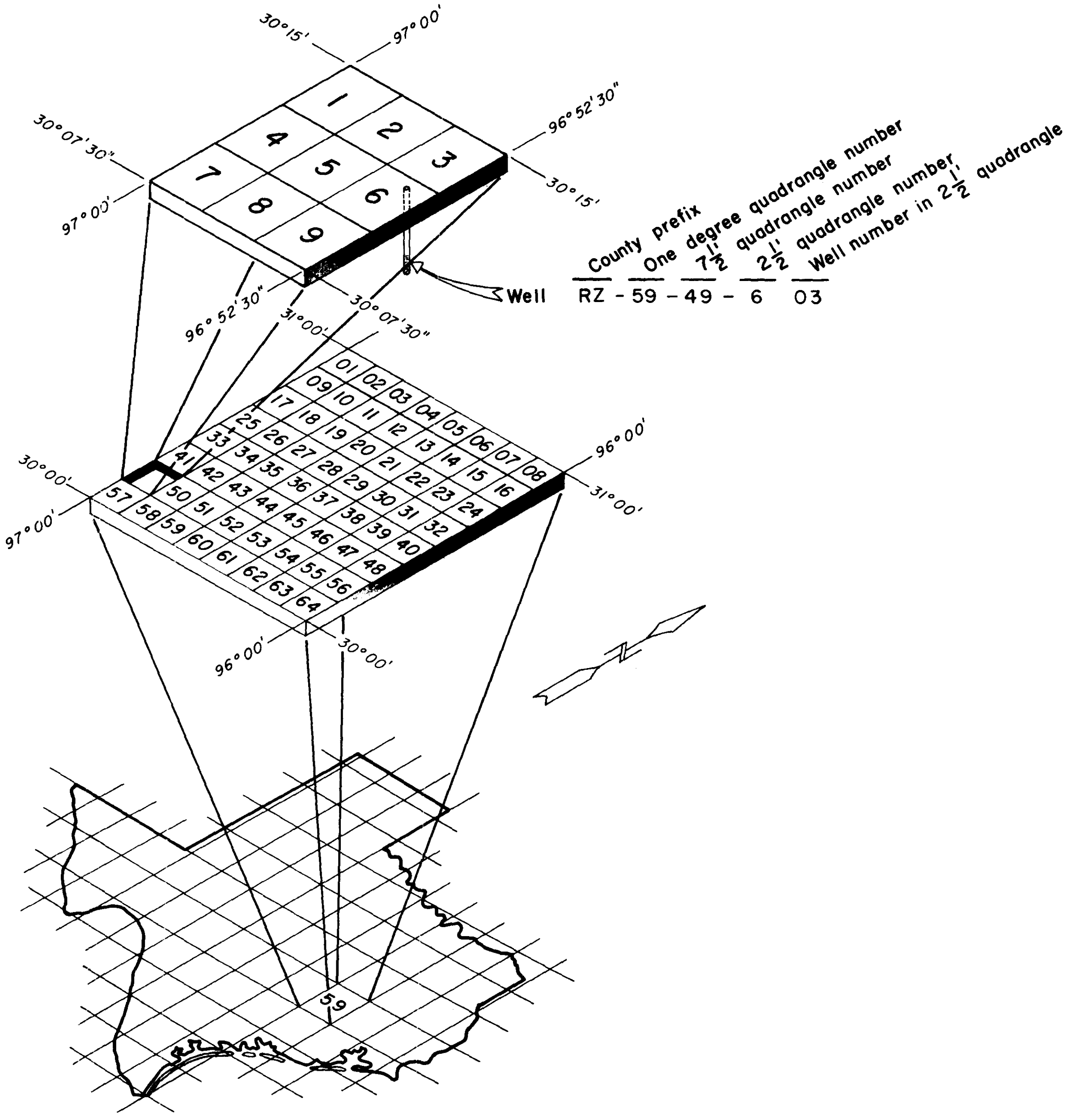


Figure 4

Well - Numbering System

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

## Acknowledgments

The author is indebted to the property owners in Lee County for supplying information about their wells and for permitting access to their properties; to the local well drillers for logs and other information on water wells; to the city officials of Giddings, Lexington, and Dime Box who supplied pumpage data and cooperated in pumping tests on municipal wells; to federal and State agencies, especially the Soil Conservation Service, U.S. Department of Agriculture, in Giddings, and to Brown 0. Spivey, the Lee County Agricultural Agent. Considerable geological information was made available by Dr. Virgil Barnes of the Bureau of Economic Geology, University of Texas, through the courtesy of the Shell Oil Co.

Appreciation is expressed to Layne-Texas Co., Inc., Houston, Texas, for supplying information from their files on public supply wells in Lee County; and to Pan American Petroleum Co., Houston, Texas, for supplying an electric log of a part of a Lee County test hole drilled in 1964.

# GEOLOGY

## General Stratigraphy and Structure

The geologic formations pertaining to ground water in Lee County range in age from Paleocene to Recent. Accordingly, they are, from oldest to youngest: the Midway Group, Wilcox Group, Carrizo Sand, Reklaw Formation, Queen City Sand, Weches Greensand, Sparta Sand, Cook Mountain Formation, Yegua Formation, Jackson Group,, and various surficial deposits. All of the formations are aquifers of varying degrees of significance except the Midway, Weches, and some surficial deposits. The area1 geology (Darton and others, 1937) of Lee County is shown in Figure 5.

Thicknesses, lithologic characteristics, age, and water-bearing properties of the formations are summarized in Table 1. The maximum thickness for a complete geologic formation as shown in this table was determined from interpretations of all available electric logs in the county.

About 6,000 feet of alternating beds of friable sandstone, highly indurated sandstone, silt, siltstone, clay, shale, and some thin local limestone lenses form the entire geologic section containing the aquifers. This series of aquifers, ranging in age from Eocene to Recent, is underlain by the Midway Group (a thick shale) of Paleocene age (Plates 2 and 3).

All formations except the surficial deposits crop out in belts that generally trend northeastward and dip southeastward, in areas undisturbed by faulting, about 100 to 200 feet per mile. The rate of dip varies with the depth of the formation.

An intricate fault system trending northeastward across the county complicates the geologic structure in a large part of the northwestern half of the county. Much of the literature refers to this faulting as the Luling-Mexia-Talco fault system. Murray (1961, p. 178; Zink, 1957, fig. 1) contends, however, that the data now available distinguish the Luling system from the Mexia-Talco system. He further states that the Luling system extends from the vicinity of

Table 1.--Geologic units, their physical character, and water-bearing properties in Lee County

| System | Series | Group | | Geologic unit | Maximum thickness (feet) | Physical character of rocks | Water-bearing properties† |
|---|---|---|---|---|---|---|---|
| Quaternary | Recent and Pleistocene | | Surficial deposit | Flood-plain alluvium | ? | Clay, silt, and fine sand. | May yield very small quantities of water to wells. |
| | | | | Terrace sand | ? | Well-sorted fine sand. | Does not yield water to wells. |
| | | | | Reworked unsorted alluvium | ? | Sandy clay and scattered fragments of silicified wood. | Yields very small quantities of water to dug wells. |
| | | | | Ferruginous conglomerate | ? | Highly indurated reworked upland gravel and angular fragments of medium- to coarse-grained ferruginous sandstone. | Does not yield water to wells. |
| Tertiary(?) | Pliocene(?) | | | Uvalde Gravel (Upland gravel) | ? | Gravel and cobbles of flint, chert, and silicified wood. | Do. |
| Tertiary | Eocene | Jackson | | McElroy Formation | ? | Chocolate-colored shale containing bentonitic clay, tuff, and some sandstone. | Not known to yield water to wells. |
| | | | | Wellborn Sandstone | 95 | Chiefly medium- to coarse-grained gray sandstone; chocolate-colored lignitic shale in middle part. | Capable of yielding small to moderate quantities of water to wells. |
| | | | | Caddell Formation | 40 | Chocolate- to grayish-colored, lignitic, and locally glauconitic shale. | Not known to yield water to wells. |
| | | Claiborne | | Yegua Formation | 750 | Interbedded sand, sandy and carbonaceous clay, and lignite. | Yields small quantities of water to domestic and stock wells. Capable of yielding moderate quantities of water. |
| | | | | Cook Mountain Formation | 400 | Predominantly fossiliferous shale. The Spiller Sand Member of Stenzel (1940), about 50 to 75 feet thick, is near the middle of the formation. | Yields small quantities of fresh to slightly saline water to wells. The Spiller Sand possibly can yield moderate quantities. |
| | | | | Sparta Sand | 170 | Fine- to medium-grained sandstone and some brown, lignitic shale. Shale in middle of formation splits sandstone into upper and lower units in some areas. | Yields small to moderate quantities of fresh to slightly saline water to municipal, domestic, and stock wells. Capable of yielding large quantities of water. |

Table 1.--Geologic units, their physical character, and water-bearing properties in Lee County--Continued

| System | Series | Group | Geologic unit | Maximum thickness (feet) | Physical character of rocks | Water-bearing properties† |
|---|---|---|---|---|---|---|
| Tertiary | Eocene | Claiborne | Weches Greensand | 110 | Predominantly fossiliferous glauconitic shale; some sandstone and fossiliferous thin limestone. | Not known to yield water to wells. |
| | | | Queen City Sand | 500 | Massive to thin-bedded, ferruginous and slightly lignitic sandstone interbedded with some gray or brown, silty, lignitic shale; thin ironstone ledges are common; sandstone becomes more shaly downdip. | Yields small to large quantities of fresh to slightly saline water to municipal, domestic, and stock wells. |
| | | | Reklaw Formation | 270 | Gray to brown shale in upper part and glauconitic sandstone interbedded with shale in lower part. Weathered sandstone is fine- to coarse-grained, highly ferruginous, and bright red to vermilion in color. | Upper shaly part can yield only very small quantities of water to wells. Sandstone in lower part possibly can yield moderate quantities. |
| | | | Carrizo Sand | 465 | Massive, friable, commonly cross-bedded, well sorted, fine- to medium-grained, light-gray sandstone. | Capable of yielding large quantities of water to wells. |
| | | Wilcox | | *1,690 | Interbedded lignitic and carbonaceous sandstone and shale. Sandstone is argillaceous, silty, and poorly sorted. | Capable of yielding moderate quantities of water to wells. |
| | | | Simsboro Sand Member of Rockdale Formation of Plummer (1933) | * 765 | Massive, fine- to medium-grained, well-sorted sandstone. | Capable of yielding large quantities of water to wells. |
| | | | | *1,380 | Interbedded lignitic and carbonaceous sandstone and shale. Sandstone is argillaceous, silty, and poorly sorted. | Capable of yielding moderate quantities of water to wells. |
| | Paleocene | Midway | | ? | Predominantly shale; some silty shale, siltstone, and sandstone. | Not known to yield water. |

* Determined from electric logs of different test holes.

† See "Yield of a Well" in section entitled "Definitions of Terms."

Zavala County across the San Marcos arch into Williamson County, which is northwest of Lee County. Luling-system faults predominantly are normal, northwestward dipping, and upthrown on the gulf-coast side.

Murray (1961, p. 180, 184; Zink, 1957, p. 21) believes that the Mexia-Talco system, a zone of en *echelon* grabens, commences approximately in Bastrop County on the north flank of the San Marcos arch and extends slightly east of north across Lee, Burleson, Milam, and Robertson Counties, and on to Hunt County. In Hunt County the graben-zone faulting arcs abruptly eastward, crossing Titus and Bowie Counties into Arkansas.

The distinguishing feature of the Mexia-Talco system is that an 8-mile-wide structural belt of parallel, en *echelon*, normal faults, dipping in opposing directions, forms a downthrown central zone of en *echelon* grabens. The individual faults trend slightly obliquely to the trend of the structural belt of faulting. Plates 2 and 3 illustrate the graben effect of the Mexia-Talco system in the county.

The strike and dip of beds in the zone of complex faulting may deviate considerably from the attitude of beds elsewhere in the county. Some examples of erratic bedding attitudes are: road cut 0.15 mile south of well RZ-59-33-206, beds strike N90°E and dip 15°S; road cut 0.2 mile northeast of well RZ-58-48-602, beds strike N50°E and dip 6°SE; road cut 0.6 mile southeast of spring RZ-58-40-807, beds strike N35°-40°W and dip 6°- 7°SW; in gully 0.22 mile north-northwest of well RZ-58-48-105, thin flagstone beds strike N25°W and dip about 8°SW. Southeast of the area of complex faulting, shale interbeds in the Wellborn Sandstone of the Jackson Group in the escarpment trending northeastward from oil test RZ-59-50-301 strike N74°-84°E and dip 2°-10°SSE. This relatively steep dip suggests faulting, although faults are not known to be mapped in this area.

Most faults in the zone of complex faulting are normal moderately high-angle en *echelon* faults that trend acutely a few degrees north of the general strike of the beds.

The attitude of fault planes in two localities is: about 0.75 mile southwest of test hole RZ-58-40-506, a narrow resistant ridge about 3 to 5 feet high shows a nearly vertical fault plane that trends N23°E; and in a gulley about 0.18 mile south of water well RZ-58-48-108, a fault strikes N15°E and dips 34°SE. Although faults are common in the area of complex faulting, good exposures of fault planes are uncommon.

Formations are downthrown toward the southeast within the northwest margin of complex faulting, and they are downthrown toward the northwest within the southeast margin of faulting. The combination of faulting forms the structurally broken, downthrown graben zone which averages about 7 or 8 miles in width in Lee County. The fractures and faults cutting the rocks of this zone are immensely complex. Electric logs of test holes RZ-58-48-403, RZ-58-48-801, and RZ-59-33-202 indicate that two distinct faults intersected these holes. As interpreted on an electric log, the usual stratigraphic throw, or vertical displacement: by a single fault ranges from about 200 feet to at least 770 feet. The maximum known total displacement of 1,015 feet is in test hole RZ-58-48-801 (Plate 2). Here an upper fault displaced 770 feet of rock section near the top of the Midway Group, and a lower fault displaced 245 feet near the top of the Upper Cretaceous Austin Chalk. The amount of vertical displacement increases with increasing depth of the fault plane. Possible explanations of this increased displacement are either that movement along established fault planes continued periodically during deposition (Lahee, 1929, p. 356), or that the angle of the fault plane approaches a vertical attitude with increasing depth, or both.

## Physical Characteristics and Water-Bearing Properties of the Geologic Units

## Tertiary System

### Paleocene Series

### Midway Group

The outcrop of the Midway Group of Paleocene age was not observed during the investigation in Lee County, although the unit is shown on the Geologic Map of Texas (Darton and others, 1937) as cropping out in the extreme northwestern tip of the county. The group underlies the entire county; the top of the unit occurs at very shallow depths in the northwestern part but extends to about 6,000 feet near test hole RZ-59-50-803. The top of the Midway Group, as used in this report, is where the electric-log characteristics indicate that lithology changes from the predominant sand and silt of the Wilcox Group to an underlying predominance of silt and clay of the Midway. A predominance of shale, silty shale, some siltstone, rare thin sandstone beds, plus a moderate abundance of marine fossil fauna characterizes the Midway (Murray, 1961, p. 367-369). The thin sandstone beds or lenses, where present, most commonly are near the top of the formation. Electric logs indicate that the Midway is several hundred feet thick, but definite limits in thickness were not established.

Electric-log interpretations place the top of the Midway Group considerably below the base of fresh to slightly saline water throughout most of Lee County. The shaly and relatively impermeable character of the Midway excludes it from aquifers of any significance.

### Eocene Series

### Wilcox Group

The Wilcox Group of early Eocene age crops out in the northwestern part of the county west of the zone of complex faulting (Figure 5). The group includes a widespread deltaic accumulation of lignitic or carbonaceous sand and interbedded shale which interfingers coastward with marine deposits. Generally the sand beds are moderately argillaceous and silty, cross-bedded, and lenticular. The shale beds, commonly lignitic, silty, and sandy, maintain their lateral continuity over greater distances than the sandstones. Although most sandy beds in the Wilcox are limited laterally in extent, they probably are hydrologically interconnected.

Poor sorting of sediments characterizes most of the Wilcox Group; silicified wood is abundant in many beds. Because the water-yielding ability or permeability of beds relates to the sediment size and degree of sorting, permeability of the Wilcox is highly variable through short distances. Certain beds may be excellent water producers locally, but very poor elsewhere.

The complete thickness of the Wilcox Group as interpreted from electric logs ranges from about 2,050 feet in test hole RZ-58-40-506 in the northern part of the county to about 2,800 feet in test hole RZ-59-50-803 in the southern part. The top of the Wilcox dips southeastward to a maximum depth of about 3,000 feet below land surface in the latter test hole.

The Wilcox includes a massive sandy facies-- the Simsboro Sand Member of the Rockdale Formation of Plummer (1933). On electric logs that part of the Simsboro above the base of fresh water is highly resistive, massive, and distinctive from the constant repetitions of alternating sandstone and shale characterizing other parts of the Wilcox Group.

Except for some massive sandstone in the upper part of the Wilcox and the Simsboro Sand Member, the Wilcox Group can yield only small to moderate quantities of water.

Simsboro Sand Member of the Rockdale Formation of Plummer (1933).--The Simsboro Sand Member of the Rockdale Formation of Plummer (1933) was mapped by W. A. Reiter from near Rockdale, Milam County, to the Trinity River (Plummer, 1933, p. 586), and samples from several hundred described sections in this area were examined petrographically by Kohls (1963, p. 111). Kohls (p. 116) concluded that the Simsboro Sand Member included five rock types that represented two facies-- a continental and a marine facies: "The continental facies is composed of material that was eroded, transported, and deposited in stream channels as small, sand sized, consolidated, clay fragments; the clay carried in suspension was deposited on the adjacent flood plains. The marine facies, exposed south of the Brazos River, consists of white, medium- to fine-grained, massive to cross-bedded, well sorted, cherty sand with local clay pebbles near the base." In Bastrop County, Adams (1957) observed a small amount of glauconite in thin sections and almost no interstitial clay.

The bodies of sand constituting the Simsboro Sand Member probably are lentitular, but they show a broad lateral extent. The separate lentils of sand may become attenuated and ultimately disappear; but other lentils replace them in the stratigraphic section, and the predominantly sandy character of the Simsboro Sand Member is maintained (Hoeman and Redfield, 1943, p. 283-284). The pattern of sedimentation, as interpreted from electric logs in Lee County, indicates that deposition of the massive sand beds continuously shifted with time--even as an oscillating off-shore bar responds to a shifting strand line and the changing longshore currents.

The Simsboro Sand Member in Lee County ranges from 400 to about 765 feet in thickness. The maximum altitude below sea level of the top of the member is about 4,500 feet (Figure 6). The massive character of the Simsboro continues downdip far below the base of fresh to slightly saline water and at least into the northern part of Fayette County. Although the Simsboro Sand Member in Lee County is tapped only by rural domestic and stock wells, interpretations of the electric logs and chemical analyses of water in Lee County and of the pumping-test data from adjacent areas indicate that permeability is good, water quality is good to fair above the base of fresh to slightly saline water, and the massive thickness is capable of yielding large quantities of water in most areas. The strike of the top of the Simsboro Sand Member varies between about N35°E and N45°E, and the dip generally increases from about 120 feet per mile in central Lee County to about 200 feet per mile in the southeastern part of the county.

## Claiborne Group

The Claiborne Group includes those beds between the base of the Carrizo Sand and the top of the Yegua Formation. This group of beds reflects a rhythmic series of alternating continental and marine environments.

Carrizo Sand.--The Carrizo Sand, a continental deposit, lies unconformably on the eroded top of the Wilcox Group. Cropping out in a belt that is partly traversed by the zone of complex faulting, the Carrizo completely disappears on the surface in the northeastern corner of the county where the Queen City Sand is downfaulted against the Wilcox Group (Figure 5). The unfaulted outcrop of the Carrizo Sand in western Lee County ranges from 1.5 to 2.5 miles in width. The altitude of the top of the Carrizo ranges from more than 350 feet above sea level near the outcrop to about 2,400 feet below sea level in the southeastern part of the county (Figure 7). Southeast of the area of complex faulting, the general strike of the top of the Carrizo varies between about N30°E and N50°E; the dip gradually increases from about 90 feet per mile in central Lee County to about 140 feet per mile in the southeastern part of the county.

Unweathered outcrops of the Carrizo Sand are rare in Lee County. Where exposed, the Carrizo is a massive, friable, commonly cross-bedded, clean, fine- to medium-grained, well sorted, light-gray sandstone. It weathers at the land surface to form a deep loose sand, which generally ranges from pale orange to light gray (or ashen) in color. The weathered Carrizo Sand on the outcrop forms numerous rounded hills which generally support deep-rooted vegetation, such as post oak and some cedar or pine.

As used in this report and as shown by electric logs in the geologic sections, the Carrizo Sand includes all sand beds which show a high electrical resistivity and generally appear massive on electric logs. These beds are below the shaly section of the Reklaw Formation and above the thin interbedded sand and shale constituting the upper part of the Wilcox Group.

The Carrizo Sand is generally characterized by clean, well sorted, friable, massive sandstone throughout Texas, and generally is a highly permeable geologic formation. In contrast, the Wilcox Group consists of some shale and interbedded, fine to medium, poorly sorted, lenticular sand containing various amounts of clay and lignite. However, some upper sandy parts of the Wilcox Group have high electrical resistivity and appear massive on electric logs. On these logs, therefore, a distinctive break or change in electrical characteristics may or may not indicate a formational contact between the Carrizo and the underlying Wilcox. The massive and resistive sand beds immediately above and below the actual contact, however, constitute a hydrologic unit.

In places in Lee County, very hard beds of coarse, highly ferruginous to hematitic, argillaceous sandstone having abundant interbedded ironstone, and oblate concretions of clay-ironstone (lower part of the Reklaw Formation or Newby Glauconitic Sand Member of Stenzel, 1938, p. 65-71) overlie light-colored siltstone and grayish-silty shale in the upper Carrizo Sand. The total thickness of the sandy beds in the lower part of the Reklaw is indefinite. These resistant beds are medium- to very coarse-grained, and can show high electrical resistivity on electric logs. However, on the electric logs the identification of these beds as Carrizo or Reklaw is inconclusive. The Carrizo Sand, as defined previously, may include locally some beds that are stratigraphically equivalent to beds in the lower part of the Reklaw Formation. But, as in the previously described relation of the Carrizo to the Wilcox, sand beds immediately above and below the actual formational contact here also constitute a hydrologic unit.

The complete section of the Carrizo Sand as determined from electric logs of test holes in Lee County ranges in thickness from 170 feet in test hole RZ-59-25-805 to 465 feet in test hole RZ-59-49-802. Faulting and the absence of prominent bedding prevent accurate determinations of the formation thickness in the outcrop area. Consequently, the width of the outcrop cannot be correlated accurately with the subsurface thickness of the Carrizo Sand that is shown in the geologic sections.

Stenzel (1953, p. 51) states that in Bastrop County near Coppera Creek, approximately 2.5 miles east of Bastrop, the Carrizo Sand is about 80 to 120 feet thick; and in Leon County, he states (1938, p. 65), "...calculates 57 feet for the Carrizo sand thickness west of Marquez, if the rate of dip is 33 feet per mile." A cross section constructed from electric logs in Leon County (Peckham, 1965, pl. 2) reveals that the Carrizo is about 160 feet thick in test hole SA-39-47-604. The Carrizo Sand is 82 feet thick in the northwest part of the Smithville quadrangle (Craddock, 1947, p. 34).

The Carrizo Sand is thicker in the west-central part of Lee County than elsewhere. The proportion of shale interbeds progressively increases downdip as shown by test holes RZ-59-49-802 and JT-59-58-701 in Plate 2, and by RZ-59-42-404 to JT-59-59-101 in Plate 3. In areas where shale interbeds are prominent in the Carrizo Sand, it diminishes in importance as an aquifer. The chemical quality of the water also deteriorates in these areas.

Most wells tapping the Carrizo Sand are in the area of complex faulting. These wells are chiefly rural domestic and stock wells drawing only small quantities of water. In general, wells properly developed in the Carrizo are capable of yielding large quantities of water.

Reklaw Formation.--The geologic map (Figure 5) shows a narrow surface wedge of Reklaw Formation in the west-central part of Lee County. A fault terminates the surface exposure of this geologic unit on the map at a point along the general trend of the outcrop about 5 miles northeast of the Bastrop County boundary. Faulting limits the outcrops of the Reklaw, but numerous unmapped remnants of the formation occur along some of the faults, especially in the area north of Lexington.

The Reklaw Formation consists of gray, chocolate-brown, or red-brown shale in the upper part and of glauconitic sandstone interbedded with shale in the lower part. Fresh exposures of the upper part are rare. Where exposed in the county, the lower glauconitic sandstone commonly is highly ferruginous and weathers to bright red, reddish brown, and vermilion in color. The thickness of this lower sandstone section is difficult to determine because of faulting and poorly exposed outcrops. Locally, the sandstone is medium- to very coarse-grained, and highly indurated; it is ferruginous throughout the county. These beds interfinger with other ferruginous and argillaceous sandstone beds containing layers of red-brown, crinkly bedded, glauconitic, sandstone partings, and brownish oblate clay-ironstone concretions about 4 to 6 inches in diameter.

The formational contact separating the non-ferruginous upper silty and argillaceous beds in the Carrizo Sand and the overlying highly ferruginous medium- to very coarse-grained sandstone in the lower part of the Reklaw Formation is visible near the boundary between Bastrop and Lee Counties. According to Stenzel (1938, p. 70), these lower sandstone beds in Leon County have a measured thickness of 20.7 feet; but he does not state whether this is a total thickness for these beds. Lyth (1949, p. 93) states that the lower unit is 125 feet thick. No fossils were observed in the lower part of the Reklaw in Lee County.

The Reklaw Formation shown in the subsurface in the geologic sections is predominantly shale below the base of the Queen City Sand and above the top of the electrically high-resistive sandstone beds in the Carrizo Sand. Downdip the lower part of the Queen City becomes shaly, and it is increasingly difficult to distinguish the upper part of the Reklaw Formation from the lower part of the Queen City Sand on electric logs.

A complete section of the Reklaw Formation ranges in thickness from about 150 feet near the outcrop to 270 feet in test hole RZ-59-50-803 near the southeastern edge of the county. The formation thickens considerably as the depth to the Reklaw increases. The top of the formation about 6 miles north-northwest of Dime Box trends N52°E and dips about 76 feet per mile southeastward. About 4 miles northeast of Giddings, the top trends N33°E and dips about 138 feet per mile southeastward. The maximum depth from land surface to the top of the formation is about 2,350 feet in the southeastern part of the county.

The Reklaw Formation's upper shale unit can yield only very small quantities of water; however, the lower sandstone beds possibly can yield moderate quantities. No wells are definitely known to tap the Reklaw.

Queen City Sand,--The Queen City Sand, a continental deposit, conformably overlies the Reklaw Formation and crops out in a northeastward-trending belt. Complex faulting and a moderate easterly swing in the trend of the formation east of Tanglewood and Lexington gradually broadens the belt eastward from a width of about 2 miles in western Lee County to about 8 miles in the northeastern part of the county (Figure 5).

Massive to thin-bedded, ferruginous, and slightly lignitic sandstone interbedded with some gray or brown, silty, lignitic shale constitute the formation. The sandstone generally is cross-bedded and fine- to medium-grained. Thin ironstone ledges commonly occur in the sandstone throughout the Queen City, especially in the lower part of the formation. Shale becomes more prominent downdip (Plate 3, see wells RZ-59-50-803 and JT-59-59-101).

The Queen City Sand forms some rounded hills where sandy ironstone ledges prevail and some subdued sand flats, but much of the outcrop forms rolling sand hills. The weathered surface sand on the hills and flats is light in color, and superficially resembles outcropping Carrizo Sand. A few inches below the surface, however, the distinctive reddish color of the unleached parent formation is present everywhere. In fresh exposures, the Queen City Sand ranges from light gray to orange and brown in color; but prolonged weathering oxidizes tile formation to various shades of bright red or reddish-orange and vermilion, tan, and dark reddish-brown, especially in areas where ironstone is common.

A complete section of the Queen City Sand ranges approximately from 260 to 500 feet in thickness. In central Lee County the strike of the formation varies between about N35°E and N45°E. The dip gradually increases southeastward from about 77 feet per mile near Dime Box to about 140 feet per mile in the southern part of the county. The top of the formation dips to a maximum altitude of about 1,700 feet below sea level near the southeast corner of the county (Figure 8].

The Queen City Sand yields small to moderate quantities of fresh to slightly saline water to domestic and stock wells in the area of outcrop and downdip for a distance of about 3 to 4 miles. Farther downdip, in public supply well RZ-59-49-505 at Giddings, the Queen City yields up to 400 gpm from a depth interval between 900 and 1,385 feet (400 to 885 feet below sea level). Electric-log interpretive data indicate that all sand beds in the Queen City can yield fresh to slightly saline water as far southeastward as the northern margin of Fayette County.

Weches Greensand.--The Weches Greensand, a marine deposit, disconformably overlies the Queen City Sand (Stenzel, 1938, p. 109-110). At least, these formations probably are disconformable along the updip contact where marine glauconitic shale and fossiliferous limestone of the Weches make a sharp lithologic contrast with the underlying non-fossiliferous, continental, cross-bedded sandstone of the Queen City. A disconformable contact in Lee County was not discernible in the field even though exposures of the Weches here are similar lithologitally to described outcrops of the Weches in Leon County by Stenzel (1938, p. 93-110). The stratigraphic contact between the marine deposits of the Weches and the underlying nonmarine Queen City is sharp and distinct on some electric logs (Plate 3, well RZ-59-42-404). Because an ungradational lithology in many of the relatively shallow sections is indicated by electric logs, a possible updip disconformable contact is implied; downdip the contact locally appears transitional and less sharp (Plate 3, well JT-59-59-101), and the formations are possibly conformable.

According to Figure 5, the Weches Greensand crops out in numerous irregular patches which commonly are faulted. Some outcrops shown on the map seem uncommonly wide for a formation that averages about 80 feet thick. Electric logs show that the complete Weches is from 50 to 110 feet thick.

Fossiliferous glauconitic shale, minor sandstone, and some fossiliferous thin limestone constitute the Weches Greensand. The fresh shale exposures in recent road cuts in or near Lee County are dark greenish-gray to greenish-black in color. Shale is the principal rock type in the formation; greensand refers to the glauconite grains characterizing the unit. No known water wells tap the

Weches Greensand, and the shaly, relatively impermeable character of the formation excludes it from classification as an aquifer.

Sparta Sand.--The Sparta Sand in Lee County probably is conformable with the underlying Weches Greensand, although Stenzel (1938, p. 119) states that the contact in Leon County is disconformable. Although the true nature of the contact in Lee County is uncertain, electric-log interpretations suggest some minor lithologic transition near the contact of the Weches Greensand and Sparta Sand. The deposition of the continental Sparta Sand probably moved quickly over the marine Weches Greensand, and nothing locally suggests that the Weches was extensively eroded and reworked into the lower part of the Sparta Sand.

Topsoil from the Sparta Sand is very similar to that of the Queen City and the Carrizo Sands. Topsoil from the Sparta is yellowish-light gray to moderately grayish-orange pink in contrast , with the white to light-gray color that characterizes unstained soil from the Carrizo Sand. The soil from the Sparta is similar to that from the Carrizo also because both soils are loose, unstratified, and deep; but soil derived from the Carrizo generally is deeper, whiter, and looser than soil derived from the Sparta. The subsoil from the Sparta Sand shows a moderately reddish-pink color and contains some clay beds not characteristic in the subsoil from the Carrizo Sand.

Most of the Sparta Sand consists of fine- to medium-grained, stratified, loose sand beds. The individual sand beds are somewhat cross-bedded and separated by thin layers of shale or silt. Brown, lignitic shale is generally subordinate to sand; but in some parts of the county, a thick shale bed divides the Sparta Sand into an upper and lower sand (Plate 3, test hole RZ-59-50-803). In northern Fayette County the aquifer consists of much interbedded shale.

Some local glauconitic sandstone beds in the lower part of the Cook Mountain Formation may interfinger with the upper part of the Sparta Sand (Stenzel, 1938, p. 123). Therefore in this report, the upper part of the Sparta may include some beds that could be the Stone City Beds of Stenzel (1935) of the Cook Mountain Formation.

The complete Sparta Sand in the county ranges from 85 to about 170 feet in thickness. The strike of the top of the formation varies between N30°E and N50°E. The top gradually increases in dip southeastward from about 125 feet per mile in the central part of the county to 145 feet per mile in the southern part. The maximum altitude of the top in the southern part of the county is about 1,350 feet below sea level (Figure 9).

The Sparta, which yields small to moderate quantities of fresh to slightly saline water in the county, is, however, capable of yielding large quantities. Numerous domestic and stock wells tap the aquifer in the outcrop and downdip for several miles. Water for public supply comes from the Sparta at Dime Box (well RZ-59-42-203) at a depth between 365 and 450 feet, and at Giddings (well RZ-59-49-506) at a depth between 755 and 815 feet.

Cook Mountain Formation.--The Cook Mountain Formation, a marine deposit, overlies the Sparta Sand and crops out in a northeasterly trending belt across the south-central part of the county. The belt ranges in width from about 6 miles in the southwestern part of the county to about 1 mile in the east-central part (Figure 5). Because much of the land surface in the southern half of the county is capped by alluvial gravel and sand, exposures of the Cook Mountain are uncommon.

The lower part of the Cook Mountain Formation consists of interfingering glauconitic sandstone and fossiliferous shale beds that resemble the fossiliferous shale of the Weches Greensand. This lower part is overlain by dark brownish-black, lignitic, slightly calcareous shale that commonly contains secondary gypsum crystals.

Overlying the dark gypsum-bearing shale, and near the middle of the formation, is about 50 to 75 feet of sand known as the Spiller Sand Member of Stenzel (1940) of the Cook Mountain Formation. In southeastern Leon County, Stenzel (1938, p. 150) describes the Spiller Sand Member as being 105 feet thick and as having beds that are characteristically of gray or brown, lignitic, muscovitic sand ranging in thickness from a few inches to about 2 feet. Brown silty or sandy shale separates the beds of sand. The Spiller Sand Member differs from older sand formations, such as the Carrizo and Sparta, by the considerably greater amount of argillaceous material which the fresh rock contains.

The upper part of the Cook Mountain Formation consists of another sequence of interbedded gray to light-brown silt and brown to gray-green shale that overlies the Spiller Sand Member. Shale predominates in the upper part overlying the Spiller.

The Cook Mountain Formation in Lee County ranges from 350 to 400 feet in thickness, its top being about 1,160 feet below land surface in test hole RZ-59-50-803 in the southeastern part of the county. The formation yields to wells only small quantities of fresh to slightly saline water. The Spiller Sand Member possibly could yield moderate quantities of water to properly constructed wells.

Yegua Formation.--The Yegua Formation, a continental deposit, overlies the predominantly shaly Cook Mountain Formation. Their formational contact, as identified on electric logs in Lee County and adjacent counties, probably is transitional and arbitrarily is placed where sand beds predominate over the shale lithology of the underlying Cook Mountain. The outcrop of the Yegua trends northeastward in a belt that widens gradually from about 2 miles in southwestern Lee County to about 8.5 miles at East Yegua Creek southeast of Dime Box.

Dumble (1918, p. 102-103) described the original type locality of the Yegua Formation in sections on Elm and Yegua Creeks in Lee County. He also published lists of marine fossils from the outcrop along Elm Creek north of Giddings. These fossils now are regarded as in the upper part of the Cook Mountain Formation (Stenzel, 1939, p, 898-899).

The Yegua Formation consists of layers of sand, sandy and carbonaceous clay, and lignite. None of the layers can be traced or correlated any great distance. In many respects the depositional environment during Yegua time was similar to that of the Wilcox. The Yegua contains more sand, carbonaceous matter, gypsum, and locally fossilized wood than the Cook Mountain. Thin beds of bentonite and some volcanic ash also occur in the Yegua but not in the Cook Mountain.

The complete Yegua Formation in the county ranges from about 630 to 750 feet in thickness, increasing to more than 800 feet downdip in northern Fayette County. The formation top dips to 540 feet below land surface in well RZ-59-50-803.

The Yegua Formation yields small quantities of water to wells for domestic and stock use in the county, but is capable of yielding moderate quantities. Most wells tapping the Yegua are in the outcrop or only a short distance downdip.

## Jackson Group

The Jackson Group (Eargle, 1959, p. 2626) conformably overlies the Yegua Formation. In Lee County is found only the lower part of this group. The group crops out in a belt covering a large segment of the southeastern part of the county (Figure 5). The belt of Jackson beds slightly north of the county boundary averages from 3.5 to 5 miles in width. The remaining upper part of the group extends into northern Fayette and Washington Counties.

The geologic formations in the Jackson Group that crop out in the county are, in ascending order: the Caddell Formation, a 40-foot section of chocolate- to grayish-colored, lignitic, and locally glauconitic shale; the Wellborn Sandstone (described below); and the McElroy Formation, a predominantly chocolate-colored shaly section of bentonitic clay, volcanic tuff, and some interbedded lenses of sandstone (Renick, 1936, p. 33-34). The Wellborn Sandstone is the only formation of this group in the county that yields adequate quantities of water for domestic and stock use.

Wellborn Sandstone.--The Wellborn Sandstone is chiefly sandstone but contains some thin interbeds of chocolate-colored, lignitic clay and gray, fissile, lignitic shale in the middle part of the formation (Renick, 1936, p. 25, 30). The lower sandstone, which is gray and medium grained, contains ashy material; the upper beds of this sandstone are massive and vary from hard sandstone to quartzite. The middle part of the formation contains, in addition to beds of clay and shale, hard ledges of sandstone which extend for several miles. The upper part of the Wellborn Sandstone is generally well exposed. It is gray to white in color, is more argillaceous than the basal sandstone section, and also contains lignitized and silicified wood as well as some medium- and coarse-grained cross-bedded sand beds. Electric logs indicate that the Wellborn Sandstone in the southern part of the county is about 95 feet thick.

The formation is capable of yielding small to moderate quantities of water; however,, the water becomes rapidly more mineralized downdip.

## Tertiary(?) and Quaternary Systems

### Pliocene(?), Pleistocene, and Recent Series

### Surficial Deposits

Five kinds of surficial deposits cover bedrock surfaces in the county: upland gravel, terrace sand, local ferruginous pebble and cobble conglomerate, reworked unsorted alluvium, and flood-plain alluvium. Of these deposits only the flood-plain alluvium, mainly along Yegua Creek, is shown in Figure 5.

A large part of the uplands in the southern half of the county, especially that beginning a short distance south of Lincoln, is covered by a loose, coarse gravel and a moderate amount of cobbles. Chert, especially dark-colored flint, and some silicified wood constitute the bulk of the deposits. This upland material is either a widespread terrace deposit of the Colorado River or, more probably, an older dissected sheet of siliceous gravel known as Uvalde Gravel (Pliocene(?)). Although these deposits yield no water, they retard runoff and facilitate ground-water recharge.

A highly indurated, ferruginous conglomerate consisting of reworked upland gravel and angular blocks or boulders of medium- to coarse-grained ferruginous sandstone occurs in scattered patches and forms a belt that is restricted to the region of complex faulting. Excellent exposures of this conglomerate are along the north side of Farm Road 696 about 4.8 miles west of Lexington. The conglomerate probably is related to the fault zone and to mineralized solutions that moved along the fault planes. The conglomerate, which is above the present water table, does not yield water.

Reworked unsorted alluvium several feet thick covers many lower slopes and fills some of the broad valleys in the north-central part of the county. These deposits, consisting of sandy clay and scattered angular chunks of silicified wood, yielded small quantities of water to many old dug wells; but the wells were unreliable and few are still in use.

The terrace sand is a fine-grained, well sorted deposit, which flanks some hills in the central and western parts of the county. This deposit, originating after the upland gravel, yields no water to wells but facilitates recharge to underlying bedrock.

Flood-plain alluvium occurs along nearly all streams in the county. These deposits generally consist of clay, silt, and fine sand. Wells tapping flood-plain alluvium may yield very small quantities of water.

# GROUND-WATER HYDROLOGY

## Source and Occurrence of Ground Water

The primary source of ground water in Lee County is precipitation on the outcropping geologic formations and drainage from adjoining areas. A large proportion of precipitation becomes surface runoff because it moves rapidly down inclined hill surfaces or across relatively impermeable rocks such as shale and limestone. If the rain is intense, the proportion of surface runoff increases because the time available for absorption of the precipitation is inadequate even in very sandy areas. Some of the water from precipitation evaporates at the land surface, some leaves the soil zone by evapotranspiration through plants, some remains in the subsoil owing to cohesive capillary forces, and a small part of the original precipitation infiltrates downward by gravity through essentially dry rocks to the local water table or zone of ground-water saturation. In the zone of saturation, the infiltrating water fills all the intergranular spaces and becomes ground-water recharge to the water-bearing formations.

Ground water occurs under either water-table or artesian conditions. Many publications describe the general principles of the occurrence of ground water in all kinds of rocks: Meinzer (1923a, p. 2-142; 1923b), Meinzer and others (1942, p. 385-478), Todd (1959, p. 14-114), and Baldwin and McGuinness (1963). Ground water in the outcrop of many formations is unconfined and under water-table conditions. Water under these conditions does not rise above the point where first encountered in a well. In most places the configuration of the water table approximates the topographic shape of the land surface. Downdip from the outcrop, the aquifer may lie beneath a relatively impermeable layer of rock. The water then is under artesian conditions and has hydrostatic pressure; the pressure is nearly equal to the weight of a column of water extending upward to the height of the water table in the area of outcrop of the aquifer. Where the altitude of the land surface at a well tapping an artesian aquifer is below the general altitude of the aquifer outcrop, the hydrostatic pressure of the water may be sufficient to raise the water level in the well substantially--possibly even high enough for the well to flow. Flowing wells commonly are in areas of low altitudes, especially in the valleys of the largest streams.

## Recharge, Movement, and Discharge of Ground Water

Recharge of ground water to the aquifers underlying Lee County initially begins with precipitation on the outcrop of the aquifers. Only a small percentage of the precipitation becomes recharge, the bulk of the precipitation being diverted by various means. Some of the precipitation is evaporated, some transpired by vegetation, and some becomes surface runoff to local tributaries, lakes, and earthen tanks. However, these bodies of water are local sources of recharge. The quantity of water that becomes recharge is affected not only by evapotranspiration and runoff, but also by such factors as intensity of rainfall, absorbing character of the land surface, topographic slope, air temperature and humidity, depth of root penetration by various plants, and the depth of the water table below land surface.

In some areas, water from irrigation and uncontrolled flowing wells infiltrates the land surface. Recharge from these sources is negligible in Lee County.

Recharge also occurs in the subsurface in the county because of differences in hydrostatic pressure in the aquifers. Recharge by this means is accomplished by vertical movement of water from one aquifer to another through overlying semiconfining beds and along fault planes in the zones of faulting. Recharge by these means is not a primary source of water but actually incidental to underground-water movement.

The dominant direction of ground-water movement after initial infiltration is vertically downward under the force of gravity through the zone of aeration to the water table, or zone of saturation. In the zone of saturation, the movement of water generally possesses a large horizontal component in the direction of decreasing head or pressure. The rate of movement rarely is uniform in direction or velocity, but is directly proportional to the hydraulic gradient. The hydraulic gradient tends to steepen with increasing flow near areas of natural discharge and around pumping wells.

Adequate data were not available for the preparation of water-level maps in Lee County, but in general the ground water moves southeastward down the dip of the aquifers at a natural velocity of about 10 to 40 feet per year. The hydraulic gradient in most of the principal aquifers ranges from about 6 to 10 feet per mile.

Fresh to slightly saline water in the aquifers underlying Lee County moves constantly toward areas of either natural or artificial discharge. The most obvious means of natural discharge of water are by springs, seepage to streams and marshes where the water table intersects the land surface, transpiration by vegetation, evaporation through soil, and by eventual downdip movement of ground water into adjacent counties bordering on the south and southeast.

## Hydraulic Characteristics of the Aquifers

The value of an aquifer as a source of ground water principally relates to the ability of the aquifer to transmit and to store water. Coefficients of transmissibility, permeability, and storage, determined by pumping tests, are the measurements of that ability.

The coefficients of transmissibility and storage are also used to predict the drawdown or decline in water levels caused by pumping from an aquifer. Where a well pumps from an aquifer, a cone of depression develops in the piezometric surface or water table around the pumping well. Pumping from wells drilled close together may create cones of depression that intersect, thereby causing additional lowering of the piezometric surface or water table. The intersection of cones of depression or interference between wells will result in lower pumping levels (and increased pumping costs) and may cause serious declines in yields of the wells. The proper spacing of wells, determined from aquifer-test data, can minimize interference between wells.

Aquifer tests were conducted at three sites in Lee County. The tests were made in wells which probably tapped the uppermost part of the Carrizo Sand at Lexington, the Queen City Sand at Giddings, and the Sparta Sand at Dime Box. Some of the wells tested did not screen all of the water-bearing sand in the aquifers. Therefore, the coefficients of transmissibility determined from these tests represent only a part of the total thickness of saturated sand in the aquifers. To obtain estimates of the hydraulic characteristics of all the principal aquifers in Lee County, the local tests were supplemented with tests in other counties.

No aquifer tests were made on the Simsboro Sand Member of the Rockdale Formation of Plummer (1933) in Lee County. The only water-well data that indicate the Simsboro's hydraulic characteristics come from other counties. The Aluminum Co. of America taps the aquifer with three wells in southwestern Milam County about 10 1/2 miles north-northwest of Lexington. Records of test pumping each of these wells indicate coefficients of transmissibility (based on specific capacities) ranging from 15,000 to 28,000 gpd (gallons per day) per foot for 40 to 50 feet of sand out of about 300 feet of saturated sand in the Simsboro Sand Member at the well sites. Coefficients of permeability ranged from 300 to more than 500 gpd per square foot. The average saturated sand thickness of the Simsboro Sand Member in Lee County is about 500 feet (Figure 19). Assuming a coefficient of permeability of 300 gpd per square foot in Lee County and on the basis of an average saturated sand thickness of 500 feet, a coefficient of transmissibility of 150,000 gpd per foot is possible for the Simsboro Sand Member in Lee County. This aquifer is an impressive ground-water reservoir for large-capacity wells in most of Lee County.

No conclusive hydraulic data on the Carrizo Sand were obtained in Lee County. Aquifer tests were made in Lexington in public supply wells RZ-58-40-903 and RZ-58-40-904, which probably tap the uppermost part of the Carrizo Sand. Because the identity of the aquifer was questionable, the application of the hydraulic data is questionable. However, values of transmissibility and storage for the Carrizo in other counties are available in the following reports: Cronin and others (1963, p. 94), Peckham and others (1963, p. 72-73), and Shafer (1965). Based on data in other counties, a coefficient of transmissibility of 40,000 gpd per foot and a coefficient of storage of 0.0002 are presumed to be about average for the total average thickness of the Carrizo Sand in Lee County. Figure 20 indicates that the average thickness of sand in the Carrizo is about 250 feet.

The time-distance-drawdown curves of the Carrizo Sand under artesian conditions (Figure 10) show that a Carrizo well pumping continuously at a rate of 1,000 gpm (gallons per minute) for 1 day, theoretically will lower the water level about 12 feet in other Carrizo wells 1,000 feet from the pumping well. At the same pumping rate and distance the water levels would be lowered about 21 feet after 30 days; about 25 feet after 1 year; and a maximum of about 26 feet after nearly 3 years, at which time equilibrium will be established.

The aquifer tests on the Queen City Sand were made in public supply well RZ-59-49-505 at Giddings. The coefficient of transmissibility at that site was about 7,000 gpd per foot. Because the average sand thickness of the Queen City Sand in the county is about 260 feet (Figure 21) and because only 160 feet of sand was screened in the test well at Giddings, the average coefficient of transmissibility in the county was estimated to be about 10,000 gpd per foot. Peckham and others (1963, p. 88-89) cite coefficients of transmissibility ranging from 3,000 to 12,700 gpd per foot in the Neches and Sabine River Basins, and also state that "..coefficients of transmissibility up to 10,000 gpd per foot can be expected in the western part of the [Trinity River] basin." The coefficient of storage of the artesian part of the Queen City Sand in Lee County was estimated to be 0.0002.

The time-distance-drawdown curves for the Queen City Sand under artesian conditions (Figure 11) show that a Queen City well pumping continuously at the rate of 300 gpm for 1 day, theoretically will lower the water level about 9 feet in any other Queen City well 1,000 feet from the pumping well. At the same pumping rate and distance the water level would be lowered about 21 feet after 30 days; about 29 feet after 1 year; and a maximum of about 31 feet after about 12 years, at which time equilibrium would be established.

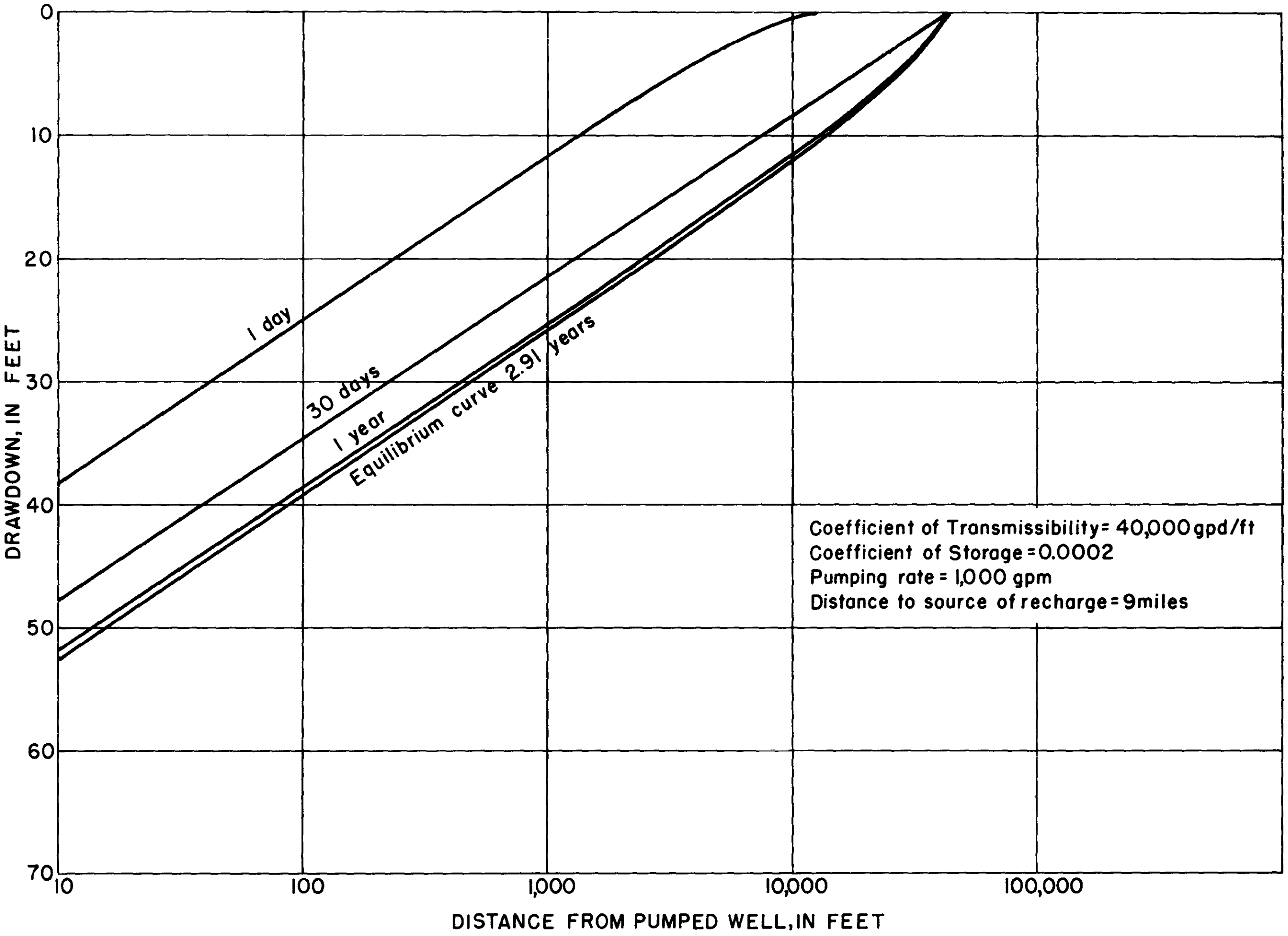


Figure 10

Relation of Drawdown and Time to Distance in the Carrizo Sand

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

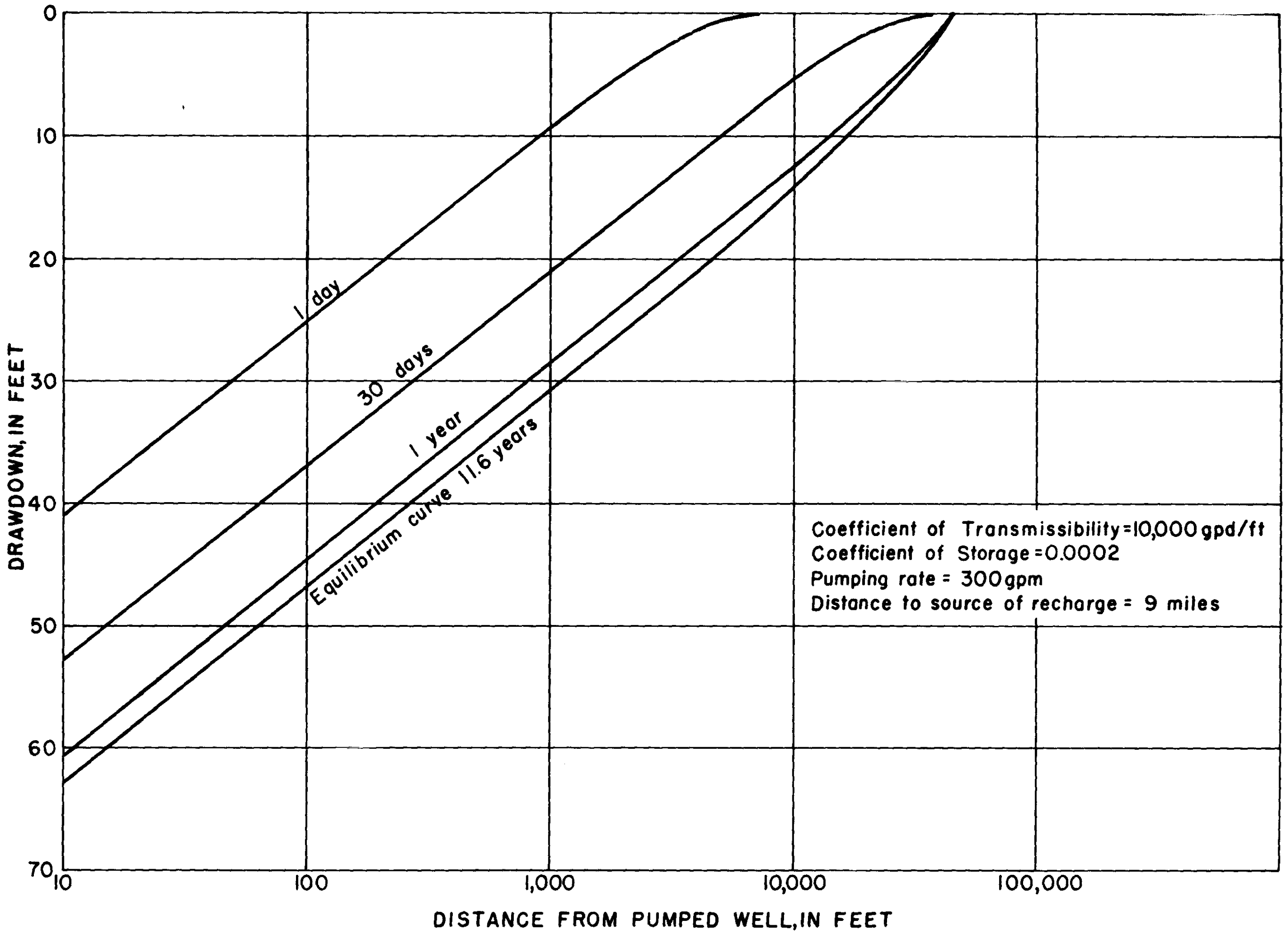


Figure 11

Relation of Drawdown and Time to Distance in the Queen City Sand

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

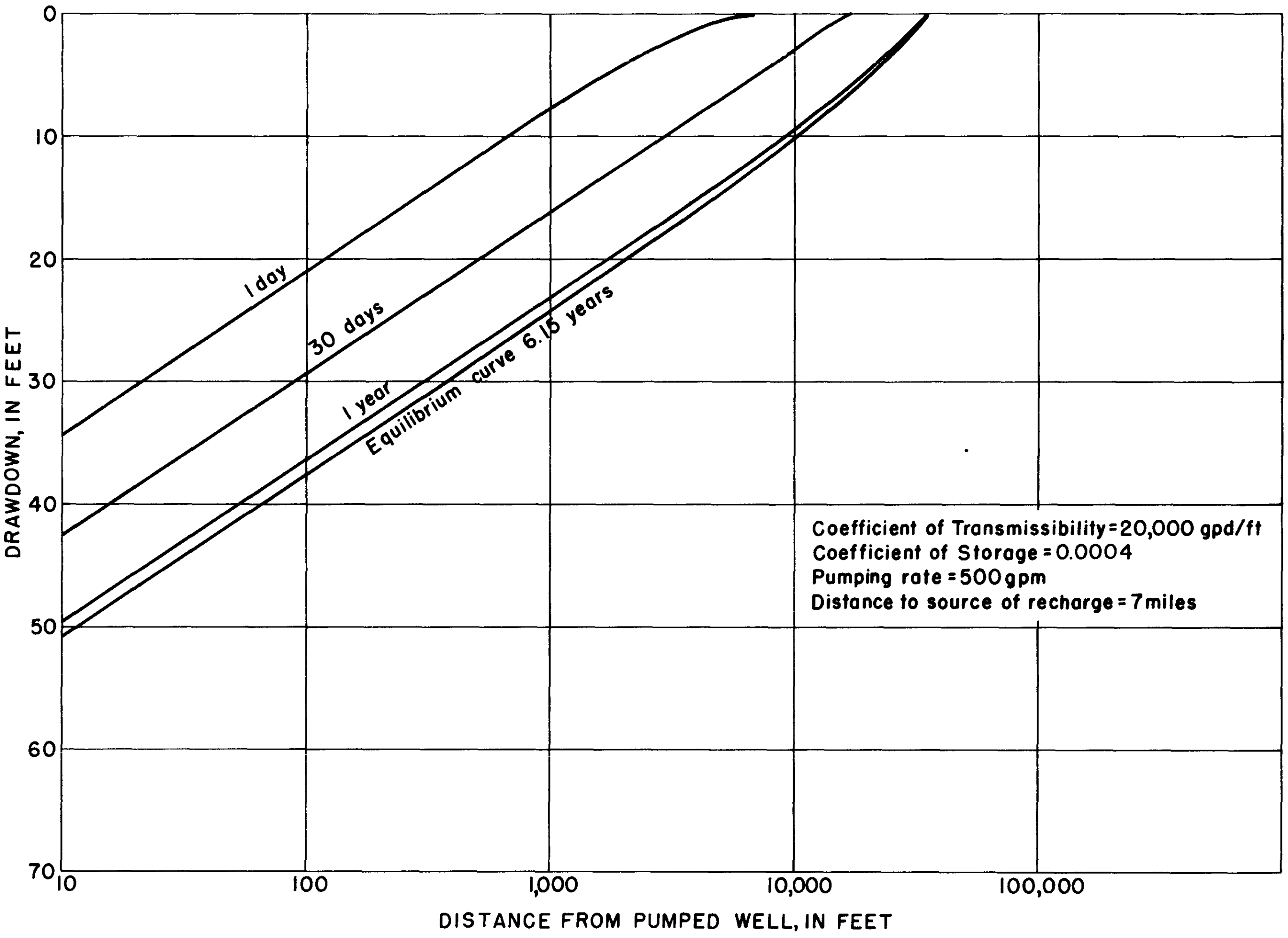


Figure 12

Relation of Drawdown and Time to Distance in the Sparta Sand

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

The aquifer tests on the Sparta Sand were made at Dime Box in public supply wells RZ-59-42-203 and RZ-59-42-201. The coefficient of transmissibility from tests in well RZ-59-42-203 is about 14,000 gpd per foot. This well screened about all the saturated sand in the Sparta at that location. Because the saturated sand thickness of the Sparta at Dime Box is 75 feet and the saturated sand thickness of the Sparta in Lee County averages about 120 feet (Figure 22), the estimated average coefficient of transmissibility of the Sparta in the county is probably about 20,000 gpd per foot. Cronin and others (1963, p. 103) cite coefficients of transmissibility near Bryan in western Brazos County that average about 12,000 gpd per foot based on an average saturated sand thickness of 75 feet. The coefficient of storage of the artesian part of the Sparta Sand in Lee County is about 0.0004.

The time-distance-drawdown curves for the Sparta Sand under artesian conditions (Figure 12) show that a Sparta Sand water well, pumping continuously at a rate of 500 gpm for 1 day, theoretically will lower the water level about 8 feet in any other Sparta well 1,000 feet from the pumping well. At the same pumping rate and distance, the water level would be lowered about 16 feet after 30 days; about 23 feet after 1 year; and a maximum of about 24 feet after about 6 years, at which time equilibrium would be established.

The hydraulic characteristics of the minor aquifers in Lee County are not known.

The time-distance-drawdown curves indicate that the rate of drawdown decreases with time and that drawdown caused by pumping is proportional to the time of pumping and to the distance from the center of pumping. A comparison of all the curves shows that drawdowns will be greatest in the Queen City Sand and smallest in the Carrizo Sand.

## Use and Development of Ground Water

About 1.5 mgd (million gallons per day), or 1,700 acre-feet, of ground water was used in the county during 1963 for public supply (Giddings, Lexington, and Dime Box), irrigation, rural domestic needs, and livestock (Table 2). The calculations of water consumption for livestock are based on agricultural statistics by the U.S. Department of Commerce (1961, p. 326-327) and on water requirements of livestock by Anderson (1964, p. 38).

Table 2.--Use of ground water, 1963

| Use | Million gallons per day | Acre-feet per year |
|---|---|---|
| Public supply | 0.37 | 420 |
| Irrigation | .02 | 27 |
| Rural domestic | .50 | 560 |
| Livestock | .60 | 660 |
| Total* | 1.5 | 1,700 |

* Figures are approximate because some pumpage is estimated. Totals are rounded to two significant figures.

Additional large quantities of water are consumed each year through evaporation of soil moisture and evapotranspiration by various crops, pasture land, and forests. The quantity of water transpired from woodlands alone in much of northern Lee County is estimated to be about 40 times the total quantity of water used during 1963 for public supply, irrigation, and rural domestic, and livestock needs.

Records of 329 wells, springs, and test holes were obtained in Lee County and adjacent areas (Table 4) during the ground-water investigation. The inventory included only a part of the total number of wells in the county. Locations of the inventoried wells, springs, and test holes are shown in Plate 1.

## Public Supply

Ground water is used for public supply at Giddings, Lexington, and Dime Box. Ground water for all public supply increased from about 200 acre-feet (0.18 mgd) in 1943 to about 420 acre-feet (0.37 mgd) in 1963. However, the largest use of water for public supply was during 1959, a year of below-average precipitation at Giddings, when 520 acre-feet (0.46 mgd) was pumped (Figure 13). The increased use of water since 1943 is related to an increase in municipal population; the yearly fluctuation is related largely to the local annual precipitation.

The city of Giddings is the largest user of ground water for public supply in the county. Giddings used a total of about 300 acre-feet (0.27 mgd) during 1963, which was about 71 percent of all public supply used in the county that year, or about 18 percent of the total water used in the county in 1963 for public supply, irrigation, and rural domestic, and livestock needs.

From before 1930 to 1964, the city had utilized six wells ranging from 300 to 1,387 feet in depth. City wells 1 and 2 have been abandoned, but subsequent wells RZ-59-49-503 (drilled in 1930), RZ-59-49-504 (1936), RZ-59-49-505 (1942), and RZ-59-49-506 (1952) have provided public supply for Giddings. Wells RZ-59-49-503, RZ-59-49-504, and RZ-59-49-505 obtain water from the Queen City Sand; well RZ-59-49-506 obtains water from the Sparta Sand and the Queen City Sand. In 1963 storage for public supply in Giddings consisted of two elevated and two ground-level tanks having a total capacity of 658,000 gallons.

Lexington is the second largest user of ground water for public supply. During 1963 Lexington used a total of about 100 acre-feet (0.09 mgd), which is about 24 percent of all public supply used in the county that year, or about 6 percent of the total of all water used. City well 1, drilled to 517 feet (in 1938) has been abandoned, and subsequent wells drilled to about the same depth, RZ-58-40-903 (1945) and RZ-58-40-904 (1947), are currently in use. The wells probably tap the uppermost part of the Carrizo Sand.

Dime Box is the third largest user of ground water for public supply. During 1963 Dime Box used a total of 34 acre-feet (0.03 mgd), which is about 8 percent of all public supply used in the county that year, or about 2 percent of the total water used. The first city well, now abandoned, was drilled in 1914 to a depth of 460 feet. A second well, now unused, was drilled in 1944 to 465 feet. A third well, RZ-59-42-203, was drilled in 1961 to a depth of 498 feet, but plugged at 465 feet. All three wells tapped the Sparta Sand. Dime Box has a storage tower with a capacity of 92,000 gallons.

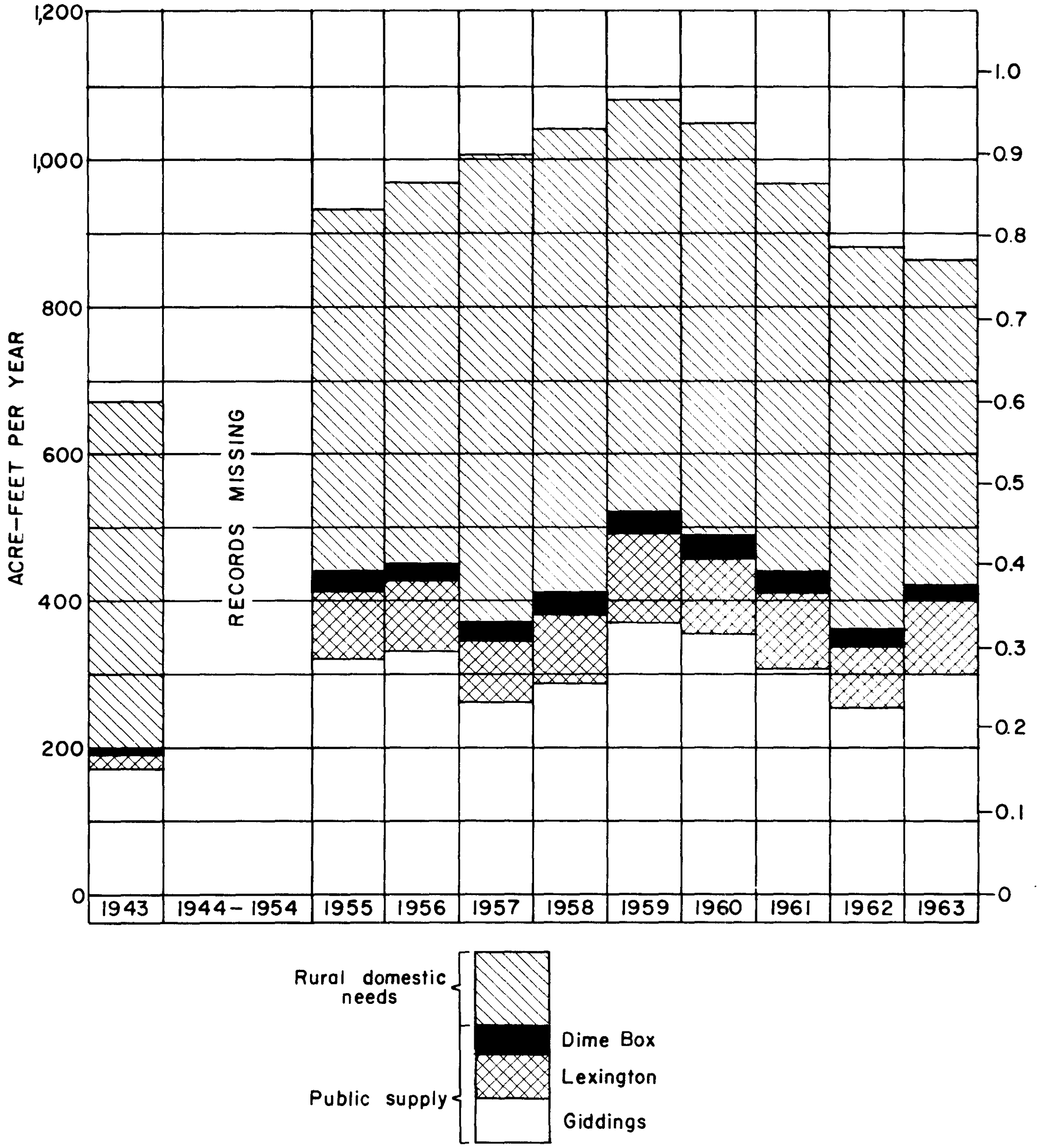


Figure 13

Use of Ground Water for Public Supply and Rural Domestic Needs, 1943-63

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

Industrial use of ground water in the county is grouped with public supply because all industrial water needs are fulfilled by local public supply systems.

## Irrigation

About 27 acre-feet of ground water was used for irrigation in Lee County in 1963. Only two wells, RZ-58-39-504 and RZ-59-33-701, were used for this purpose; the former pumped about 7 acre-feet, the latter about 20. Surface water from earthen tanks is used in some areas for small-scale irrigation.

## Rural Domestic and Livestock Needs

The average annual quantity of ground water used for rural domestic needs in Lee County since 1943 was influenced chiefly by three factors--a gradually declining rural population, a gradually increasing daily requirement of water per capita because of modernization of rural homes, and the annual fluctuations in local precipitation.

In 1943 the county's rural population of about 8,455 used an estimated 470 acre-feet (0.42 mgd) of ground water. By 1963 the rural population, probably slightly less than 5,000, used an estimated 560 acre-feet (0.50 mgd) of ground water (Figure 13); this is about 33 percent of the total ground water used in the county in that year for all needs.

The quantity of ground water used in 1963 by livestock was about 660 acre-feet (0.60 mgd). This is 39 percent of all ground water used in the county in that year for all needs. Surface water from earthen tanks and intermittent streams supplied the water needs for some livestock, but ground water from pumped and flowing wells was the principal source of supply.

In summary, rural domestic and livestock needs required about 1,220 acre-feet, or about 72 percent of all ground water used in the county for all needs in 1963.

## Flowing Wells

Part of the development of ground water includes flowing wells that were drilled to facilitate livestock and domestic water use or irrigation. Of the flowing wells inventoried in Lee County only four are equipped with valves; the others flow under full pressure, without control. A considerable quantity of the total flow exceeds the intended use, the excess water evaporating into the atmosphere or becoming local runoff to intermittent streams. Hence the excess flow needlessly reduces the water assets of the property owner and the county.

Of the total number of inventoried wells in the county, 52 can flow at ground level; but the static level of five of these wells stands in the casing slightly above ground level. These five wells currently do not overflow their casings because, owing to a continued loss of ground water, the present hydrostatic pressure in the aquifer is less than the original.

The total quantity of water flowing from these wells is about 225 gpm. The individual uncontrolled flows range from a slight trickle to 20 gpm. The annual rate is approximately 365 acre-feet, which is 55 percent of the total quantity of water used by livestock in the county during 1963, or 21 percent of the combined annual quantity of ground water used for all needs.

The inventoried flowing wells are only a part, perhaps 25 to 30 percent, of the actual number of uncontrolled flowing wells in the county. The actual loss of ground water from storage by uncontrolled flow is thus much greater than the quantity stated in the preceding paragraph.

## Well Construction

Although almost all wells in the southern half of Lee County were either drilled or bored between 1930 and 1964, the majority were completed after 1950. Dug wells are rare. Drilled wells in this area exceed the number of bored wells because most of the aquifers are too deep for boring.

Shallow wells ranging from 10 to 80 feet in depth are common in the northern half of the county, because the water table here usually is near the land surface. About 40 percent of all water wells inventoried in this area are dug wells, some having been completed prior to 1900. The remaining wells in the northern part probably are divided equally between tile-cased bored wells and metal-cased drilled wells. The bored wells range from 8 to 10 inches in diameter and from 40 to 100 feet in depth. The drilled wells range from 2 to 12 inches in diameter, commonly being 4 inches.

Shallow dug wells and bored wells of small diameter yield only small quantities of water. The shallow dug well penetrates the zone of saturation no more than a few feet, and the tile-cased bored well possesses a small cross-sectional bottom area which restricts the well's ground-water intake.

Many domestic and stock wells drilled in the county in recent years are 4-inch-diameter wells that penetrate several hundred feet of rock and expose 10 to 20 feet of slotted or perforated metal casing opposite the desired water-bearing sandstone.

The municipal public supply wells, which usually are larger in diameter and deeper than domestic and stock wells, range from 4 to 13 inches in diameter and from 465 to 1,380 feet in depth in Lee County. Figure 14 shows an example of the good well construction which is characteristic of many of the public supply wells in the county. The well construction (as shown) is adaptable to any domestic or stock well. This construction eliminates or greatly reduces many undesirable effects inherent in water-well construction throughout much of Lee County.

Several problems and undesirable effects relating to dependability of the well and water quality may be avoided by proper well construction. Because a loose, very fine- to fine-grained sandy texture characterizes some aquifers, sand is pumped with the water. This factor reduces the effective life of most pumps, especially submersible pumps. A properly gravel-packed screen will greatly reduce the sand intake and thus lengthen pump life.

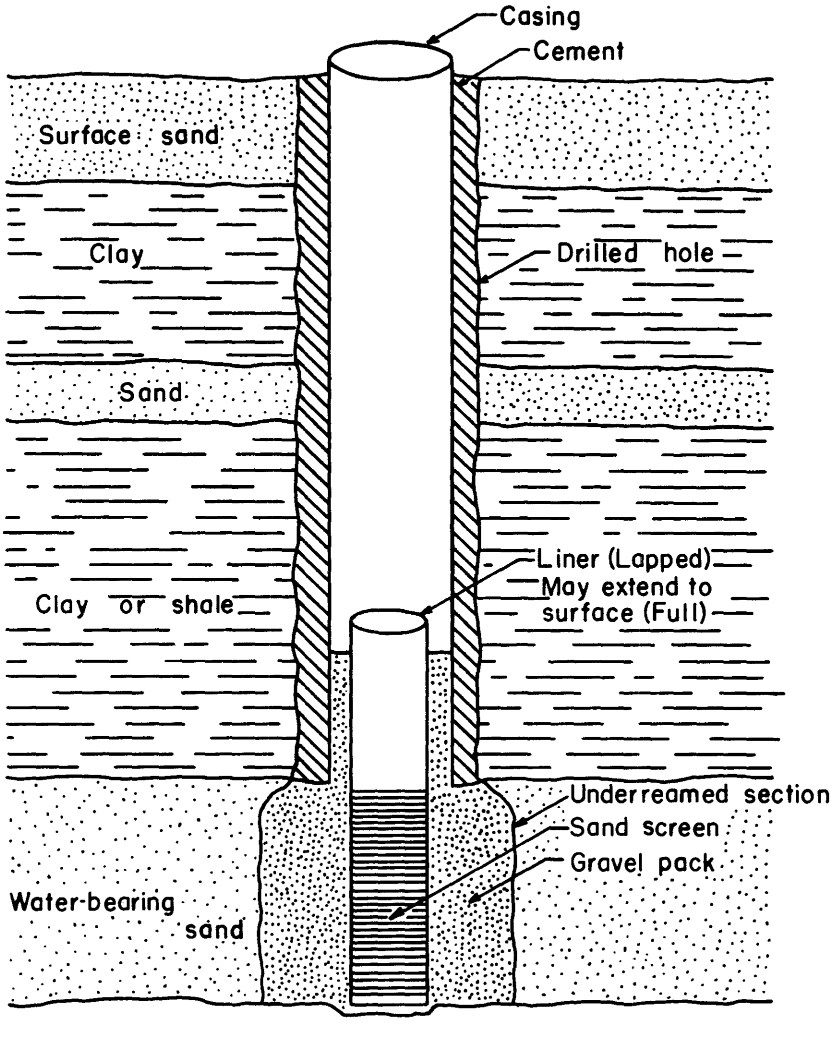


Figure 14

Typical Construction of Public Supply Wells

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

To avoid undesirable iron concentrations, wells should not produce from a chemical zone of oxidation containing high-iron and high-acid ground water. This zone occurs throughout most of Lee County at a depth interval from about 80 to about 300 or 350 feet below the land surface. The lower depth limit varies locally. A high-acid water (pH 3 to 4), commonly associated with lignitic beds, attacks unprotected steel well casings, and holes can develop in the unprotected casing within 2 to 4 years. In addition, ground water pumped from an aquifer in the acid zone may contain at least 3 ppm (parts per million) total iron and possibly much more (well RZ-58-48-104 produces water having 105 ppm total iron). A cemented casing protects the iron pipe against corrosion and the entry of undesirable water through holes. Cementing also prevents the movement of high-iron water from a higher zone downward between the outside of the casing and the drilled hole to the water intake at the bottom of the well casing.

Well RZ-59-33-203 demonstrates an example of how high-iron water can contaminate a well. This well, drilled in 1959, is 527 feet deep. It has a 6-inch uncemented casing extending the full depth of the well. Wells at this depth in Lee County normally do not yield water that contains iron in excess of 0.5 ppm and a pH of less than 7.0 unless foreign water leaks into the well from the zone of high-iron water above 300 to 350 feet. Well RZ-59-33-203, however, produces water having a pH of 6.7 and a total iron content in excess of 5 ppm (Table 7). Iron staining from the water dates back to a time slightly after the well's completion. The high-iron content and the acid pH level of the water indicate that much of the water pumped from this well comes from the zone of high-iron water above 300 to 350 feet and that the water enters the well probably by moving downward around the outside of the 6-inch casing and into the bottom of the well below 500 feet. A nearby well (RZ-59-33-206) produces relatively low-iron water (0.9 ppm) with a pH of 7.1 from a depth of 455 feet (Table 6).

Another example of a water-quality problem related to well construction is supplied by well RZ-59-49-801. This well's reported depth is 750 feet; the upper 4-inch casing extends to about 172 feet where a 2-inch casing, joined to the larger casing by a packer, extends to the bottom of the well. The pumped water contains 4 ppm iron and is slightly alkaline (pH 7.8). The pH level indicates that most of the water comes from 750 feet, but the iron content suggests a leak in the zone of high-iron water, probably at 172 feet around the packer.

## Water-Level Changes in Wells

Water levels in wells continuously respond to natural and artificial influences which act on the aquifers. In general, the major influences that control water levels are the rates of recharge to and discharge from the aquifer. Relatively minor changes are due to variations in atmospheric pressure and in load on aquifers. Fluctuations usually are gradual, but in some wells levels occasionally rise or fall several inches or even a few feet in a few minutes.

Water-level declines of considerable magnitude usually result from large withdrawals of water from wells. In shallow wells under water-table conditions and in some shallow artesian wells near the recharge area, water-level declines may reflect drought conditions or overpumping in the aquifer. Where artesian conditions prevail, water levels respond to increasing or decreasing hydrostatic pressures in the aquifer; nevertheless, the change in the quantity of water in storage nay be small.

Long-term records of annual water levels in Lee County are not available, but information on changes of water levels is afforded by several wells (under artesian conditions) in the county. The net change in water levels measured in four wells ranged from a rise of 25 feet from 1937 to 1964 in well RZ-59-41-802 tapping the Cook Mountain Formation to a decline of 4 feet from 1959 to 1964 in well RZ-59-50-401 tapping the Yegua Formation. Wells RZ-59-33-602 and RZ-59-34-701 tapping the Queen City Sand showed a net rise of 1 foot from 1959 to 1964. The causes of the rises and declines in the water levels are not clearly known because of an inadequate number of water-level measurements for each well. However, because these wells are not near centers of heavy pumping, the changes of water levels are probably related to changes in the amount of recharge in the outcrop of the aquifer. An example of a water-level decline that is probably related to heavy pumping is afforded by well RZ-59-49-505, a public supply well in Giddings. From 1942 to 1964 the water level of this well declined a reported 16 feet, that is, at a rate of about 0.7 foot per year.

## QUALITY OF GROUND WATER

### Chemical Quality

The suitability of a water supply largely depends on the chemical quality, the contemplated use, and the available quantity of the water. Wells in and near the outcrop of nearly all the aquifers underlying Lee County generally yield water of good chemical quality suitable for most uses. In moving downdip through the aquifer, however, the water dissolves soluble rock material and increases its mineral content. Consequently, the aquifers lying at considerable depth yield water that is more mineralized than the water from these same aquifers at shallow depths.

The chemical analyses from 180 sampled wells and springs in or near Lee County are in Tables 6 and 7. Except where otherwise noted, the analyses shown in Table 6 were done by personnel of the U.S. Geological Survey in Austin, Texas. Table 7 shows the field analyses for the total iron content and the pH level of water from most wells and springs inventoried in 1964. The kit used for field determinations of iron is suitable only for samples containing less than 5 ppm total iron; estimates were necessary when iron exceeded 5 ppm.

The limited number of water samples analyzed does not represent the full range of conditions and water quality in all the aquifers in Lee County. Because the tables of chemical quality record only data from those wells sampled, conditions may exist that are not indicated thereby.

The depth of a well is an important influence on many chemical constituents and properties of ground water, especially iron, hardness, dissolved solids, salinity, and pH. Of the analyses in Tables 6 and 7, 108 (the majority) represent water at depths ranging from 80 to 375 feet, 38 from less than 80 feet, and 43 from depths greater than 375 feet.

Much of the ground water in Lee County conforms to chemical standards established by the U.S. Public Health Service (1962, p. 7-8) for drinking water used on common carriers engaged in interstate commerce. According to the standards, chemical constituents should not be present in a water supply in excess of the stated concentrations whenever more suitable supplies are, or can be made, available at reasonable cost. Some of the chemical constituents used in evaluating public water supplies are fluoride, iron, sulfate, chloride, nitrate, and dissolved solids.

Table 3 summarizes all laboratory analyses in Lee County (in Table 6) as well as all field determinations of iron (in Table 7) from the various ground-water units and compares them with standards recommended by the U.S. Public Health Service and other authorities.

Table 3 lists 20 ppm as the upper limit for silica in boiler-feed water if boiler pressures are as much as 250 psi (pounds per square inch). Of the samples analyzed, the minimum concentration of silica was 5.4 ppm in well RZ-58-47-103 (depth 355 feet) tapping the Wilcox Group, and the maximum was 85 ppm in well RZ-58-40-909 (depth 80 feet) tapping the Queen City Sand. In slightly more than half of all samples the silica concentration exceeded 20 ppm. No water samples from the Carrizo Sand or the Sparta Sand contained more than 20 ppm silica, but all samples from the Simsboro Sand Member of Plummer (1933), the Yegua Formation, and the Jackson Group (Wellborn Sandstone) contained more than 20 ppm.

An excessive concentration of iron (greater than 0.3 ppm) contributes a metallic taste to water that can be unpleasant; and if iron occurs in excess of 0.5 or 0.6 ppm (determined by observation in Lee County), yellow or reddish stains appear on plumbing fixtures and in washed clothing.

Excessive iron in water is one of the chief problems in the county. Of the laboratory and field determinations, the minimum concentration for iron was 0.01 ppm in well RZ-59-49-504 (depth 1,354 feet) tapping the Queen City Sand, and the maximum was 105 ppm in well RZ-58-48-104 (depth 200 feet), also tapping the Queen City Sand. Iron concentration in about four-fifths of all samples exceeded 0.3 ppm; but, as previously stated, the majority (57 percent) of all water samples came from a depth between 80 and 375 feet, which, in general, is the zone of high-iron water. Most aquifers yield water containing less than 0.6 ppm iron at depths below 375 feet.

Large concentrations of sulfate in combination with other ions impart a bitter taste to water, commonly referred to as an alum taste. Sulfate in water in excess of 250 ppm acts in some people as a laxative. The upper limit for sulfate in drinking water is 250 ppm. The minimum concentration for sulfate in the analyzed samples was 6.2 ppm in well RZ-58-40-910 (depth 28 feet) tapping the Queen City Sand, and the maximum was 1,160 ppm in well RZ-58-64-601 (depth 198 feet) tapping the Cook Mountain Formation. Only in the Cook Mountain Formation, the Yegua Formation, and the Jackson Group is sulfate a significant problem.

The upper limit for chloride is the same as for sulfate, 250 ppm. Water having a chloride content exceeding 250 ppm may have a salty taste. If the concentration is not too excessive, persons may become conditioned to these waters in a relatively short time. Of the samples analyzed for chloride, the minimum concentration was 8.3 ppm in well RZ-58-48-101 (depth 73 feet) tapping the Carrizo Sand, and the maximum was 3,480 ppm in well RZ-58-39-912 (depth 93? feet) tapping a faulted section of the Wilcox Group; the maximum in a well tapping an unfaulted section was 2,580 ppm in well RZ-59-50-401 (depth 300 feet) in the Yegua Formation. Again, as for sulfate, the Cook Mountain Formation, the Yegua Formation, and the Jackson Group are the principal carriers of water exceeding 250 ppm. The chloride concentration rises sharply near the depth marking the base of fresh to slightly saline water (Figure 18).

Table 3.--Comparison of quality of ground water in Lee County with standards recommended by the U.S. Public Health Service (1962, p. 7-8) and others

[Chemical constituents in parts per million except specific conductance, sodium-adsorption ratio (SAR), and residual sodium carbonate (RSC)]

| | Criteria for public and domestic supply | | | | | | | | Criteria for irrigation supply | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Silica ($SiO_2$) | Iron total[a] (Fe) | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids | Hardness as $CaCO_3$ | Specific conductance (micromhos at 25°C) | SAR | RSC | Boron (B) |
| Upper limits[b] | 20 | 0.3 | 250 | 250 | 1.0 | 45 | 500 | 60 | 2,250 | 14 | 2.5 | 1.0 |

Number of determinations

| | Total | Over 20 ppm | Total | Over 0.3 ppm | Total | Over 250 ppm | Total | Over 250 ppm | Total | Over 1.0 ppm | Total | Over 45 ppm | Total | Over 500 ppm | Over 1,000 ppm | Total | Over 60 ppm | Total | Over 2,250 | Total | Over 14 | Total | Over 2.5 | Total | Over 1.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All wells[c] | 59 | 30 | 173 | 142 | 104 | 30 | 104 | 22 | 44 | 1 | 58 | 1 | 50 | 26 | 13 | 104 | 88 | 103 | 16 | 56 | 6 | 88 | 8 | 71 | 8 |
| Wilcox Group [excluding Simsboro Sand Member of Rockdale Formation of Plummer (1933)] | 10 | 5 | 32 | 24 | 20 | 4 | 20 | 4 | 9 | 0 | 10 | 0 | 9 | 1 | 0 | 20 | 15 | 20 | 1 | 11 | 0 | 19 | 1 | 13 | 0 |
| Simsboro Sand Member of Rockdale Formation of Plummer (1933) | 3 | 3 | 24 | 15 | 13 | 1 | 13 | 1 | 3 | 0 | 6 | 1 | 2 | 1 | 0 | 13 | 13 | 13 | 0 | 5 | 0 | 12 | 0 | 7 | 0 |
| Carrizo Sand | 7 | 0 | 21 | 14 | 6 | 1 | 12 | 1 | 7 | 0 | 9 | 0 | 7 | 0 | 0 | 12 | 8 | 11 | 0 | 7 | 0 | 8 | 0 | 7 | 0 |
| Queen City Sand | 17 | 7 | 46 | 42 | 27 | 6 | 28 | 3 | 8 | 1 | 12 | 0 | 11 | 7 | 2 | 27 | 23 | 27 | 1 | 12 | 3 | 22 | 2 | 19 | 0 |
| Sparta Sand | 5 | 0 | 7 | 5 | 7 | 2 | 7 | 1 | 5 | 0 | 5 | 0 | 5 | 1 | 1 | 7 | 6 | 7 | 1 | 5 | 0 | 6 | 0 | 6 | 1 |
| Cook Mountain Formation | 4 | 3 | 7 | 7 | 6 | 4 | 6 | 5 | 2 | 0 | 4 | 0 | 4 | 2 | 2 | 6 | 6 | 6 | 4 | 4 | 1 | 5 | 2 | 6 | 2 |
| Yegua Formation | 8 | 8 | 15 | 14 | 10 | 19 | 10 | 5 | 5 | 0 | 6 | 0 | 7 | 4 | 4 | 10 | 10 | 10 | 5 | 6 | 0 | 8 | 1 | 7 | 2 |
| Jackson Group | 3 | 3 | 7 | 7 | 5 | 4 | 5 | 4 | 3 | 0 | 3 | 0 | 3 | 3 | 3 | 5 | 5 | 4 | 2 | 3 | 2 | 4 | 2 | 3 | 3 |

[a] Includes field determinations.
[b] See section entitled "Quality of Ground Water" in this report.
[c] Includes wells tapping undetermined aquifers.

The upper limit of fluoride for an area varies with the annual average maximum daily air temperatures. On the basis of the annual average of maximum daily air temperature of 77.8°F at College Station for the period 1960-64, and assuming that this temperature applies to Lee County, fluoride in water should not average more than 1.0 ppm in that county. Fluoride in average concentrations greater than 1.6 ppm constitutes grounds for rejection of the water supply by the U.S. Public Health Service. Fluoride in optimum concentration in drinking water may reduce the incidence of tooth decay if the consumer uses the water during the early period of enamel calcification. Excessive concentrations may cause teeth to become mottled. Only one sample, from a Giddings public supply well, exceeded the upper limit of fluoride for Lee County. This well, Rz-59-49-504, is screened in the lowermost part of the Queen City Sand, and the water had a fluoride content of 1.9 ppm. The fluoride content in the other city wells at Giddings was less than 1.0 ppm. Most of the other wells in the county contain low concentrations of fluoride, generally less than 0.4 ppm.

The upper limit for nitrate, according to the U.S. Public Health Service standards, is 45 ppm. Concentrations of nitrate exceeding 45 ppm in water used for infant feeding have been related to "blue baby" disease (Maxcy, 1950, p. 271). The presence of more than several parts per million of nitrate in water may indicate contamination by sewage or other organic matter (Lohr and Love, 1954, p. 10). Greater likelihood of such contamination exists in shallow dug wells than in deep wells. Nitrate concentrations were low in most of the samples analyzed, but well RZ-58-39-805 (depth 60 feet), tapping the outcrop area of the Simsboro Sand Member, contained 144 ppm nitrate. Most of the water samples analyzed were from wells deeper than 80 feet.

A major influence or limitation in the general use of ground water is the dissolved-solids content. It is a measure of the total of the mineral constituents dissolved in the water. Specific conductance, the reciprocal of electrical resistance, is a measure of the dissolved-solids concentration and expresses the ease with which an electrical current passes through water. The conductance depends directly on the amount and nature of the dissolved solids. Hem (1959, p. 40) states that the specific conductance multiplied by a value usually between 0.55 and 0.75 gives a calculated approximation of the total dissolved solids in a water sample unless the water has an unusual composition. For purposes of converting specific conductance into dissolved solids, the ground water in Lee County possesses dissolved-solids concentrations that probably approximate the specific conductances multiplied by the average factor 0.65. In this report, the degree of dissolved-solids content follows the classification proposed by Winslow and Kister (1956, p. 5):

| Description | Dissolved-solids content (ppm) |
|---|---|
| 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 |

The base of slightly saline water in Lee County roughly coincides with a 10-ohm resistivity of the water-bearing sands on electric logs. This method of estimating dissolved-solids concentration from electric logs was supplemented by a comparison of chemical analyses of water from wells tapping the aquifers.

Water containing more than 500 ppm dissolved solids is undesirable for drinking and many industrial uses. Of the samples analyzed, the minimum concentration was 62 ppm in well RZ-58-40-801 (depth 172 feet) tapping the Wilcox Group; the maximum measured concentration was 4,670 ppm in well RZ-59-50-401 (depth 300 feet) tapping the Yegua Formation. However, the maximum approximated concentration (based on specific conductance times the factor 0.65) was 7,280 ppm in well U-58-39-912 (depth 93 feet), which intersects a fault in the Wilcox Group. Almost 80 percent of the analyzed samples exceeded 500 ppm dissolved solids. Most samples exceeding 500 ppm were from the Queen City Sand, the Cook Mountain Formation, Yegua Formation, and the Jackson Group.

Calcium and magnesium are the principal causes of hardness of water. Excessive hardness consumes soap before a lather forms, and induces scale formation on the walls of hot-water heaters and water pipes. A commonly accepted classification of water is as follows:

| Hardness range (ppm) | Classification |
|---|---|
| 60 or less | Soft |
| 61 to 120 | Moderately hard |
| 121 to 180 | Hard |
| More than 180 | Very hard |

Ground water that contains moderate quantities of dissolved material may change from hard water to soft water by ion-exchange reactions in passage through sediments. In Lee County, water which contains calcium and magnesium in the outcrop moves downdip and may contain little or no calcium or magnesium at depth. Sodium and bicarbonate are the principal constituents of the deeper fresh water.

Of the samples analyzed, the minimum concentration of hardness was 8 ppm at a spring {RZ-59-41-403} in the Queen City Sand. The minimum concentration in a well was 15 ppm in well RZ-58-32-905 (depth 170 feet) probably tapping the Carrizo Sand, and the maximum was 2,290 ppm in well RZ-59-50-401 (depth 300 feet) tapping the Yegua Formation. Hardness can be a problem in the relatively shallow parts of aquifers tested in the county; but, generally, the problem becomes less acute with increasing depth of occurrence of the water.

The chemical characteristics of water that relate specifically to irrigation water are specific conductance, sodium adsorption ratio (SAR), residual sodium carbonate (RSC), and boron. In addition to the chemical characteristics of the water, the type of soil, adequacy of drainage, crops grown, climatic conditions, and quantity of irrigation water required are all important to the continual productivity of irrigated land. The following discussion offers criteria for a general evaluation of the suitability of ground water for irrigation.

The U.S. Salinity Laboratory Staff (1954, p. 69-82) proposes a classification that commonly is used for judging the quality of a water for irrigation (Figure 15). Briefly, the classification bases the suitability of irrigation water on the salinity hazard as measured by the specific conductance of the water and on the sodium hazard as measured by the SAR. Wilcox (1955, p. 15) makes the qualifying statement that this system of classification of irrigation water ". ..is not directly applicable to supplemental waters used in areas of relatively high rainfall." Because the annual rainfall in Lee County averages about 36 inches, most irrigation is supplemented; and the classification therefore is not directly applicable. Generally water is safe for supplemental irrigation, according to Wilcox (1955, p. 16), if its conductivity is less than 2,250 micromhos per centimeter at 25°C and its SAR is less than 14.

Figure 15 shows the SAR and specific conductance of water from various aquifers and indicates the suitability of the water for irrigation. Most of the water represented on the diagram is within the upper limits of SAR (14) and specific conductance (2,250 micromhos at 25°C), and therefore is generally safe for supplemental irrigation. The water exceeding the upper limits is chiefly from the Cook Mountain Formation, the Yegua Formation, and the Jackson Group. However, water from the other aquifers, especially from the relatively deep parts, generally has an excessive SAR.

Of the 103 determinations of specific conductance, 16 exceeded 2,250 micromhos. For the samples analyzed, the minimum value for specific conductance was 81.5 micromhos in well RZ-58-4-O-801 (depth 172 feet) tapping the Wilcox Group, and the maximum was 11,200 micromhos in well RZ-58-39-912 (depth 93? feet) tapping a faulted section of the Wilcox Group. In wells tapping unfaulted sections the maximum was 7,940 micromhos in well RZ-59-50-401 (depth 300 feet) in the Yegua Formation. In no sample from the Simsboro Sand Member of the Rockdale Formation of Plummer (1933) and the Carrizo Sand did the specific conductance exceed 2,250 micromhos; and in only one sample each from the Wilcox Group, the Queen City Sand, and the Sparta Sand did the specific conductance exceed the upper limit.

The upper limit of the SAR for supplemental irrigation water is 14. This limit is valid only if the specific conductance is 2,250 micromhos. If the specific conductance is less than 2,250, the allowable upper limit of the SAR may be increased. Of the samples analyzed, the minimum SAR was 0.5 in well RZ-58-40-801 (depth 172 feet) tapping the Wilcox Group, and the maximum was 40 in public supply well RZ-59-49-504 (depth 1,354 feet) tapping the Queen City Sand. Slightly more than 10 percent of all samples exceeded an SAR of 14. However, in no water samples from the Wilcox Group, the Carrizo Sand, the Sparta Sand, and the Yegua Formation did the SAR exceed 14. Excessive SAR may be expected in relatively deep ground water in the county.

The suitability of water for irrigation is also determined by the RSC. Wilcox reports (1955, p. 11) that water containing more than 2.5 epm (equivalents per million) RSC is undesirable for irrigation, 1.25 to 2.5 epm RSC is marginal, and less than 1.25 epm RSC probably is safe. Water from many of the wells in Lee County has no RSC. The maximum was 5.46 epm in well RZ-59-43-701 (depth 140? feet) tapping the Jackson Group. RSC exceeded 2.5 epm in only 11 percent of all samples tested and ranged from 1.25 to 2.5 epm in 8 percent. Water from the Cook Mountain Formation, the Jackson Group, and most deeply occurring waters have excessive RSC.

"Corrected sheet for Texas Water Development Board Report 20"

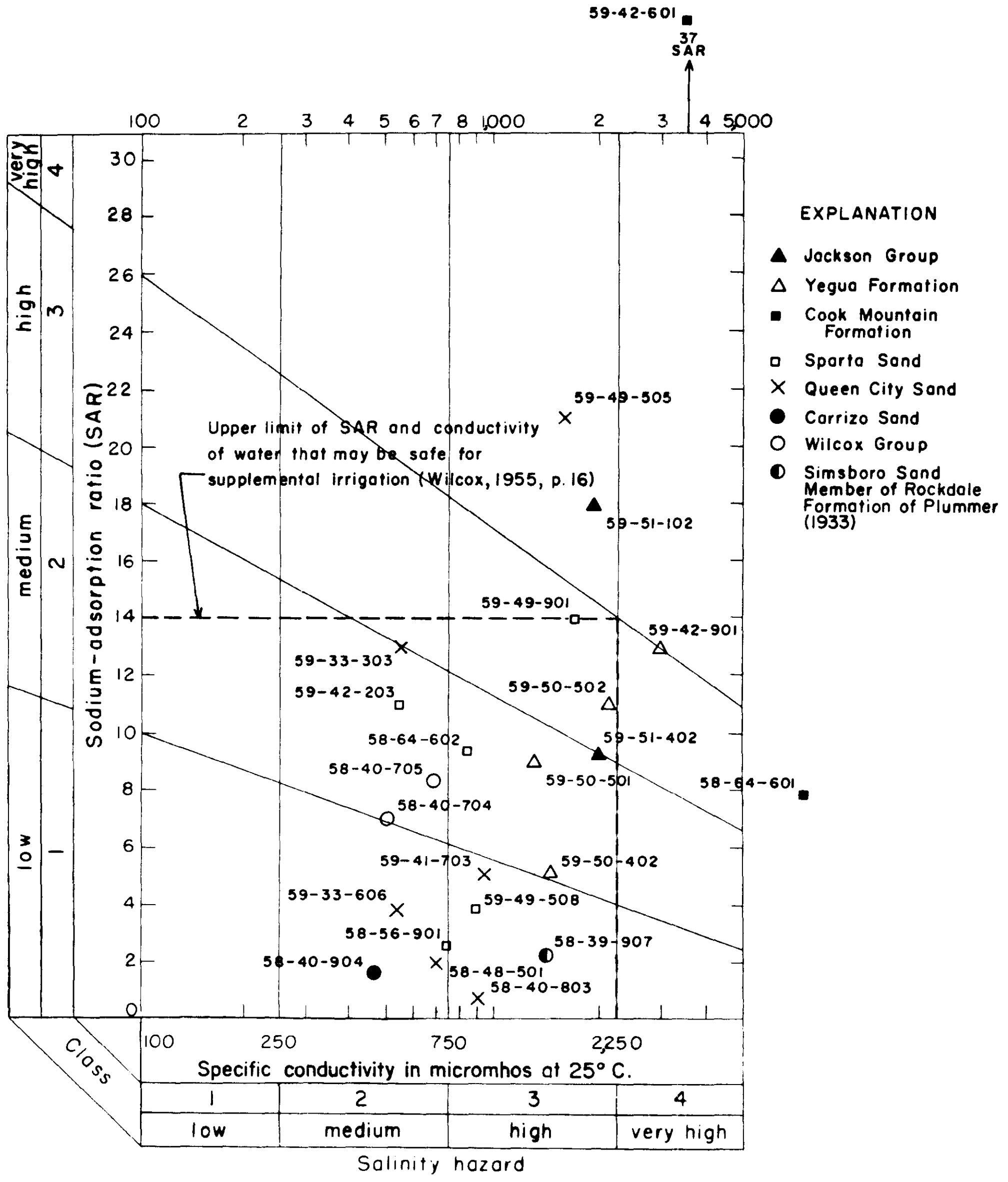


Figure 15

Classification of Irrigation Waters

(After U.S. Salinity Laboratory Staff, 1954, p.80)

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

Boron is also significant in evaluating irrigation water. Although boron is essential to normal plant growth the required amount is very small, and excesses are injurious to some plants. Wilcox (1955, p. 11) suggests that a permissible boron concentration for irrigating boron-sensitive crops can be as much as 1.0 ppm, and for boron-tolerant crops as much as 3.0 ppm. In the samples analyzed, the minimum concentration of boron was 0.01 ppm in well RZ-59-33-701 (depth 486 feet) tapping the Queen City Sand, and the maximum was 1.7 ppm in well RZ-59-50-101 (depth 350 feet) tapping the Cook Mountain Formation. Boron exceeded 1.0 ppm in only about 11 percent of all samples tested; most samples contained less than 0.4 ppm. Water samples containing more than 1.0 ppm boron were from the Sparta Sand, the Cook Mountain Formation, the Yegua Formation, and the Jackson Group.

The suitability of water for industrial use varies widely in chemical as well as temperature standards. Water temperature and seasonal fluctuations of temperatures are important considerations in water used as a coolant by industry. Ground water generally is superior to surface water as a coolant because constant temperature is an inherent ground-water characteristic; however, high-temperature ground water from considerable depth generally is undesirable. The relaticn of temperature to depth is discussed below.

Ground water of good chemical quality, suitable for most purposes, is generally obtainable from many of the aquifers in Lee County. The water obtained near the outcrop generally is less mineralized, except for iron, than water at greater depths. Supplies of ground water suitable for public supply, irrigation, and many industrial needs are available from the Simsboro Sand Member of the Rockdale Formation of Plummer (1933), the Carrizo Sand, Queen City Sand, and Sparta Sand. Aquifers having relatively poor quality water are in the Cook Mountain Formation, the Yegua Formation, and the Jackson Group.

## Temperature

The temperature of water is important to industries using water as a coolant. Therefore, a known geothermal gradient for water temperatures is useful in determining the expected temperature of water at specific depths below the land surface. Figure 16 is a geothermal graph showing temperatures of water from water wells and maximum or bottom-hole temperatures recorded on electric logs from oil tests in Lee County. The temperatures on the graph at 1,200 feet or less are from water wells, and those greater than 1,200 feet in depth are from oil tests.

The bottom-hole temperatures determined from oil tests may not represent true temperatures. Before bottom-hole temperatures are determined, circulation of the drilling mud stops and an adjustment of the mud temperature to the temperature of the bottom-hole formation begins. If sufficient time is allowed for the equalizing of temperatures, then the recorded bottom-hole temperature probably is nearly the true temperature of the bottom-hole formation; if sufficient time is not allowed, the recorded temperature is less than the true temperature.

The temperature of a water sample generally is less than the temperature of the aquifer unless the water has been discharging for a sufficient length of time.

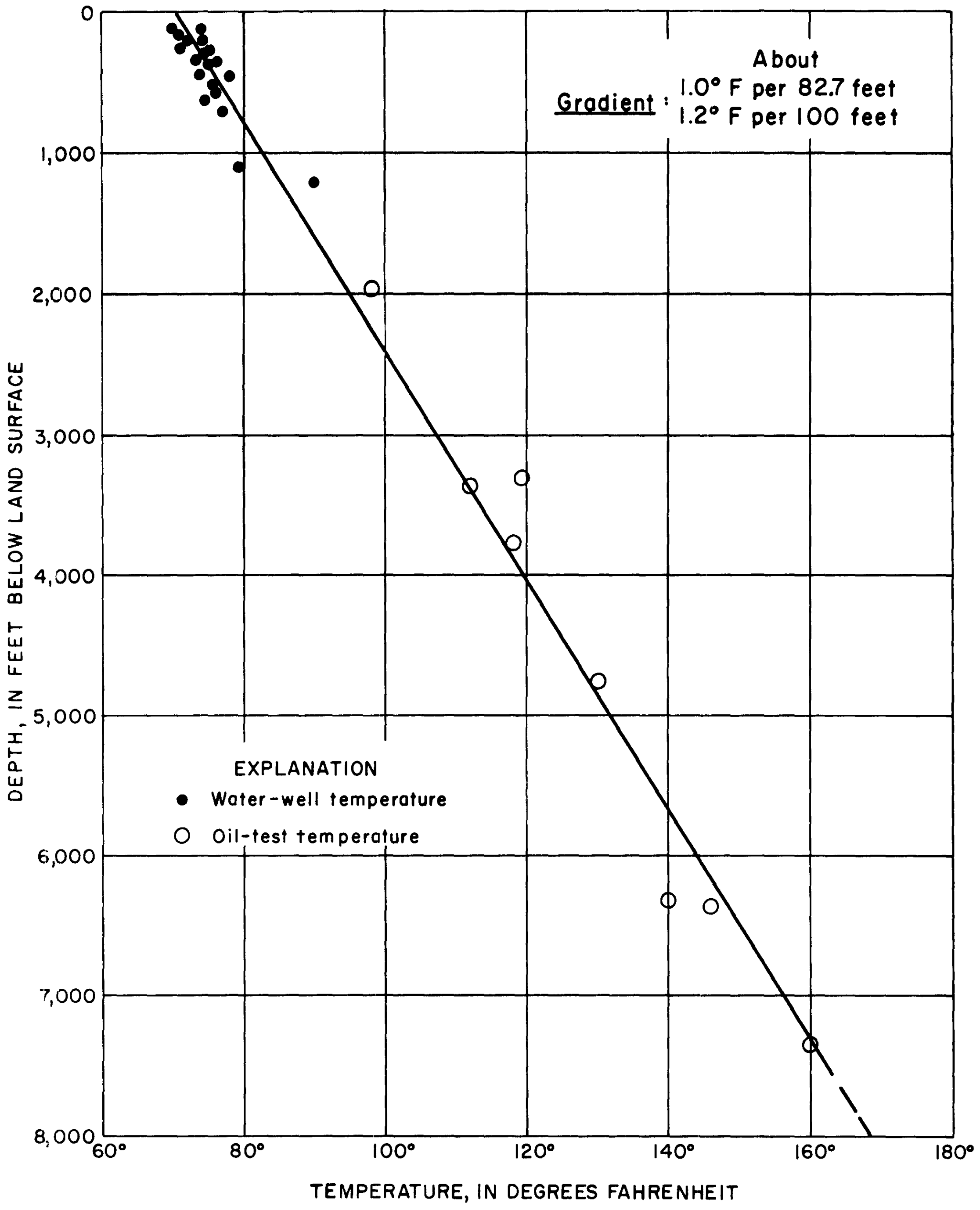


Figure 16

Geothermal Gradient

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

The temperatures from water wells and oil tests in Lee County establish an average geothermal gradient in the county of about 1°F increase for every 83 feet in depth, or an average of about 1.2°F increase per 100 feet. Because the mean annual air temperature for the county (about 69°F) approximates the temperature of ground water near the land surface, this temperature is a base to which the geothermal gradient is applied. Temperatures may be read directly from the geothermal-gradient line in Figure 16.

## Quality of Ground Water Near Faults

Deviations in expected chemical quality and temperature of ground water are common near faults. Water well RZ-58-39-912 probably is near a fault. The well is about 93 feet deep; the temperature of the water is 74°F (compare Figure 16); and the chemical analysis shows: chloride, 3,480 ppm; sulfate, 874 ppm; bicarbonate, 804 ppm; sodium plus potassium, 1,670 ppm; silica, 69 ppm; total hardness, 2,840 ppm; specific conductance, 11,200 micromhos (approximated dissolved solids of 7,280 ppm); pH, 7.2; and total iron (field tested), 0.2 ppm. This water is significantly different in chemical composition and temperature from the more normal water in nearby well RZ-58-39-904. This well (only 0.1 mile from well RZ-58-39-912) is 120 feet deep, the water having a temperature of 72°F, and containing 25 ppm iron. Area1 photos indicate that a structural lineament (probably a fault) intersects well RZ-58-39-912.

Relatively shallow wells in the county do not ordinarily yield a highly mineralized water unless they intersect faults or fracture zones along which highly mineralized water may move upward from greater depths. However, not all faults are conduits for upward movement of deep-seated water. They commonly function as a relatively impervious barrier to ground-water movement, and locally inhibit fresh-water circulation.

Plummer and Sargent (1912, p. 65-70) demonstrated the relation of ground-water composition and temperature as a technique in locating faults in northeast Texas.

## Chemical Quality and Ground-Water Depth

The depth of occurrence of ground water largely determines the chemical character of that water. Figure 17 shows the locations and depths of wells tapping various aquifers and the iron and chloride concentrations of water from the wells in the county. A significant fact to keep in mind is that the well depth does not always indicate the actual depth from which water enters the well. Older casings may leak because of corrosion, and improper well construction may allow contamination from shallow zones. Some aquifers contain a smaller proportion of water-soluble material than other aquifers. Naturally, water entering the outcrop of these less mineralized aquifers can move downdip a considerable distance before the water becomes very mineralized. The water-bearing sandstones associated with the Cook Mountain Formation, the Yegua Formation, and the Jackson Group commonly contain an abundance of water-soluble material even in the outcrop. Ground water in these aquifers, therefore, becomes rapidly more mineralized in short distances downdip.

In general, Figure 17 shows that, especially in the unfaulted areas, a relatively low-chloride water occurs in all aquifers older than the Cook Mountain

Formation, and that the chloride content tends to increase with depth of the aquifer. For example, the municipal well at Dime Box, RZ-59-42-203 (depth 465 feet), yields water from the Sparta containing 41 ppm chloride, whereas the water from well RZ-59-49-901 (depth 1,097 feet, 3.4 miles southeast of Giddings), also tapping the Sparta, contains 93 ppm chloride. Other aquifers show similar trends.

The interface between the fresh to slightly saline water and the underlying, more highly mineralized water is not a sharp contact but is transitional. Although the concentrations of chloride and dissolved solids in ground water rise sharply near the base of fresh to slightly saline water, the actual configuration of this base is irregular. Faults, changes in formation permeability, interformational leakage of different quality water (either naturally or by improperly constructed wells), and lithologic changes are factors influencing the configuration of the base. The base of fresh to slightly saline water ranges from less than 200 to about 3,700 feet below sea level, and is deepest about 5 miles southeast of Dime Box (Figure 18).

Lithologic changes in the Carrizo Sand are responsible for the shallower downdip extent of fresh to slightly saline water in that aquifer as compared to that in the Simsboro Sand Member. Shale beds, impeding the downdip movement of fresh water, are increasingly prominent downdip in the Carrizo near Fayette County. The Simsboro Sand Member, on the other hand, retains much of its massive non-argillaceous sandstone character far below the base of fresh to slightly saline water. An electric log of well BS-59-43-501 indicates that water quality of the Simsboro Sand Member is slightly better than that of the Carrizo. Chemical analyses from well BS-59-43-501 show a dissolved-solids content of 1,650 ppm in water between 2,154 and 2,202 feet in the Carrizo; a later analysis shows a dissolved-solids content of 1,380 ppm in water which was a mixture from the same Carrizo interval and from the upper part of the Simsboro Sand Member between 3,750 and 3,838 feet. On the basis of these analyses the downdip massive sand of the Simsboro Sand Member apparently permits fresh-water flushing further down the dip than that which occurs in the Carrizo.

A high percentage of wells in Lee County contain undesirable concentrations of soluble iron in the water. The principal factors controlling the amount of soluble iron in well water are the depth and the pH of the water in the aquifer.

In natural waters iron is present in the form of ions, but the total amount of iron in solution depends partly on the differing pH values of the water (Mason, 1952, p. 141-147). For instance, the solubility of iron at pH 6 is about 100,000 times greater than at pH 8.5. The presence of bicarbonate or alkalinity in the water decreases the solubility of ferrous iron and promotes the precipitation of stable iron minerals. Generally water with a pH of 7 or higher cannot retain large quantities of dissolved iron. In Lee County the greater the depth of a well the greater the probability that the water is alkaline and therefore low in iron. With respect to soluble iron in ground water, three distinct zones of chemical stratification may constitute an aquifer: a shallow zone of oxidation; an intermediate zone of relatively high iron concentration; and a deep zone of reduction (Broom, Alexander, and Myers, 1965). The zone of oxidation, which ranges from the land surface to about 80 feet in depth in Lee County, largely contains stable insoluble compounds of iron and has relatively low-iron (less than 0.5 ppm) water. The change in dissolved iron concentration, usually between 75 and 85 feet in depth, is very abrupt.

The intermediate zone, averaging about 250 feet in thickness, ranges in depth from about 80 feet to about 300 to 350 feet. The base varies in depth according to: local topographic relief, local concentration of soluble alkaline constituents in the aquifer, permeability of the aquifer, and rate of increase of the ground water pH level in the aquifer. Consequently, the base of the intermediate zone is not as abrupt as that of the zone of oxidation and may possibly range from 285 to 375 feet in depth below the land surface. Regardless of depth, the principal control is the pH of the water in the aquifer. The pH in the intermediate zone generally ranges from about 5 to 7. The iron concentration in the intermediate zone usually ranges from about 0.8 to more than 100 ppm.

The deep zone of reduction begins immediately below the base of the intermediate zone. Generally, a properly constructed well can obtain relatively low-iron water (less than 0.7 or 0.8 ppm) at a depth of 300 to 350 feet below land surface. If the well is in a lowland near a stream, low-iron water is possible at depths less than 300 feet. The water in the deep zone is usually alkaline--that is, it has a pH greater than 7.

## Contamination From Oil-Field Operations

Although oil-field operations (such as disposal of salt water) are a potential source of contamination of ground water in Lee County, no wells were found that were contaminated by this source. Records for the county show three oil fields--Giddings, Tanglewood, and McDade. McDade field, which produced less than 400 barrels of oil, stopped operations in 1953. No records of salt-water production are available for the McDade field.

On the other hand, both the Giddings and the Tanglewood fields produce brine, for which open unlined surface pits are the only means of disposal (Texas Water Commission and Texas Water Pollution Control Board, 1963, p. 238). In 1961, Tanglewood reported 2,157 barrels of brine from an oil-producing well and 120 barrels from a gas well. Since 1961, the oil well has stopped producing. The Queen City Sand crops out in the Tanglewood field where the brine was disposed.

The Giddings field, discovered in 1960, reported 265 barrels of brine production during 1961. Probably the annual volume will increase each year until operations cease. The Yegua Formation is exposed in the Giddings field.

At least in part, salt water placed in unlined open surface pits seeps into the ground and can contaminate the shallow aquifers. When saline water percolates downward to the water table, fresh water in the aquifer somewhat dilutes the brine. Because ground water moves at a very slow rate, two important conditions exist in the aquifer. First, because salt water added to the ground at one point does not affect the quality of the water in nearby wells for many years, the contamination may not be apparent. Second, when a well is finally contaminated, the salt water remains for a long period because purification by leaching and dilution requires more time than that of the original contamination.

Aquifers also may be contaminated through inadequately cased, improperly plugged, or unplugged oil and gas wells and test holes that allow migration of undesirable water up the bore hole into aquifers containing good-quality water. Some uncased and unplugged test holes exist throughout the county. The Railroad

Commission requires that fresh-water strata be protected by surface casing and cement, however no field rules regarding surface casing depths are specified for any of the fields in the county.

## AVAILABILITY OF GROUND WATER

The ground-water resources of Lee County are practically untapped. Of the water available in the aquifers, only a small quantity is currently being used. The principal aquifers are in the Simsboro Sand Member of the Rockdale Formation of Plummer (1933), and in the Carrizo, Queen City, and Sparta Sands. Other aquifers in the county are relatively unimportant. The isopachous maps (Figures 19 to 22) which show the thickness of sand containing fresh to slightly saline water in the principal aquifers are useful in indicating areas most favorable for developing large ground-water supplies, for areas of relatively thick sands are usually able to yield relatively large quantities of ground water.

The exact quantity of water available from the principal aquifers is difficult to determine accurately. It depends upon the rate of recharge to the aquifers, the ability of the aquifers to transmit water, and the quantity of ground water in transient storage. In this report, two values are given for the quantity of ground water that is suitable for municipal use as well as for use by most industries and that is perennially available from each of the principal aquifers in the county. The first value, a minimum estimate, is the quantity of water currently moving through the aquifer under the present hydraulic gradient. Not included, therefore, is the water which may be salvaged from processes of evapotranspiration and rejected recharge on the outcrop. The second value is based on: (1) a theoretical line of pumping wells extending the width of the county parallel to the outcrop of the aquifer, and spaced midway between the outcrop and the downdip limit of fresh to slightly saline water; and (2) pumping lifts in proportion to the potential quantity of water, which may be transmitted to the line of pumping wells without exceeding an assumed maximum rate of recharge to the aquifer.

The quantity of water perennially available from the Simsboro Sand Member was not determined because of insufficient hydrologic data in the county; however, an indication of the potential of the Simsboro in Lee County was gained from pumping tests in nearby counties (such as Milam and Brazos) where the formation is tapped by large-capacity wells. Yields of 700 to 900 gpm have been obtained from wells in the Simsboro in Milam County at the Aluminum Co. of America plant about 10 miles northwest of Lexington, and yields of 2,500 gpm have been obtained from the Simsboro in Brazos County at the city of Bryan well field about 40 miles east-northeast of Lexington. Similar yields may be expected from properly constructed wells screened opposite all available sand in the Simsboro in Lee County in places where the aquifer is relatively thick.

The thickness of sand containing fresh to slightly saline water in the Simsboro Sand Member (Figure 19) ranges from zero feet near its northwest margin of outcrop and near the southeast edge of the county to at least 750 feet a few miles east of Tanglewood. The thickest sand is in the eastern part of the county, especially in the eastern part of the area of complex faulting.

The quantity of water perennially available from the Carrizo Sand ranges from about 6 mgd to possibly as much as 19 mgd. The estimate of the minimum value of 6 mgd, or 6,700 acre-feet per year, was based on the present hydraulic gradient of 6 feet per mile. The maximum value was based on a theoretical northeasterly trending line of pumping wells about 10 miles northwest of Giddings. At a gradient established by pumping lifts of 200 feet along the line of discharge, the Carrizo would transmit 19 mgd, or about 21,000 acre-feet per year. The amount of recharge necessary to replace this water is difficult to determine because much of the Carrizo does not crop out owing to faulting; thus, the effective recharge area is not known. However, on the basis of an unfaulted Carrizo outcrop in the county, 19 mgd would be equivalent to about 5.5 inches of water per year for recharging the outcrop. This amount of water is about 15 percent of the average annual precipitation at Giddings. Whether or not the 19 mgd could be perennially available is somewhat questionable, because it may exceed the recharge of the Carrizo.

The thickness of sand containing fresh to slightly saline water in the Carrizo Sand (Figure 20) ranges from zero near its northwest margin of outcrop and near the southeast tip of the county to at least 320 feet near Giddings. The thickest sand is in the western part of the county. In areas of relatively thick sand, properly constructed wells screening all available sand in the Carrizo will probably yield from 1,500 to 2,000 gpm.

The quantity of water available from the Queen City Sand ranges from about 2 mgd to possibly as much as 12 mgd. The minimum value of 2 mgd, or about 2,200 acre-feet per year, was based on the present hydraulic gradient of about 8 feet per mile. The maximum value of 12 mgd was based on a theoretical northeasterly trending line of pumping wells extending through Giddings. At a gradient established by pumping lifts of 400 feet along the line of discharge, the Queen City would transmit about 12 mgd, or about 13,000 acre-feet per year. The amount of recharge necessary to replace the water moving downdip (12 mgd) is equivalent to about 4.5 inches of rainfall per year. This quantity of water is 12 percent of the average annual precipitation at Giddings.

The thickness of sand containing fresh to slightly saline water in the Queen City Sand (Figure 21) ranges from zero near its northwest margin of outcrop to at least 310 feet in an area from Giddings westward to Bastrop County. In areas of relatively thick sand, yields of perhaps as much as 1,000 gpm might be obtained from properly constructed wells screening all available sand in the aquifer.

The quantity of water available from the Sparta Sand ranges from 4 mgd to possibly as much as 9 mgd. The minimum value of 4 mgd, or about 4,500 acre-feet per year, was based on the present hydraulic gradient of about 9 feet per mile. The maximum value of 9 mgd was based on a theoretical northeasterly trending line of pumping wells extending through Giddings. At a gradient established by pumping lifts of 200 feet along the line of discharge, the Sparta Sand would transmit about 9 mgd, or about 10,000 acre-feet per year. The amount of recharge necessary to replace the water moving downdip (9 mgd) is equivalent to about 4.9 inches of rainfall per year. This quantity of water is about 13 percent of the average annual precipitation at Giddings.

The thickness of sand containing fresh to slightly saline water in the Sparta Sand (Figure 22) ranges from zero near its northwest margin of outcrop to about 140 feet at Yegua Creek near the southeast tip of the county. Generally, the amount of sand increases southward. In areas of relatively thick sand, yields of 1,000 gpm might be obtained from properly constructed wells screening all available sand in the aquifer.

In summary, the Carrizo, Queen City, and Sparta Sands are capable of supporting a ground-water development of at least 12 mgd or possibly as much as 40 mgd indefinitely and without impairing the quality of the water. These quantities are from 8 to 25 times the pumpage for all purposes in the county in 1964. Because the quantity of water available from the Simsboro Sand Member was not computed, 12 mgd and probably 40 mgd is a conservative estimate for all of the aquifers in Lee County.

Any extensive ground-water development could be affected by faults having relatively large displacement in north-central Lee County. The faults may interrupt the normal flow of ground water from the outcrops of the aquifers (especially the Simsboro Sand Member and the Carrizo and Queen City Sands) to the centers of pumping, and cause excessive drawdowns in wells. Because of insufficient geologic and hydrologic data in the area of complex faulting, an appraisal of the effect of this faulting on the movement of ground water was not possible. Thus, the estimates of availability necessarily did not take into account any effects of faulting.

Of course, the estimates of availability are based on a limited amount of basic data, theoretical lines of discharge, and assumptions of maximum rates of recharge; moreover, no consideration was given to the effect of future large-scale withdrawals from the aquifers in adjoining counties--a possibility which could have a significant influence on the total quantity of water perennially available.

The proper ground-water development in the county requires that a wealth of basic data be available. Such data, which include records of pumpage, water levels, and chemical analyses of water, would permit the calculation of more reliable estimates of availability, and allow for revision of the estimates as development takes place.

# DEFINITIONS OF TERMS

Many of these definitions have been selected from reports by: Meinzer (1923b), American Geological Institute (1960), Langbein and Iseri (1960), and Ferris and others (1962).

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

Acre-feet per year.--One ac-ft/yr equals 892.13 gallons per day.

Alluvial deposits.--See alluvium.

Alluvium.--Sediments deposited by streams; includes flood-plain deposits and stream-terrace deposits. Also called alluvial deposits.

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

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

Artesian aquifer, confined aquifer.--Artesian (confined) water occurs where an aquifer is overlain by rock of lower permeability (e.g., clay) that confines the water under pressure greater than atmospheric. The water level in an artesian well will rise above the top of the aquifer. The well may or may not flow.

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

Base flow of a stream.--Fair weather flow in a stream supplied by groundwater discharge.

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

Confining bed.--One which because of its position and its impermeability or low permeability relative to that of the aquifer keeps the water in the aquifer under artesian pressure.

Contact.--The place or surface where two different kinds of rock or geologic units come together, shown on both maps and cross sections (e.g., the Wilcox Group-Midway Group contact and the Weches Greensand-Sparta Sand contact on Figure 5 and Plates 2 and 3).

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

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

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

En echelon.--Parallel structural features that are offset like the edges of shingles on a roof when viewed from the side.

Equivalents per million (epm).--An expression of the concentration of chemical substances in terms of the reacting values of electrically charged particles, or ions, in solution. One epm of a positively charged ion (e.g., $Na^+$) will react with 1 epm of a negatively charged ion (e.g., $Cl^-$).

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

Facies.--The "aspect" belonging to a geological unit of sedimentation, including mineral composition, type of bedding, fossil content, etc. (e.g., sand facies). Sedimentary facies are areally segregated parts of differing nature belonging to any genetically related body of sedimentary deposits.

Fault.--A fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture.

Ferruginous.--Containing iron; usually ranging from pale yellow brown, through dark brown, to deep reddish brown in color depending on the amount of iron in the rock.

Formation.--A body of rock that is sufficiently homogeneous or distinctive to be regarded as a mappable unit, usually named from a locality where the formation is typical (e.g., Carrizo Sand, Reklaw Formation, and Queen City Sand).

Fresh water.--Water containing less than 1,000 ppm (parts per million) of dissolved solids (Winslow and Kister, 1956, p. 5). For dissolved solids, see Table 6.

Gallons per day (gpd).

Gallons per hour (gph).

Gallons per minute (gpm).

Graben.--A block of rock, generally long compared to its width, that has been downthrown along faults relative to the rocks on either side.

Greensand.--A mixture of granular (sand size) iron silicate mineral of the glauconite group with varying proportions of quartz sand and clay (Eckel, 1938, P. 1)

Ground water.--Water in the ground that is in the zone of saturation from which wells, springs, and seeps are supplied.

Head, or hydrostatic pressure.--Artesian pressure measured at the land surface Reported in pounds per square inch or feet of water.

Hematite, hematitic.--A mineral of iron, $Fe_2O_3$. The principal ore or iron, usually metallic black to deep red in color.

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

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

Irrigation, supplemental.--The use of ground or surface water for irrigation in humid regions as a supplement to rainfall during periods of drought. Not a primary source of moisture as in arid and semiarid regions.

Lignite.--A brownish-black coal in which the alteration of vegetal material has proceeded further than in peat but not so far as sub-bituminous coal.

Limonite.--Brown iron ore. A generic term for brown hydrous iron oxide, not specifically identified.

Lithology.--The description of rocks, usually from observation of hand specimen, or outcrop.

Marl.--A calcareous clay.

Million(s) gallons per day (mgd).--One mgd equals 3.068883 acre-feet per day or 1,120.91 acre-feet per year.

Mineral.--Any chemical element or compound occurring naturally as a product of inorganic processes.

Outcrop.-- That part of a rock layer which appears at the land surface. On an areal geologic map a formation or other stratigraphic unit is shown as an area of outcrop where exposed and where covered by alluvial deposits (contacts below the alluvial deposits are shown on map by dotted lines).

Parts per million (ppm--weight).--One part per million represents 1 milligram of solute in 1 kilogram of solution. As commonly measured and used, parts per million is numerically equivalent to milligrams of a substance per liter of water.

Permeability of an aquifer.--The capacity of an aquifer for transmitting water under pressure.

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

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

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

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

Resistivity (electrical log)-- The resistance of the rocks and their fluid contents penetrated in a well to induced electrical currents. Permeable rocks containing fresh water have high resistivities.

Salinity of water.--From a general classification of water based on dissolved-solids content by Winslow and Kister (1956, p. 5): fresh water, less than 1,000 ppm; slightly saline water, 1,000 to 3,000 ppm; moderately saline water, 3,000 to 10,000 ppm; very saline water, 10,000 to 35,000 ppm; and brine, more than 35,000 ppm.

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

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

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

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

Stream terrace.--A level and rather narrow plain in a valley at some height above the flood plain composed of alluvial deposits that represent a former flood plain of the stream.

Structural feature, geologic.-- The result of the deformation or dislocation (e.g., faulting) of the rocks in the earth's crust. In a structural basin, the rock layers dip toward the center or axis of the basin. The structural basin may or may not coincide with a topographic basin.

Structural lineament.--A topographic line that is structurally controlled and commonly resulting from a fault.

Surface water.--Water on the surface of the earth.

Transmissibility, coefficient of.-- The rate of flow of water in gallons per day through a vertical strip of the aquifer 1 foot wide extending through the vertical thickness of the aquifer at a hydraulic gradient of 1 foot per foot and at the prevailing temperature of the water. The coefficient of transmissibility from a pumping test is reported for the part of the aquifer tapped by the well.

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

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

Water level.--Depth to water, in feet below the land surface, where the water occurs under water-table conditions (or depth to the top of the zone of saturation). Under artesian conditions the water level is a measure of the pressure on the aquifer, and the water level may be at, below, or above the land surface.

Water level, pumping.--The water level during pumping measured in feet below the land surface.

Water level, static.--The water level in an unpumped or nonflowing well measured in feet above or below the land surface or sea-level datum.

Water table.--The upper surface of a zone of saturation except where the surface is formed by an impermeable body of rock.

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

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

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## Table 5.--Drillers' logs of wells

### Well RZ-58-32-901

Owner: Ike D. Duncum. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Clay, surface, thin streaks of brown sand | 24 | 24 | Sand | 10 | 195 |
| Sand, white | 6 | 30 | Shale | 5 | 200 |
| Shale, and sandy shale | 110 | 140 | Sand | 15 | 215 |
| Sand | 12 | 152 | Shale, sandy | 10 | 225 |
| Shale | 18 | 170 | Shale | 11 | 236 |
| Shale, sandy, and streaks of sand | 15 | 185 | Sand | 19 | 255 |

### Well RZ-58-38-904

Owner: R. H. Rister well 1. Driller: Sayre Oil Co.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Sand | 90 | 90 | Lignite | 2 | 342 |
| Sand and shale | 47 | 137 | Shale, sandy | 53 | 395 |
| Sandrock | 1 | 138 | Sandrock | 1 | 396 |
| Shale, sandy | 100 | 238 | Sand, hard | 44 | 440 |
| Sandrock, hard | 3 | 241 | Sandrock | 1 | 441 |
| Lignite | 3 | 244 | Shale, sandy | 10 | 451 |
| Shale, sandy | 42 | 286 | Sandrock | 1 | 452 |
| Sandrock | 2 | 288 | Sand and boulders | 48 | 500 |
| Lignite | 2 | 290 | Sand, hard | 3 | 503 |
| Shale, sandy | 22 | 312 | Shale and boulders | 492 | 995 |
| Sandrock | 1 | 313 | Sand, green | 5 | 1,000 |
| Shale, sandy | 26 | 339 | Shale, sandy | 43 | 1,043 |
| Sandrock | 1 | 340 | Limerock, sandy | 2 | 1,045 |

(Continued on next page)

Table 5.--Drillers' logs of wells--Continued

Well RZ-58-38-904--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Shale, sticky | 25 | 1,070 |
| Limerock, sandy | 2 | 1,072 |
| Shale, sticky | 18 | 1,090 |
| Limerock | 1 | 1,091 |
| Shale, sandy | 39 | 1,130 |
| Shale, sticky and boulders | 70 | 1,200 |
| Shale, sandy and boulders | 17 | 1,217 |
| Shale, sticky | 113 | 1,330 |
| Gumbo | 12 | 1,342 |
| Shale and boulders | 118 | 1,460 |
| Shale, sticky | 505 | 1,965 |
| Gumbo | 9 | 1,974 |
| Shale, sticky | 121 | 2,095 |
| Chalk | 15 | 2,110 |
| Shale, sticky | 80 | 2,190 |
| Shale, brown, sandy | 15 | 2,205 |
| Lime, hard | 185 | 2,390 |
| Chalk | 530 | 2,920 |
| Total depth | | 3,128 |

Well RZ-58-39-905

Owner: C. L. Ruthven. Driller: --

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Topsoil | 2 | 2 |
| Clay, mixed | 18 | 20 |
| Sand, white | 25 | 45 |
| Sand and shale, gray (water) | 5 | 50 |
| Shale, sandy, brown | 17 | 67 |
| Sand, brown (water) | 70 | 137 |
| Shale, hard | 10 | 147 |
| Shale, sandy, brown | 25 | 172 |
| Caprock | 1 | 173 |
| Sand, gray | 7 | 180 |
| Sand, gray (water) | 30 | 210 |
| Shale, hard | 15 | 225 |
| Sand, gray (water) | 16 | 241 |
| Caprock, hard | 1 | 242 |
| Sand (water) | 5 | 247 |

Table 5.--Drillers' logs of wells--Continued

Well RZ-58-40-903

Owner: City of Lexington. Driller: Pomeroy & McMasters Co.

|  | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface clay | 9 | 9 |
| Rock ledges ------------ | 11 | 20 |
| Rock, hard ------------- | 2 | 22 |
| Shale, hard ------------ | 42 | 64 |
| Sand ------------------ | 8 | 72 |
| Shale ----------------- | 5 | 77 |
| Sandrock -------------- | 40 | 117 |
| Gumbo ----------------- | 9 | 126 |
| Sand ------------------ | 5 | 131 |
| Rock ------------------ | 1 | 132 |
| Sand ------------------ | 16 | 148 |
| Gumbo ----------------- | 6 | 154 |
| Sand, packed ---------- | 34 | 188 |
| Rock ------------------ | 2 | 190 |
| Sand, packed ---------- | 10 | 200 |
| Rock ------------------ | 2 | 202 |
| Sand, packed ---------- | 6 | 208 |
| Gravel and packsand ---- | 39 | 247 |
| Rock ------------------ | 1 | 248 |
| Shale ----------------- | 32 | 280 |
| Packsand -------------- | 30 | 310 |
| Shale ----------------- | 6 | 316 |
| Sand ------------------ | 8 | 324 |
| Rock ------------------ | 1 | 325 |
| Sand ------------------ | 5 | 330 |
| Rock, hard ------------ | 1 | 331 |
| Shale ----------------- | 9 | 340 |
| Rock ------------------ | 1 | 341 |
| Rock ledges and shale -- | 9 | 350 |
| Shale ----------------- | 50 | 400 |
| Sand ------------------ | 10 | 410 |
| Shale, sandy ---------- | 26 | 436 |
| Rock ------------------ | 2 | 438 |
| Shale, sandy ---------- | 5 | 443 |
| Sand ------------------ | 6 | 449 |
| Shale, hard ----------- | 3 | 452 |
| Sand ------------------ | 21 | 473 |
| Rock ------------------ | 1 | 474 |
| Sand ------------------ | 26 | 500 |

## Table 5.--Drillers' logs of wells--Continued

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|

### Well RZ-58-40-904

Owner: City of Lexington well 3. Driller: Layne-Texas Co.

| | | | | | |
|---|---|---|---|---|---|
| Clay | 16 | 16 | Shale | 4 | 129 |
| Sandrock | 3 | 19 | Sand, thin shale breaks | 26 | 155 |
| Clay | 36 | 55 | Shale | 20 | 175 |
| Clay, sandy | 20 | 75 | Sand | 6 | 181 |
| Sand | 9 | 84 | Shale, sand and boulders | 23 | 204 |
| Rock | 1 | 85 | Sand, thin shale breaks | 93 | 297 |
| Sand | 11 | 96 | Shale, sandy | 100 | 397 |
| Shale | 6 | 102 | Sand | 5 | 402 |
| Sand | 12 | 114 | Shale | 43 | 445 |
| Shale | 7 | 121 | Shale, sandy, and shale | 23 | 468 |
| Sand | 3 | 124 | Sand | 49 | 517 |
| Rock | 1 | 125 | Shale | 4 | 521 |

### Well RZ-58-48-507, partial log

Owner: Andrew Richter well 1. Driller: Holland Oil Co. & Longhorn Drilling Corp.

| | | | | | |
|---|---|---|---|---|---|
| Surface | 13 | 13 | Sand, soft | 58 | 315 |
| Clay, sand and gravel | 40 | 53 | Sand, hard, and lime | 3 | 318 |
| Sand, hard | 3 | 56 | Sand, soft | 69 | 387 |
| Sand, hard with soft shale streaks | 138 | 194 | Sand, hard | 1 | 388 |
| Sand, hard | 3 | 197 | Sand, soft | 5 | 393 |
| Sand and lignite | 145 | 242 | Sand, hard | 2 | 395 |
| Sand, firm | 15 | 257 | Sand, lignite, and hard sand streaks | 85 | 480 |

(Continued on next page)

Table 5.--Drillers' logs of wells--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well RZ-58-48-507, partial log--Continued | | |
| Sand and sandy shale streaks | 96 | 576 |
| Lime, hard, sandy | 3 | 579 |
| Shale | 74 | 653 |
| Lime, hard, sandy | 3 | 656 |
| Sand, soft | 128 | 784 |
| Shale, sandy | 42 | 826 |
| Sand, soft with hard streaks | 20 | 846 |
| Sand, hard and soft | 60 | 906 |
| Sand and shale streaks | 84 | 990 |
| Sand with streaks of shale | 60 | 1,050 |
| Sand | 60 | 1,110 |
| Shale, with streaks of sand and lignite | 180 | 1,290 |
| Sand | 136 | 1,426 |
| Sand and shale streaks | 59 | 1,485 |
| Shale and hard sand streaks | 49 | 1,534 |
| Sand, hard and soft | 41 | 1,575 |
| Shale | 65 | 1,640 |
| Sand | 20 | 1,660 |
| Shale and hard sand | 102 | 1,762 |
| Shale and hard sand streaks | 58 | 1,820 |
| Shale, sandy shale, hard sand and lime | 85 | 1,905 |
| Shale and hard lime streaks | 70 | 1,975 |
| Shale and sand, hard | 25 | 2,000 |
| Shale, hard sand, lime and pyrites | 125 | 2,125 |
| Shale, sandy, and lignite | 80 | 2,205 |
| Shale and lime | 45 | 2,250 |
| Shale, sandy shale and pyrites | 65 | 2,315 |
| Shale, hard and lime streaks | 17 | 2,332 |
| Shale, hard, and lime | 38 | 2,370 |
| Sand with streaks of lignite and shale | 96 | 2,466 |
| Shale and lime | 59 | 2,525 |
| Shale, hard, lime and pyrites | 44 | 2,569 |
| Shale, hard, lime and calcite | 19 | 2,588 |
| Shale, hard, lime and pyrites | 137 | 2,725 |
| Shale, sandy shale and lime | 44 | 2,769 |
| Shale, hard sand, lime and calcite streaks | 216 | 2,985 |

(Continued on next page)

Table 5.--Drillers' logs of wells--Continued

Well RZ-58-48-507, partial log--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Sand, hard, and lime with lignite streaks | 111 | 3,096 |
| Shale, hard, lime and hard sand | 43 | 3,139 |
| Lime, hard, shale, sand and lignite streaks | 93 | 3,232 |
| Sand, hard, and lime | 33 | 3,265 |
| Sand | 33 | 3,298 |
| Sand, hard and lime | 28 | 3,326 |
| Sand | 45 | 3,371 |
| Sand, hard and pyrite with shale streaks | 42 | 3,413 |
| Shale, hard, lime and sand streaks | 61 | 3,474 |
| Sand, hard, with streaks of lignite | 106 | 3,580 |
| Sand, hard, shale and lignite | 107 | 3,687 |
| Shale and sand, hard | 58 | 3,745 |
| Sand, hard, and lime | 77 | 3,822 |
| Sand and shale, hard | 77 | 3,899 |
| Total depth | | 6,787 |

Well RZ-59-25-702

Owner: W. E. Greenwood. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface, clay and sand | 36 | 36 |
| Sand and lignite | 3 | 39 |
| Shale, sandy and thin streaks of sand | 51 | 90 |
| Shale, thin streaks of sand and lignite | 25 | 115 |
| Shale and sandy shale | 17 | 132 |
| Sand | 3 | 135 |
| Shale | 7 | 142 |
| Sand | 3 | 145 |
| Shale, thin streaks of sand | 14 | 159 |
| Sand | 3 | 162 |
| Sandrock | 3 | 165 |
| Shale | 22 | 187 |
| Sand (water) | 28 | 215 |

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-33-101

Owner: Ernest C. Bauer. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Surface | 20 | 20 | Sand | 16 | 160 |
| Coal | 7 | 27 | Shale | 32 | 192 |
| Shale, blue | 18 | 45 | Sand | 8 | 200 |
| Sand | 25 | 70 | Sand, fine | 35 | 235 |
| Coal | 4 | 74 | Shale | 25 | 260 |
| Shale | 50 | 124 | Sand | 70 | 330 |
| Rock | 1 | 125 | Shale | 50 | 380 |
| Shale | 18 | 143 | Sand (water) | 27 | 407 |
| Rock | 1 | 144 | | | |

Well RZ-59-33-102

Owner: Andrew Hays. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Surface | 15 | 15 | Rock | 1 | 189 |
| Sand | 26 | 41 | Sand | 31 | 220 |
| Coal | 1 | 42 | Clay, blue | 95 | 315 |
| Shale | 30 | 72 | Shale | 45 | 360 |
| Rock | 1 | 73 | Sand | 55 | 415 |
| Shale | 21 | 94 | Shale | 10 | 425 |
| Rock | 1 | 95 | Sand | 11 | 436 |
| Sand | 20 | 115 | Clay, blue | 39 | 475 |
| Shale | 45 | 160 | Sand | 30 | 505 |
| Rock | 1 | 161 | Shale, sandy | 15 | 520 |
| Shale, sandy | 27 | 188 | Sand | 23 | 543 |

Table 5.--Drillers' logs of wells--Continued

### Well RZ-59-33-402

Owner: San Antonio & Aransas Pass Ry. Co. Driller: --

|  | Thickness (feet) | Depth (feet) |  | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Conglomerate | 86 | 86 | Rock | 2 | 450 |
| Clay, yellow | 18 | 104 | Sand with shells of rock | 36 | 486 |
| Sand | 11 | 115 | Sand (water) | 66 | 552 |
| Rock, very hard pyrite | 3 | 118 | Rock | 1 | 553 |
| Rock, and hard sand | 2 | 120 | Sand, hard and fine | 12 | 565 |
| Packsand | 25 | 145 | Rock | 1 | 566 |
| Shale, black | 20 | 165 | Sand, fine packed | 29 | 595 |
| Sand and shale with shells | 85 | 251 | Shale and pyrites | 41 | 636 |
| Rock, hard | 1 | 252 | Packsand and rock | 118 | 754 |
| Sand, gray | 113 | 365 | Rock, very hard | 2 | 756 |
| Gumbo | 15 | 380 | Packsand and rock | 26 | 782 |
| Sand, fine, with shells of rock | 13 | 393 | Rock, hard | 3 | 785 |
| Sand, fine, packed | 55 | 448 | Sand, water | 45 | 830 |
|  |  |  | Rock, lignite and gumbo | 54 | 884 |

### Well RZ-59-33-501

Owner: John F. Holton. Driller: W. Frank Love.

|  | Thickness (feet) | Depth (feet) |  | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Sand | 50 | 50 | Shale and rock | 61 | 247 |
| Shale | 10 | 60 | Shale, sandy, and boulders | 53 | 300 |
| Shale, sandy | 40 | 100 | Sand | 16 | 316 |
| Sand | 10 | 110 |  |  |  |
| Shale, sandy | 76 | 186 |  |  |  |

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-33-606

Owner: Wilburn Wiederhold. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Clay | 25 | 25 | Shale, sandy | 35 | 300 |
| Clay and rock | 25 | 50 | Sand, dark | 25 | 325 |
| Shale | 18 | 68 | Rock | 1 | 326 |
| Rock | 2 | 70 | Shale, sandy | 19 | 345 |
| Shale | 25 | 95 | Sand and coal | 30 | 375 |
| Shale and rock | 5 | 100 | Shale | 20 | 395 |
| Shale, sandy | 10 | 110 | Shale, sandy | 10 | 405 |
| Shale | 30 | 140 | Sand and coal | 30 | 435 |
| Sand and coal | 15 | 155 | Shale, sandy | 15 | 450 |
| Shale, sandy | 15 | 170 | Shale | 30 | 480 |
| Shale | 55 | 225 | Sand | 54 | 534 |
| Shale, sandy | 20 | 245 | Shale | 21 | 555 |
| Sand and coal | 20 | 265 | | | |

Well RZ-59-41-101

Owner: Isaac Cooper. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Surface | 15 | 15 | Shale, sandy | 20 | 105 |
| Sand | 3 | 18 | Shale, blue | 30 | 135 |
| Shale, blue | 9 | 27 | Shale, sandy | 13 | 148 |
| Shale and sandy shale | 13 | 40 | Sand | 27 | 175 |
| Shale, blue and boulders | 45 | 85 | | | |

## Table 5.--Drillers' logs of wells--Continued

### Well RZ-59-41-102

Owner: Alice Taylor. Driller: Love Drilling Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface | 12 | 12 |
| Clay and sand | 21 | 33 |
| Sand, showing of coal | 10 | 43 |
| Shale, showing of coal | 9 | 52 |
| Shale and boulders | 103 | 155 |
| Sand (no flow) | 13 | 168 |
| Shale | 52 | 220 |
| Sand (small flow) | 18 | 238 |
| Shale, sandy | 19 | 257 |
| Sand (nice flow) | 18 | 275 |
| Sand | 55 | 330 |

### Well RZ-59-41-201

Owner: Lucile Dowdy Jackson. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface, sand, and clay | 20 | 20 |
| Clay, blue | 40 | 60 |
| Shale and boulders | 70 | 130 |
| Sand and shale | 25 | 155 |
| Shale and boulders | 125 | 280 |
| Sand, good | 25 | 305 |
| Sand | 10 | 315 |

### Well RZ-59-41-301

Owner: Oscar S. Exner. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface material and clay | 10 | 10 |
| Shale | 45 | 55 |
| Shale, sandy | 25 | 80 |
| Sand | 92 | 172 |

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-42-101

Owner: Joe J. Mikulin. Driller: --

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Surface clay, gravel and rock | 72 | 72 | Shale, hard thin streaks of sandy shale and hard sand | 100 | 195 |
| Shale, thin streaks of hard sand | 15 | 87 | Sand, clean (water) | 36 | 231 |
| Sand | 8 | 95 | | | |

Well RZ-59-42-203

Owner: Lee County Water Control & Improvement District No. 1. Driller: Layne-Texas Co.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Surface clay | 18 | 18 | Shale, sandy | 47 | 406 |
| Shale | 274 | 292 | Shale, sandy breaks | 47 | 453 |
| Sand and hard breaks | 67 | 359 | Shale | 45 | 498 |

Well RZ-59-42-301

Owner: Edwin Zgabay. Driller: Gus Brinkman.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Clay | 1 | 1 | Sand | 33 | 182 |
| Sand | 7 | 8 | Shale | 7 | 189 |
| Clay | 6 | 14 | Rock | 1 | 190 |
| Sand | 5 | 19 | Shale | 31 | 221 |
| Clay | 8 | 27 | Gumbo, blue | 15 | 236 |
| Shale | 7 | 34 | Sand | 10 | 246 |
| Sand and shale | 98 | 132 | Gumbo | 110 | 356 |
| Shale | 16 | 148 | Shale | 17 | 373 |
| Rock | 1 | 149 | Gravel | 1 | 374 |

(Continued on next page)

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-42-301--Continued

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Clay ------------------ | 6 | 380 | Shale ------------------ | 5 | 443 |
| Shale ----------------- | 5 | 385 | Gravel ----------------- | 5 | 448 |
| Gumbo ----------------- | 8 | 393 | Shale ------------------ | 33 | 481 |
| Sand ------------------ | 1 | 394 | Clay ------------------- | 12 | 493 |
| Shale ----------------- | 32 | 426 | Shale ------------------ | 11 | 504 |
| Dirt, soft ------------ | 12 | 438 | Sand (water) ----------- | 88 | 592 |

Well RZ-59-42-401

Owner: Otto F. and Albert J. Marburger. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Surface and sand ------ | 43 | 43 | Rock ------------------- | 2 | 197 |
| Gravel ---------------- | 3 | 46 | Shale, blue, and boulders ------------- | 121 | 318 |
| Clay, blue, and boulders ------------ | 129 | 175 | Sand (water) ----------- | 27 | 345 |
| Shale and boulders ---- | 20 | 195 | | | |

Well RZ-59-42-409

Owner: Shelby H. Curlee. Driller: W. Frank Love.

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Surface clay ---------- | 30 | 30 | Rock ------------------- | 1 | 223 |
| Shale, sandy, and sand | 15 | 45 | Shale, thin boulders --- | 42 | 265 |
| Shale ----------------- | 15 | 60 | Shale ------------------ | 50 | 315 |
| Shale, sandy ---------- | 25 | 85 | Shale, sandy, and sand - | 10 | 325 |
| Shale, sandy shale with thin streaks of sandrock ---------------- | 137 | 222 | Sand, clean ------------ | 30 | 355 |

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-49-501

Owner: City of Giddings well 1. Driller: Layne-Texas Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| No record | 345 | 345 |
| Shale | 30 | 375 |
| Rock | 1 | 376 |
| Shale | 150 | 526 |
| Rock | 1 | 527 |
| Shale | 36 | 563 |
| Rock | 1 | 564 |
| Shale | 3 | 567 |
| Rock | 1 | 568 |
| Shale | 216 | 784 |
| Sand | 47 | 831 |

Well RZ-59-49-503

Owner: City of Giddings well 3. Driller: Layne-Texas Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface soil | 2 | 2 |
| Shale and rock | 224 | 226 |
| Shale | 7 | 233 |
| Rock, hard and soft layers | 30 | 263 |
| Shale | 24 | 287 |
| Sand | 37 | 324 |
| Shale | 12 | 336 |
| Sand | 7 | 343 |
| Shale | 4 | 347 |
| Rock | 1 | 348 |
| Shale | 23 | 371 |
| Rock | 1 | 372 |
| Shale | 142 | 514 |
| Shale, hard layers | 84 | 598 |
| Shale | 184 | 782 |
| Sand | 54 | 836 |
| Shale | 171 | 1,007 |
| Sand layers and shale | 66 | 1,073 |
| Shale, sandy | 29 | 1,102 |
| Sand, fine | 34 | 1,136 |
| Gumbo | 20 | 1,156 |
| Shale, hard, and very hard rock | 114 | 1,270 |
| Shale, sticky | 24 | 1,294 |
| Sand, good | 45 | 1,339 |
| Shale, sticky | 6 | 1,345 |
| Sand, fine | 10 | 1,355 |
| Shale, sticky | 7 | 1,362 |

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-49-504

Owner: City of Giddings well 4. Driller: Layne-Texas Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Topsoil | 4 | 4 |
| Clay, white | 5 | 9 |
| Sand, fine, gray | 5 | 14 |
| Clay, white | 16 | 30 |
| Sand, fine, gray | 6 | 36 |
| Clay, red | 30 | 66 |
| Shale, sandy, black | 157 | 223 |
| Shale, layers of rock | 14 | 237 |
| Rock, hard, layers of shale | 24 | 261 |
| Shale, hard | 11 | 272 |
| Shale, black | 99 | 371 |
| Rock | 2 | 373 |
| Shale, hard | 28 | 401 |
| Rock | 1 | 402 |
| Shale, hard | 71 | 473 |
| Rock, hard | 1 | 474 |
| Shale, hard, brown | 30 | 504 |
| Sand, hard | 3 | 507 |
| Shale, hard, brown | 26 | 533 |
| Rock | 8 | 541 |
| Shale, hard, brown | 21 | 562 |
| Rock | 1 | 563 |
| Shale, brown | 24 | 587 |
| Rock | 1 | 588 |
| Shale, hard, brown | 67 | 655 |
| Rock, hard | 1 | 656 |
| Lignite and shale | 15 | 671 |
| Shale, hard, brown | 50 | 721 |
| Sand, fine, gray | 112 | 833 |
| Shale, brown, and boulders | 177 | 1,010 |
| Shale, brown, and shell | 32 | 1,042 |
| Shale, hard, layers of sand | 54 | 1,096 |
| Shale, hard, brown | 15 | 1,111 |
| Sand, fine, gray | 32 | 1,143 |
| Shale, dark-brown | 25 | 1,168 |
| Shale, hard | 123 | 1,291 |
| Sand, hard packed | 58 | 1,349 |
| Shale, brown | 1 | 1,350 |

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-49-505

Owner: City of Giddings well 5. Driller: Layne-Texas Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface soil and gravel | 3 | 3 |
| Clay, white ----------- | 18 | 21 |
| Clay, sandy ----------- | 8 | 29 |
| Sand and gravel -------- | 2 | 31 |
| Shale, soft ----------- | 27 | 58 |
| Shale, hard ----------- | 3 | 61 |
| Sand, fine ------------ | 15 | 76 |
| Sand and shale breaks -- | 15 | 91 |
| Sand ------------------ | 6 | 97 |
| Rock, hard, sandy ------ | 1 | 98 |
| Shale, tough ---------- | 24 | 122 |
| Sand and shale breaks -- | 14 | 136 |
| Shale, blue ----------- | 17 | 153 |
| Sand ------------------ | 8 | 161 |
| Shale, blue ----------- | 8 | 169 |
| Sand breaks ----------- | 2 | 171 |
| Shale, brown ---------- | 22 | 193 |
| Shale, blue, hard ------ | 27 | 220 |
| Sand, good ------------ | 16 | 236 |
| Sandrock, hard --------- | 6 | 242 |
| Sand and shale breaks -- | 5 | 247 |
| Sandrock and shale breaks -------------- | 7 | 254 |
| Sand breaks ---------- | 2 | 256 |
| Lignite -------------- | 12 | 268 |
| Rock ----------------- | 4 | 272 |
| Shale and sand breaks - | 19 | 291 |
| Shale and rock layers - | 16 | 307 |
| Shale ---------------- | 9 | 316 |
| Shale and gravel ------ | 18 | 334 |
| Shale, tough --------- | 72 | 406 |
| Sandrock ------------- | 1 | 407 |
| Shale, tough, sticky -- | 4 | 411 |
| Shale, sandy --------- | 2 | 413 |
| Shale, sticky and lime layers ------------- | 9 | 422 |
| Shale, tough, sticky -- | 6 | 428 |
| Shale, hard ---------- | 10 | 438 |
| Shale, tough, sticky -- | 22 | 460 |
| Shale, sticky -------- | 91 | 551 |
| Shale and sand breaks - | 3 | 554 |
| Shale, sticky -------- | 18 | 572 |
| Shale, sandy --------- | 18 | 590 |
| Shale, tough, sticky -- | 79 | 669 |
| Sand breaks ---------- | 2 | 671 |

(Continued on next page)

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-49-505--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Shale, sticky, and shell breaks | 63 | 734 |
| Shale, hard | 31 | 765 |
| Sand and shell | 76 | 841 |
| Shale, tough, sticky | 49 | 890 |
| Shale, hard | 9 | 899 |
| Shale, sandy | 11 | 910 |
| Shale and shell | 6 | 916 |
| Sand | 18 | 934 |
| Shale, sticky | 5 | 939 |
| Sand, hard | 5 | 944 |
| Rock | 4 | 948 |
| Sand and shell | 70 | 1,018 |
| Shale, tough, sticky | 28 | 1,046 |
| Sand and shell | 26 | 1,072 |
| Sand, fine, hard packed | 37 | 1,109 |
| Sand and shell, layers of shale | 109 | 1,218 |
| Sand and shell | 40 | 1,258 |
| Shale, tough | 24 | 1,282 |
| Sand | 5 | 1,287 |
| Shale, hard | 33 | 1,320 |
| Sand and shell | 12 | 1,332 |
| Shale, sticky | 17 | 1,349 |
| Sand and shale layers | 5 | 1,354 |

Well RZ-59-49-506

Owner: City of Giddings well 6. Driller: Layne-Texas Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface clay, sandy | 30 | 30 |
| Clay and sandy clay | 34 | 64 |
| Sand | 31 | 95 |
| Sand and boulders | 18 | 113 |
| Boulders and gravel | 103 | 216 |
| Shale, sandy, and gravel | 20 | 236 |
| Rock | 3 | 239 |
| Shale and boulders | 31 | 270 |
| Shale and sandy shale | 51 | 321 |
| Shale, sandy | 25 | 346 |
| Shale and gravel | 19 | 365 |
| Shale | 14 | 379 |
| Rock | 2 | 381 |
| Shale, sandy | 32 | 413 |
| Shale, blue | 12 | 425 |
| Shale | 38 | 463 |

(Continued on next page)

Table 5.--Drillers' logs of wells--Continued

### Well RZ-59-49-506--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Shale and fine sand streaks | 20 | 483 |
| Shale | 19 | 502 |
| Shale and sandy shale | 16 | 518 |
| Shale and fine streaks of gravel | 27 | 545 |
| Shale and few boulders | 75 | 620 |
| Shale, hard | 188 | 808 |
| Shale and sandy shale | 83 | 891 |
| Shale and boulders | 86 | 977 |
| Shale, sandy | 28 | 1,005 |
| Shale, blue | 20 | 1,025 |
| Shale and sand layers | 15 | 1,040 |
| Shale, hard, sandy | 23 | 1,063 |
| Shale, sandy | 17 | 1,080 |
| Shale | 25 | 1,105 |
| Shale, sandy and lignite | 123 | 1,228 |
| Shale, sandy | 81 | 1,309 |
| Sand, thin shale breaks | 70 | 1,379 |
| Shale | 8 | 1,387 |

### Well RZ-59-50-401

Owner: B. J. Stork. Driller: Sterzing Drilling Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Topsoil | 4 | 4 |
| Clay, red | 4 | 8 |
| Sand, red and clay | 35 | 43 |
| Shale, blue | 17 | 60 |
| Shale, brown | 40 | 100 |
| Shale, blue | 70 | 170 |
| Caprock, hard | 7 | 177 |
| Sand | 123 | 300 |

### Well RZ-59-50-402

Owner: F. R. Dill. Driller: Sheridan Drilling Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay | 15 | 15 |
| Rock | 10 | 25 |
| Clay | 65 | 90 |
| Sand | 2 | 92 |
| Clay | 39 | 131 |
| Sand | 12 | 143 |
| Clay | 35 | 178 |
| Sand and rock | 17 | 195 |

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-50-704

Owner: W. C. Hill well 1. Driller: W. H. Bode.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay | 8 | 8 |
| Sand and clay | 32 | 40 |
| Sand | 20 | 60 |
| Sand and clay | 20 | 80 |
| Sand, water | 40 | 120 |
| Shale, sandy | 30 | 150 |
| Sand and shale | 310 | 460 |
| Shale, sticky | 160 | 620 |
| Shale, sandy | 155 | 775 |
| Shale, sticky | 126 | 901 |
| Sandrock, hard | 1 | 902 |
| Sand, cored | 10 | 912 |
| Shale, sticky | 73 | 985 |
| Shale, sandy | 15 | 1,000 |
| Shale, sticky | 109 | 1,109 |
| Shale, sticky and boulders | 71 | 1,180 |
| Sand | 10 | 1,190 |
| Sand, cored | 5 | 1,195 |
| Shale, sticky | 5 | 1,200 |
| Shale, sandy | 15 | 1,215 |
| Shale, sticky | 25 | 1,240 |
| Sand, cored | 10 | 1,250 |
| Shale, sandy | 100 | 1,350 |
| Shale, sticky | 60 | 1,410 |
| Shale, sandy and boulders | 90 | 1,500 |
| Shale, sandy with hard lime streaks | 119 | 1,619 |
| Shale, hard and lime | 97 | 1,716 |
| Shale, sticky and boulders | 240 | 1,956 |
| Shale, sticky with hard lime streaks | 204 | 2,160 |
| Shale, hard, sandy | 39 | 2,199 |
| Shale, sticky with hard lime streaks | 51 | 2,250 |
| Shale, sandy | 101 | 2,351 |
| Shale, sticky | 20 | 2,371 |
| Sand | 10 | 2,381 |
| Shale, sticky | 30 | 2,411 |
| Sand with hard streaks | 39 | 2,450 |

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-50-803

Owner: Smith well 1. Driller: M. M. Miller & Sons.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface sand | 6 | 6 |
| Gravel | 10 | 16 |
| Clay and shale | 79 | 110 |
| Sand, hard | 10 | 120 |
| Shale | 16 | 136 |
| Shale and lignite | 29 | 165 |
| Limerock | 4 | 169 |
| Shale and boulders | 12 | 181 |
| Sand | 24 | 205 |
| Shale, sandy | 629 | 834 |
| Sand | 23 | 857 |
| Shale, sandy | 50 | 907 |
| Sand, hard | 3 | 910 |
| Sand | 28 | 938 |
| Shale, sandy | 38 | 976 |
| Sand, hard, brown | 4 | 980 |
| Sand | 28 | 1,008 |
| Shale | 162 | 1,170 |
| Rock | 2 | 1,172 |
| Shale | 40 | 1,212 |
| Shale, sandy and lignite | 28 | 1,240 |
| Shale and boulders | 84 | 1,324 |
| Rock, hard | 3 | 1,327 |
| Shale and boulders | 348 | 1,675 |
| Shale, sandy and hard sand | 72 | 1,747 |
| Shale | 56 | 1,803 |
| Lime | 1 | 1,804 |
| Shale | 3 | 1,807 |
| Sand, hard, and rock | 13 | 1,820 |
| Shale, sandy, and lime shells | 65 | 1,885 |
| Sand, hard and soft | 40 | 1,925 |
| Shale | 96 | 2,021 |
| Sand | 2 | 2,023 |
| Shale, sandy, and shale | 78 | 2,101 |
| Sand | 57 | 2,158 |
| Sand and shale | 22 | 2,180 |
| Shale | 20 | 2,200 |
| Sand and streaks of shale | 25 | 2,225 |
| Shale, sandy | 93 | 2,318 |
| Sandrock, hard | 2 | 2,320 |
| Sand, streaks of green and brown shale | 34 | 2,354 |

(Continued on next page)

Table 5.--Drillers' logs of wells--Continued

Well RZ-59-50-803--Continued

| | Thickness (feet) | Depth (feet) | | Thickness (feet) | Depth (feet) |
|---|---|---|---|---|---|
| Rock, hard ------------- | 2 | 2,356 | Sand, gray --------- | 69 | 2,725 |
| Sand and shale, mixed -- | 44 | 2,400 | Shale, hard, sandy - | 3 | 2,728 |
| Rock ------------------- | 1 | 2,401 | Sand --------------- | 61 | 2,789 |
| Shale ------------------ | 58 | 2,459 | Shale and sand ----- | 20 | 2,809 |
| Sand and shale streaks - | 3 | 2,462 | Shale, sandy ------- | 51 | 2,860 |
| Shale, brown, with sand streaks -------------- | 61 | 2,523 | Sand --------------- | 178 | 3,038 |
| Sand and shale --------- | 40 | 2,563 | Shale, hard, sandy - | 101 | 3,139 |
| Sand, gray ------------- | 23 | 2,586 | Sand, hard --------- | 1,595 | 4,734 |
| Sand, caprock, hard crystalized ---------- | 10 | 2,596 | Sand, shale, and some lignite, alternating ------ | 1,082 | 5,816 |
| Sand and shale --------- | 60 | 2,656 | Total depth ------ | | 5,816 |

Well RZ-59-51-201

Owner: Herbert Jacob. Driller: L. D. Arrington.

| | | | | | |
|---|---|---|---|---|---|
| Surface ---------------- | 10 | 10 | Coal and shale ------- | 10 | 90 |
| Clay ------------------- | 5 | 15 | Shale ---------------- | 15 | 105 |
| Sand and gravel -------- | 5 | 20 | Rock ----------------- | 1 | 106 |
| Shale, gray ------------ | 60 | 80 | Sand (water) --------- | 12 | 118 |

Table 7.--Field analyses of water from wells and springs

Water-bearing unit: Twi, Wilcox Group; Twis, Simsboro Sand Member of Rockdale Formation of Plummer (1933); Tc, Carrizo Sand; Tqc, Queen City Sand; Ts, Sparta Sand; Tcm, Cook Mountain Formation; Ty, Yegua Formation; Tj, Jackson Group.

| Well | Water-bearing unit | Depth of well (ft) | Iron (Fe) | pH |
|---|---|---|---|---|
| RZ-58-32-903 | Twi | 135 | 3.5 | 7.3 |
| 905 | Tc(?) | 170 | 4 | 5.8 |
| 58-38-601 | Twi | 68 | .3 | 6.9 |
| 901 | Twi | 3 | .5 | 5.6 |
| 58-39-401 | Twis | 36 | .2 | 6.2 |
| 501 | -- | 85 | 8 | 6.4 |
| 502 | Twis | 14 | .75 | 6.4 |
| 503 | Twis | 38 | .2 | 6.2 |
| 602 | Twis | 90 | 5.5 | 6.5 |
| 603 | Twis | 52 | .2 | 6.8 |
| 604 | Twis | 25 | .7 | 6.9 |
| 702 | Twis | 22 | .2 | -- |
| 703 | Twi | 342 | 1.4 | 6.6 |
| 704 | Twi | 133 | 5.0 | 6.6 |
| 705 | Twi | 55 | .5 | 6.2 |
| 706 | Twi | 326 | .75 | 7.5 |
| 801 | Twis | 205 | 6.5 | 6.5 |
| 802 | Twis | 280 | 1.5 | -- |
| 803 | Twis | 224 | .5 | -- |
| 804 | Twis | 126 | .2 | 7.9 |
| RZ-58-39-805 | Twis | 65 | 0.3 | 6.2 |
| 905 | Twis | 248 | 2 | -- |
| 907 | -- | 620 | 6 | 7.5 |
| 909 | Twi | 78 | .2 | 7 |
| 911 | Twi | 90 | 5.0 | 6.5 |
| 912 | Twi | 93? | .2 | 6.8 |
| 913 | Twi | 120 | 7 | 6.5 |
| 914 | Twi | 100 | 2.0 | 7.1? |
| 915 | Twi | 140 | 5.0 | 6.7 |
| 916 | Twi | 123 | 1.2 | 6.6? |
| 917 | Twis | 150 | 6 | 7.6 |
| 918 | Twis | 1,000 | 1.0 | 5.5 |
| 58-40-201 | Twi | 38 | .4 | 6.4 |
| 202 | -- | 270 | 5.0 | 6.1 |
| 301 | -- | 202 | 8? | 6.6 |
| 302 | Twi | 222 | 10 | 6.7 |
| 401 | -- | 198 | 5.0 | 7.5 |
| 402 | Twi | 22 | .2 | 7.3 |
| 403 | Twis | 200 | .75 | 8 |
| 404 | Twi | 485? | 3.0 | 7.9 |

Table 7.--Field analyses of water from wells and springs--Continued

| Well | Water-bearing unit | Depth of well (ft) | Iron (Fe) | pH | Well | Water-bearing unit | Depth of well (ft) | Iron (Fe) | pH |
|---|---|---|---|---|---|---|---|---|---|
| RZ-58-40-501 | Twi | 55 | 6.9 | -- | RZ-58-48-103 | -- | -- | 1.2 | -- |
| 502 | Twis | 450 | .4 | 8.1 | 108 | -- | 109 | 5? | -- |
| 503 | Tc | 15 | .2 | 7.5 | 203 | Tqc | 80 | 1.5 | 5.4 |
| 504 | Tc | 38 | .5 | 6.3 | 301 | Tqc | 212 | 10? | 6.4 |
| 505 | Tc | 19 | .6 | 7.3? | 302 | Tqc | 412 | 3 | 7.5 |
| 605 | Tqc | 10 | 2.5 | 6.3 | 402 | Tqc(?) | 59 | 6? | 6.7 |
| 606 | Tqc | 60 | 2.8 | 6.9 | 502 | Tqc | 100 | 8? | 7.25 |
| 703 | Twi | 284 | .1 | 8.4? | 503 | Tqc | 35 | .6 | 6.9 |
| 704 | -- | 454 | .45 | -- | 504 | Tqc | 72 | .6 | 5.9 |
| 705 | Twi | 326 | <.1 | -- | 601 | Ts | 32 | 6? | 5.3 |
| 706 | -- | -- | .5? | -- | 602 | Tqc | 275 | 1.3 | 7.8 |
| 707 | -- | 97 | 5.0? | 6.5 | 603 | Tqc | 275 | .8 | 7.8 |
| 708 | Twi | 280 | .2 | 8.0 | 901 | Tqc | 520 | 1.5 | 7.6 |
| 709 | Twi | 199 | .3 | 7.7 | 902 | Tqc | 370 | 1.5 | 7.8 |
| 801 | -- | 172 | 8.0? | 6.4 | 56-901 | Ts | 410 | .5 | 7.8 |
| 803 | -- | 205 | 4 | -- | 902 | Ts | 460 | 2.0 | 7.8 |
| 805 | Tqc | 40 | .4 | 5.5 | 64-301 | -- | -- | .45 | 7.9 |
| 806 | Tc | 19 | .2 | 5.5 | 601 | -- | 198 | 10? | 5.7 |
| 807 | Tc | Spring | .9 | 6.1 | 59-25-401 | Twi | 156 | 8? | 7.7 |
| 912 | Tqc | 30 | .3 | 6.8 | 701 | Twi | 221 | .9 | 7.7 |
| 913 | Tqc | 400 | 5 | 7.3 | 703 | Twi | 360 | .7 | 7.9 |
| 47-104 | Twis | 43 | .2 | 6.6 | 705 | Tc | 45 | 1.2 | 4.5 |
| 106 | Twis | 18 | .15 | 7.1 | 706 | Tqc | 215 | 1.0 | 7.8 |
| 107 | Twis | 26 | 2.1 | 1.1 | 708 | Tqc | 177 | 6.0 | 5.2 |

Table 7.--Field analyses of water from wells and springs--Continued

| Well | Water-bearing unit | Depth of well (ft) | Iron (Fe) | pH |
|---|---|---|---|---|
| RZ-59-25-709 | Tqc | 335 | 4.5 | 5.0 |
| 803 | Tqc | 190 | 2.9 | 7.3 |
| 804 | Tqc | 296 | 2 | 6.7 |
| 33-101 | Tqc | 407 | 8? | 6.4 |
| 108 | Tqc | 399 | .5 | 7.8 |
| 201 | Tc | 500 | 1.5 | 7.5 |
| 203 | Tqc | 527 | 7? | 6.7 |
| 204 | Tqc | 600 | 10? | 6.8 |
| 206 | Tc | 455 | .9 | 7.9 |
| 207 | Tqc | 290 | 1.0 | 7.5 |
| 209 | Tc | 398 | 1.0 | 7.6 |
| 301 | Tc | 525 | 4.0 | 7.5 |
| 302 | Tc | 500 | .6 | 7.8 |
| 303 | Tqc | 211 | .9 | 8.0 |
| 502 | Tqc | 371 | 5 | 7.3 |
| 601 | Tqc | 309 | .7 | 7.9 |
| 602 | -- | 181 | 10? | 6.2 |
| 603 | Tqc | 136 | .5 | 7.9 |
| 604 | Tqc | 203 | .7 | 7.8 |
| 606 | Tqc | 534 | .45 | 7.8 |
| 41-103 | -- | -- | .75 | 8? |
| 104 | Tqc | -- | .9 | 7.8 |
| 402 | -- | 280 | 10? | 6.4 |
| 403 | Tqc | -- | 2.7? | 4.75 |
| RZ-59-41-404 | Tqc | 305 | 1.3 | 7.8 |
| 702 | Tqc | 375 | 4.0 | 7? |
| 703 | Tqc | 700 | .5 | 7.85 |
| 42-601 | Tcm | 500 | .85 | 7.8 |
| 602 | Ty | 300 | 2.7 | 7.3 |
| 901 | Ty | 290 | .8 | 7.8 |
| 43-401 | -- | -- | 1.3 | 7.8 |
| 402 | Ty | 364 | .5 | 8.2 |
| 701 | Tj | 140? | .5 | -- |
| 49-301 | Ty | 90 | 1.5 | -- |
| 507 | Tcm | 210 | 4 | 7.7 |
| 601 | Ty | 100 | 4.5 | 6.9 |
| 602 | Ty | 128 | .75 | 7.3 |
| 701 | Tcm | 243 | .8 | 7.8 |
| 703 | Tcm | 205 | 1.5 | 7.2 |
| 704 | Tcm | 103 | 8? | 6.3 |
| 705 | Tcm | 396 | .7 | 7.8 |
| 801 | Tcm | 750 | 4.0 | 7.8 |
| 901 | Ts | 1,097 | .8 | 7.8 |
| 902 | Ty | 305 | 3.5 | 7.1 |
| 903 | Ty | 180 | 4.0 | 6.6 |
| 50-201 | Ty | 160 | 1.7 | 7.5 |
| 501 | Ty | 510 | .2 | 7.8 |
| 502 | Ty | 400 | .5 | 7.8? |

Table 7.--Field analyses of water from wells and springs--Continued

| Well | Water-bearing unit | Depth of well (ft) | Iron (Fe) | pH | Well | Water-bearing unit | Depth of well (ft) | Iron (Fe) | pH |
|---|---|---|---|---|---|---|---|---|---|
| RZ-59-50-601 | Ty | 356 | 0.8 | 7.7? | RZ-59-51-102 | Tj | 335 | 0.5 | 7.7? |
| 702 | Tj | 160 | 10? | 6.2 | 401 | Tj | 120 | 2.2 | 7.2 |
| 705 | Tj | 96 | 7? | 6.5 | 57-101 | -- | -- | 2.2 | 7.8 |
| 802 | Tj | 240 | 1.5 | 6.8 | 301 | Ty | 525 | 6 | 7.2 |
| 805 | Tj | 304 | 5.0? | 7.3 | | | | | |