AVAILABILITY AND QUALITY OF GROUND WATER IN LEON COUNTY, TEXAS

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AVAILABILITY AND QUALITY OF GROUND WATER IN LEON COUNTY, TEXAS

ABSTRACT

Three aquifers in Leon County can support large-scale additional development. These are the Carrizo-Wilcox aquifer, which consists of the Wilcox Group and Carrizo Formation, the Queen City aquifer, and the Sparta aquifer.

Leon County covers an area of 1,099 square miles in east-central Texas. Altitudes in the county range from about 150 to 600 feet, and the topography is characterized by numerous low-lying cuestas and gently rounded hills of low relief. Approximately 80 percent of the county is covered by loose sandy soil, which is heavily timbered with oak trees and a few isolated patches of pine trees. The climate is subhumid to humid, and the average annual precipitation is about 40 inches per year. The population of the county in 1960, according to the U.S. Bureau of Census, was 9,951. Farming and ranching constitute the backbone of Leon County's economy, with additional income being obtained from oil and gas production.

The Carrizo-Wilcox aquifer is the primary source of ground water in Leon County. The aquifer is present throughout the county and can sustain yields up to as much as 1,000 gpm (gallons per minute) in individual wells. From assumed conditions of future pumpage, it is estimated that on the order of 61 million gallons per day or 68,000 acre-feet of water per year can be developed from the Carrizo-Wilcox aquifer in Leon County. The present withdrawal is small in comparison with the quantity available. Approximately 281 acre-feet of water was pumped from the aquifer in 1960 for municipal purposes and approximately 267 acre-feet for irrigation. In addition, numerous domestic and livestock wells obtain relatively small quantities of water from this aquifer. The water is of very good quality, with the dissolved-solids content generally ranging from 143 to 591 ppm (parts per million). The water is suitable for most purposes with little or no treatment except when iron or hydrogen sulfide is encountered.

The Queen City aquifer offers the next best potential for development in Leon County. The aquifer is present throughout all except the northwest corner of the county. It is estimated, under assumed conditions of future pumpage, that approximately 16,500 acre-feet of water per year could be produced from the Queen City aquifer in Leon County. The present development in the aquifer is very small, with only 107 acre-feet of water having been pumped in 1960 for municipal purposes. In addition, hundreds of domestic and livestock wells and some flowing wells discharge an undetermined amount of water from the aquifer. Yields up to 250 gpm can be anticipated from the Queen City aquifer if all of

the available sands are screened. The water from the Queen City aquifer in Leon County is generally suitable for most purposes with little or no treatment, except where high concentrations of iron are encountered. The dissolved-solids content ranged from 101 to 393 ppm in the water samples analyzed.

Although the Sparta aquifer has relatively high coefficients of transmissibility, its development in Leon County is limited by its small areal extent. The aquifer is present only in the southern part of the county. However, if wells completed in the aquifer are properly constructed and maintained, yields up to as much as 700 gpm could be expected in the southeast corner of the county. The aquifer contains generally good quality water throughout its extent in Leon County. The aquifer is virtually undeveloped, with the only pumpage being that for domestic and livestock wells located in and near the outcrop area.

Approximately 75.4 million gallons of water per day, or 84,500 acre-feet annually, is estimated to be available from the Carrizo-Wilcox and Queen City aquifers in Leon County. In addition, an undetermined quantity of water is available from the Sparta aquifer in the southern part of the county. The combined pumpage from the aquifers in 1960 was only 655 acre-feet, with additional undetermined amounts of water being pumped for domestic, livestock, and commercial uses. The development of additional supplies of ground water throughout Leon County is favorable.

AVAILABILITY AND QUALITY OF GROUND WATER IN LEON COUNTY, TEXAS

INTRODUCTION

Purpose and Scope

The purpose of this report is to assist individuals and communities in Leon County in obtaining the best possible supply of ground water available in the area and to determine the amount of water available for future development.

The ground-water study in Leon County was instigated by the East Texas Geological Society which, as result of the drought in the early 1950's, had received numerous requests for help in solving local water problems throughout east Texas. The East Texas Geological Society formed a water resources committee, which was to collect, process, and disseminate shallow subsurface geologic and hydrologic information. The water resources committee met with personnel of the Board of Water Engineers (name changed to Texas Water Commission in January 1962) in February 1957 to discuss plans for compiling basic ground-water data in an area covering many counties in northeast Texas in which the Carrizo-Wilcox aquifer either crops out or occurs at relatively shallow depths. The meeting resulted in setting up a cooperative program in which the East Texas Geological Society would conduct geological studies in east Texas on a county by county basis and the Board of Water Engineers would conduct ground-water studies to obtain hydrologic information to incorporate in the county reports. It was anticipated at that time that a final regional report would be prepared containing all the county reports in the northeast Texas area.

Leon County was selected as the initial county to be studied, and a county committee was appointed by the East Texas Geological Society to obtain geologic data in the county. The committee consisted of Donald T. Gibson (chairman), George Anderson, Ross Lessentine, Fritz Grice, Alan Mabra, and Jim Yelvington. In the summer of 1958, the Board of Water Engineers through a brief field study obtained hydrologic information on the Carrizo-Wilcox aquifer in Leon County and a manuscript was prepared presenting the geologic and hydrologic data of the Carrizo-Wilcox aquifer in Leon County.

In September 1959, the Texas Board of Water Engineers began a ground-water reconnaissance study in the Trinity, Neches, and Sabine River Basins of east Texas as part of a statewide study. It was decided at that time to expand the scope of the earlier written manuscript, which dealt primarily with the Carrizo-Wilcox aquifer, into a ground-water investigation that included all the aquifers in Leon County. This report includes data collected both in 1958 and in the fall of 1959.

The scope of this report includes the determination of the location and extent of the principal aquifers in the county, the general chemical quality of the ground water available, the utilization of the ground water, and the quantity of ground water available for future development to meet the needs of the county. The report portrays the ground-water conditions in the county along with the basic data collected during the study. In addition to supplying the local information needs, the report furnishes the Texas Water Commission with information for use in protecting the fresh-water supply from contamination through its surface casing and salt water disposal recommendations to the Railroad Commission of Texas.

The investigation was made under the direction of R. T. Littleton, former Director of the Ground Water Division and L. G. McMillion, Director of the Ground Water Division, and under the general supervision of McDonald D. Weinert, former Chief Engineer and John J. Vandertulip, Chief Engineer of the Texas Water Commission.

Location and Extent

Leon County is located in east-central Texas as shown by Figure 1. The county is bounded on the north by Anderson, Freestone, and Limestone Counties; on the west by Robertson County; on the south by Madison County; and on the east by Houston County. The county lines on the east and west are formed by the Trinity and Navasota Rivers, respectively. Leon County covers an area of 1,099 square miles.

Methods of Investigation

Field investigations for this report were conducted during the summer of 1958 and the fall and winter of 1959. During the course of the study special emphasis was placed on the following items:

1. Collection and compilation of available logs of wells and preparation of cross sections and maps of the subsurface geology.

2. Inventory of municipal, industrial, irrigation, domestic, and livestock wells.

3. Inventory of municipal, industrial, and irrigation pumpage.

4. Determination of elevations of water wells by altimeter.

5. Performance of pumping tests in selected wells to determine the water-bearing characteristics of the aquifers.

6. Compilation of existing chemical analyses and sampling of selected wells for additional analyses.

7. Correlation and analysis of all data to determine the quantity of ground water available in the aquifers of the county and the general effects of future pumping.

The geologic map (Plate 1) was constructed from the U.S. Geological Survey's geologic map of Texas, Stenzel's (1938) geology map of Leon County, and

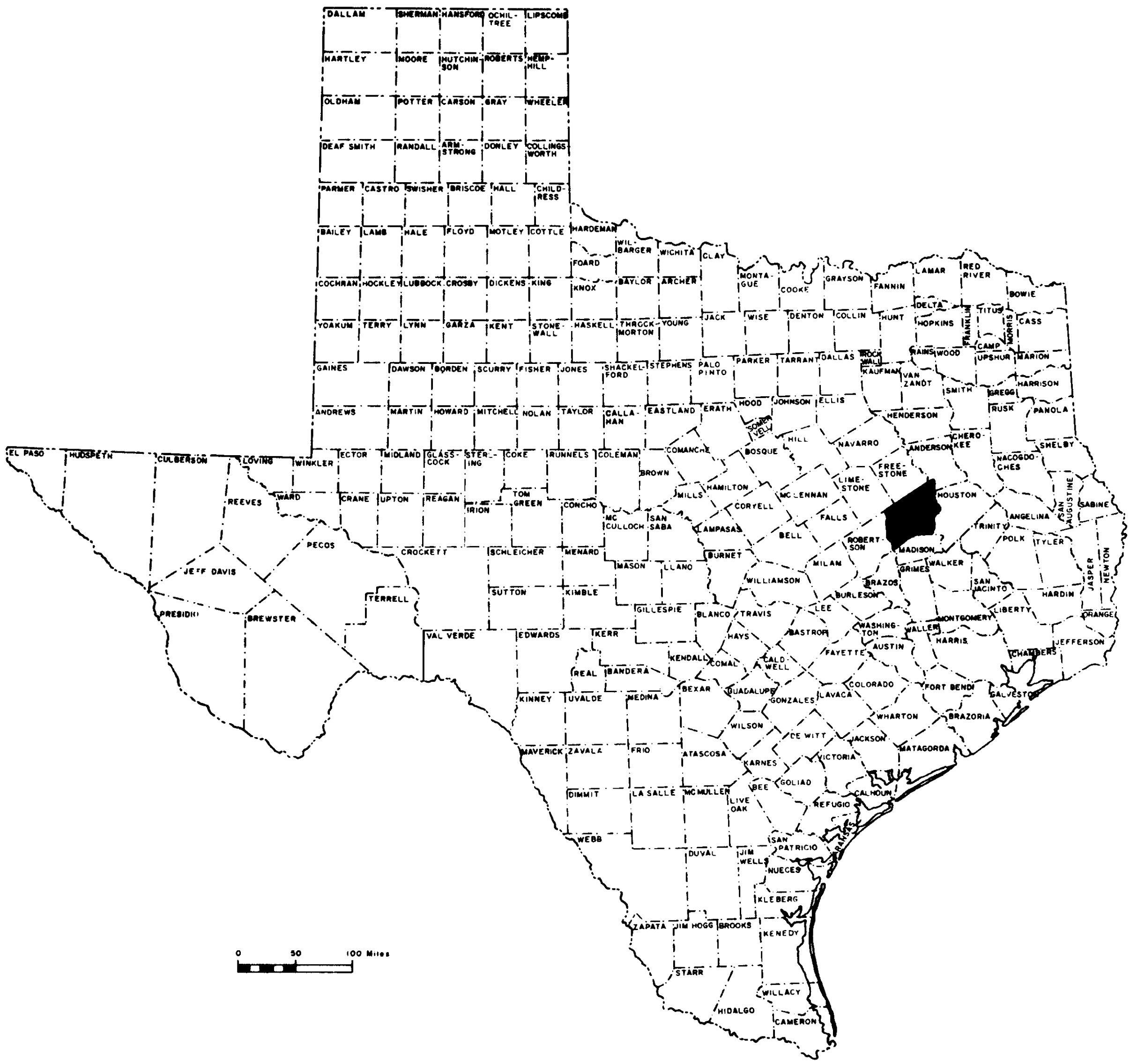

Figure 1

Map of Texas Showing Location of Leon County

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field observations. Subsurface maps and geologic sections were prepared from information obtained from 82 electric logs of wells located throughout Leon County. The location of these wells along with the 121 scheduled water wells are shown on Plate 1. Data obtained on the water wells are shown in Table 2, and the oil tests used as control points are shown in Table 4. The base of usable quality water, based on 3,000 ppm (parts per million) dissolved solids, was calculated from the self-potential curve of the electric logs. The piezometric-surface maps were prepared from water-level measurements and elevations obtained from altimeter traverses from bench marks to the wells. Elevations were also obtained from Stenzel (1938), oil tests, and U.S. Army Map Service topographic maps.

Pumping tests were run on two Carrizo wells and one Queen City well in Leon County to determine the aquifer characteristics. The aquifer characteristics of the Sparta Formation were determined from a pumping test in Madisonville approximately 10 miles south of Leon County.

Water samples were collected from 22 wells in Leon County and analyzed by the laboratory of the U.S. Geological Survey in Austin. These chemical analyses along with previous ones are shown in Table 3.

Previous Investigations

There are few publications on the ground water or geology of Leon County. "The Geology of Texas" (Sellards and others, 1932) contains some geologic information on Leon County. Stenzel (1938) made an extensive study of the surface geology with a very brief and generalized section on the ground-water resources of the county in his report titled "The Geology of Leon County, Texas." This report relies heavily upon the report by Stenzel for surface geological data. A tabulation of water wells in Leon County was published in 1937 by the Board of Water Engineers (Turner, 1937).

Well-Numbering System

The well numbers used in Leon County are part of a statewide well-numbering system adopted by the Texas Water Commission. This system is based on the division of the State into quadrangles formed by degrees of latitude and longitude, and the repeated division of these quadrangles into smaller ones as shown on Figure 2.

The State has been divided into eighty-nine 1-degree quadrangles. The first two digits of the seven digit well number indicates in which 1-degree quadrangle the well is located. Leon County is located in segments of three 1-degree quadrangles: 38, 39, and 59. These are shown at the lower center of the well location map (Plate 1) where the three quandrangles intersect.

Each 1-degree quadrangle has been divided into sixty-four $7\frac{1}{2}$-minute quadrangles. These are represented by the second pair of digits in the well number. The $7\frac{1}{2}$-minute quadrangles are numbered from left to right starting in the upper left corner of the 1-degree quadrangle. These numbers are shown on the well location map in the upper left corner of each $7\frac{1}{2}$-minute quadrangle.

The $7\frac{1}{2}$-minute quadrangles are further divided into nine $2\frac{1}{2}$-minute quadrangles. These are represented by the fifth digit of the well number. The

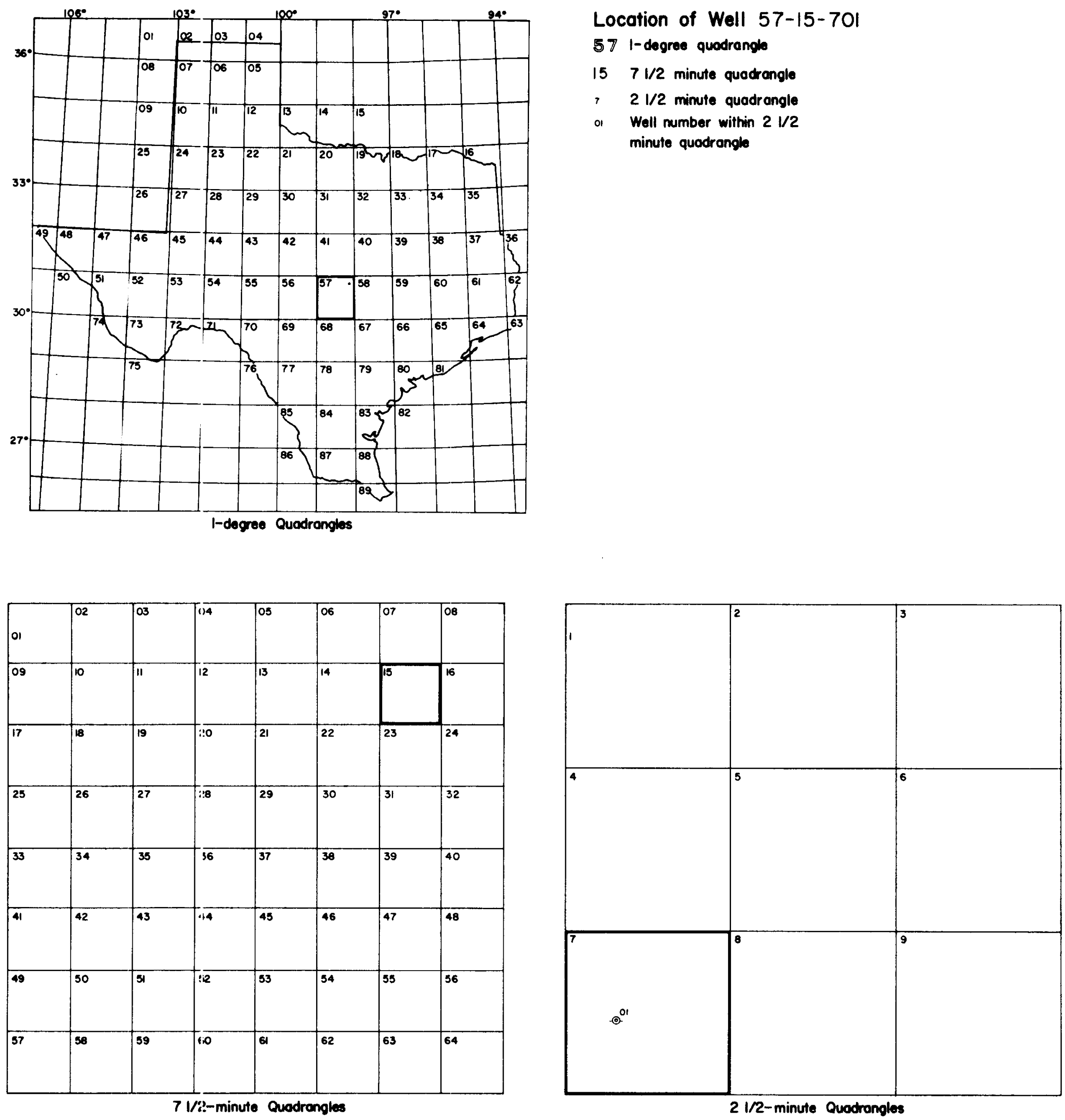

Figure 2

Well-Numbering System

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$2\frac{1}{2}$-minute quadrangles also are numbered from left to right starting in the upper left corner. These numbers are not shown on the well location map, but comprise the first of the three digits that appear on each well. The last two digits are the well number within the $2\frac{1}{2}$-minute quadrangle.

Using well 39-40-202, located in Buffalo, as an example we find that the well is located as follows:

39	40	2	02
1-degree quadrangle number 39	$7\frac{1}{2}$-minute quadrangle number 40 in the 1-degree quadrangle number 39	$2\frac{1}{2}$-minute quadrangle number 2 in the $7\frac{1}{2}$-minute quadrangle number 40	well number 2 in the $2\frac{1}{2}$-minute quadrangle number 2

Acknowledgments

The Leon County study was greatly facilitated by the aid and cooperation given by many individuals and organizations. Appreciation is expressed to the local water well drillers, the city officials of the various towns, the County Agent, the Soil Conservation Service, and the well owners in Leon County for their cooperation and contribution of data. Grateful acknowledgment is given to the Leon County Water Resources Committee of the East Texas Geological Society for their work and assistance on the project. A special word of thanks also is due the Pan American Petroleum Corporation for the use of their electric log file.

GEOGRAPHY

Physiography and Drainage

The topography of Leon County is characterized by numerous low-lying cuestas trending northeast, and by gently rounded hills of low relief. The altitude ranges from about 600 feet near Jewett to about 150 feet in the Trinity River bottom in the southeastern part of the county.

Approximately 80 percent of the county is covered by loose sandy soils that are heavily timbered with oak trees and a few isolated patches of pine trees. In addition to the areas with predominantly sandy soils, there are several blackland prairies in the southern part of the county and a strip of flat backland 1 to 2 miles wide in the northwest part of the county near Marquez. Wide alluvial plains have developed along the rivers and some of the larger creeks in the county.

The county is dissected by numerous creeks and branches that form a dendritic drainage pattern on the predominantly sandy surface. Most of these tributaries are fed by springs or seeps. Drainage in Leon County is controlled by the Brazos and Trinity River Basins. The watershed divide between these two rivers is located roughly along Farm Road 39 between Normangee and Jewett. The western third of the county is drained by the Navasota River, which flows into the Brazos River, and the remaining two-thirds of the county is drained by the Trinity River.

Climate

The climate in Leon County is subhumid to humid and is characterized by hot summers and mild winters. The temperature ranges from an average of about 51° Fahrenheit in January to about 83° in July with an average annual temperature of 67°. The first killing frost in the autumn occurs usually between November 1 and 15, while the last killing frost in the spring occurs usually between March 1 and 15.

The average annual precipitation in Leon County is about 40 inches, and the average annual potential lake evaporation is about 55 inches. The precipitation during the summer months generally is in the form of scattered thundershowers, whereas the rainfall during the winter is generally more widespread and of longer duration. Figure 3 illustrates the mean monthly and the annual precipitation for the period of record at the Centerville and Long Lake stations. The Long Lake station is located in Anderson County, a few miles north of the northeast corner of Leon County.

Population and Economy

The population of Leon County in 1960 according to the U.S. Bureau of the Census was 9,951. This was a decrease of 2,073 people from the 1950 census. The towns and their populations are: Buffalo, 1,108; Centerville (county seat), 836; Oakwood, 716; Normangee, 718; Jewett, 445; and Marquez, 194.

Farming and ranching constitutes the backbone of Leon County's economy. The principal crops grown in the county are watermelons, peanuts, peas, and hay. Crops of cotton, corn, and grain sorghums are confined mainly to the bottom lands. Most of the land area is devoted to the raising of livestock, which includes poultry, cattle, sheep, and goats.

Approximately 624,000 barrels of oil was produced in 1962 from the oil fields in Leon County, making the cumulative production total for the county approximately 2,300,000 barrels. Natural gas is also produced, but there is no record available of the total production.

Lignite mines were opened in the early 1900's, and were operated to supply fuel locally for heating and for steam locomotives. However, by 1930 oil became the chief source of fuel in the area and all of the lignite mines were shut down. The lignite deposits are in the outcrop of the upper Wilcox Group in the northwest corner of the county. Large reserves of lignite are still available as a potential source of industrial fuel for industries locating on or near the outcrop area.

Other natural resources of the county include brick clay, glass sand, road material, timber, and low-grade iron ore, but none of these have been developed extensively.

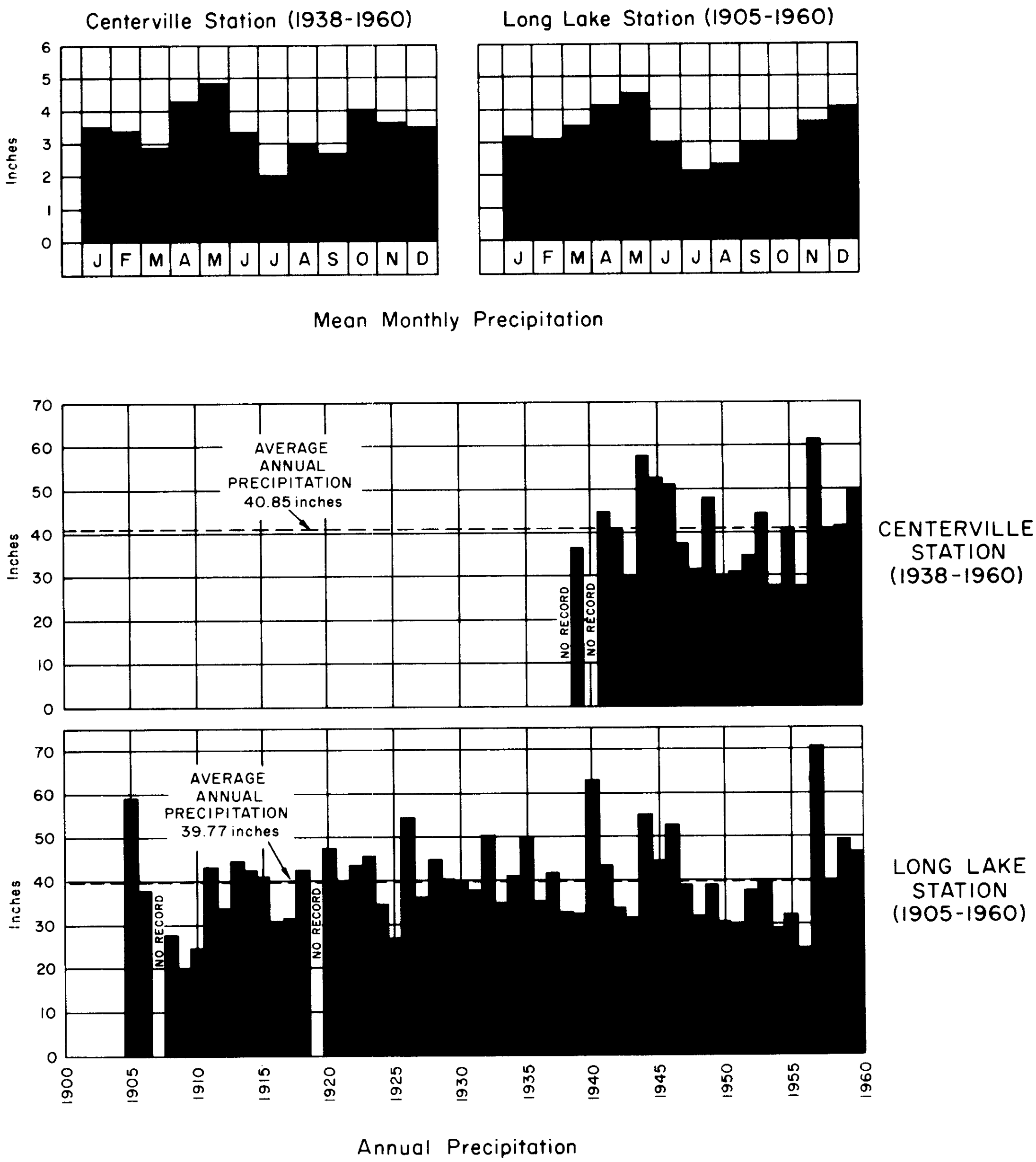

Figure 3

Mean Monthly and Annual Precipitation for Period of Record at Centerville and Long Lake Stations

(Data from U.S. Weather Bureau)

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Geologic History

Throughout geologic history, vast areas of the present-day continent were from time to time covered by seas. During the Cretaceous Period, the sea advanced from the south and covered most of Texas. Typical nearshore sands, marine shale, and limestone were deposited in Leon County during this period, before the sea retreated to the south and the area was once again emergent and subjected to erosion. The oldest rocks presently exposed in Leon County are of Cretaceous age.

The Cretaceous Period was followed by the Tertiary Period, which was marked by continued subsidence of the Coastal Plains and the Gulf of Mexico areas, and repeated transgressions and regressions of the sea. Streams, draining the area northwest of Leon County, carried large quantities of sediments to the sea. The fluctuating shoreline during the Eocene Epoch resulted in the deposition of an alternating sequence of marine and continental sediments. The marine sediments, typically characterized by clay, shale, marl, and minor amounts of sand, possess relatively poor water-bearing properties. The continental deposits consist mainly of sand, with lesser amounts of shale, clay, and lignite, and are the major water-bearing units in the county.

As the sea receded to its present position, a continental gravel was deposited during the Pliocene Epoch, the remnants of which still remain in Leon County on the high ridges and stream divides. Since Tertiary time the area has been eroded and modified by terrace and alluvium deposition of ancestral and present-day streams. The geologic units discussed in this section are listed in Table 1.

Structure

At the time of deposition of Eocene sediments, Leon County lay on the western edge of the east Texas embayment, due west of the mouth of the bay. The axis of the embayment trended north and lay to the east of Leon County. Figure 4 shows the location of the east Texas embayment and other regional structural features that affected the deposition of Eocene sediments. Continual subsidence in the embayment and the open sea to the south during deposition produced a regional dip of the beds toward the southeast. The average regional dip in Leon County is about 50 feet per mile with the rate of dip and bed thicknesses generally increasing downdip. The geologic section A-A' (Plate 2) generally is on a line with the regional dip and illustrates the increase in the rate of dip and bed thicknesses in the downdip direction. The land surface also slopes gulfward but at a lesser angle; therefore, older beds crop out to the northwest at higher elevations than the younger beds to the southeast.

The regional dip to the southeast is interrupted in the northeastern part of the county by an elongated structural high. This structural feature is best illustrated on Plate 6. In addition to this structure there are two known salt domes in Leon County. They have very small areal extent, being circular and less than 2 miles in diameter. The Marquez salt dome is located about 4 miles northwest of the town of Marquez and lies within the Wilcox outcrop. The salt plug has pushed Cretaceous rock to the surface directly above the dome so that no fresh-water sands exist over the dome. This dome is shown on Plates 1, 2, 5, 6, and 7. The other salt dome, the Oakwood dome, is located on the county line about 7 miles northeast of Buffalo. Here, the salt core lies within 1,200 feet of the surface at its apex, having pierced and compressed the beds above it, causing a reduction in sand thickness over the dome. The Oakwood salt dome is shown on Plates 5, 6, and 7.

There are a number of small faults throughout the county, but their displacement is so slight that they do not show up on any of the maps. Also, they have little or no known effect on the water conditions in Leon County.

Stratigraphy

The fresh-water-bearing part of the stratigraphic sequence of geologic units in Leon County are shown in Table 1. This table lists the geologic units from youngest to oldest, their approximate thickness, a brief description of their lithology, and a brief summary of their water-bearing properties. The location of the outcrop areas of various stratigraphic units listed in Table 1 are shown on the general geology map (Plate 1). Plates 2 and 3, generalized geologic sections, illustrate the stratigraphic position of these rocks in the subsurface.

Most of the stratigraphic units in Leon County will yield some water, but only the sands of the Wilcox Group, the Carrizo Formation, the Queen City Formation, and the Sparta Formation yield water in sufficient quantities to be considered of major importance as water producers. The geologic characteristics and water-bearing properties of these stratigraphic units will be discussed in more detail in later sections of this report. Plate 4 shows the areal extent of these aquifers in Leon County and the areas in which they produce usable quality water. For discussion purposes in this report, the term "fresh" or "usable" water refers to water containing less than 3,000 ppm dissolved solids, and the use of "aquifer" refers only to that part of the stratigraphic units containing fresh water.

The alluvium and terrace deposits, the Cook Mountain Formation, and the Reklaw Formation yield small quantities of water in the county, but their yields are either too small or the sands are not of sufficient lateral extent to be considered principal aquifers. The upland gravels, the Weches Formation, the Midway Group, and the Cretaceous rocks are not known to yield water to wells in Leon County.

GENERAL GROUND-WATER HYDROLOGY

This section on general ground-water hydrology has been included to acquaint the reader with the basic fundamentals of ground-water hydrology and to define the terms used in this report.

Hydrologic Cycle

The hydrologic cycle is the sum total of processes and movements of the earth's moisture from the sea, through the atmosphere, to the land, and eventually, with numerable delays en route, back to the sea. Figure 5 illustrates the courses that the water may take in completing the cycle. All water

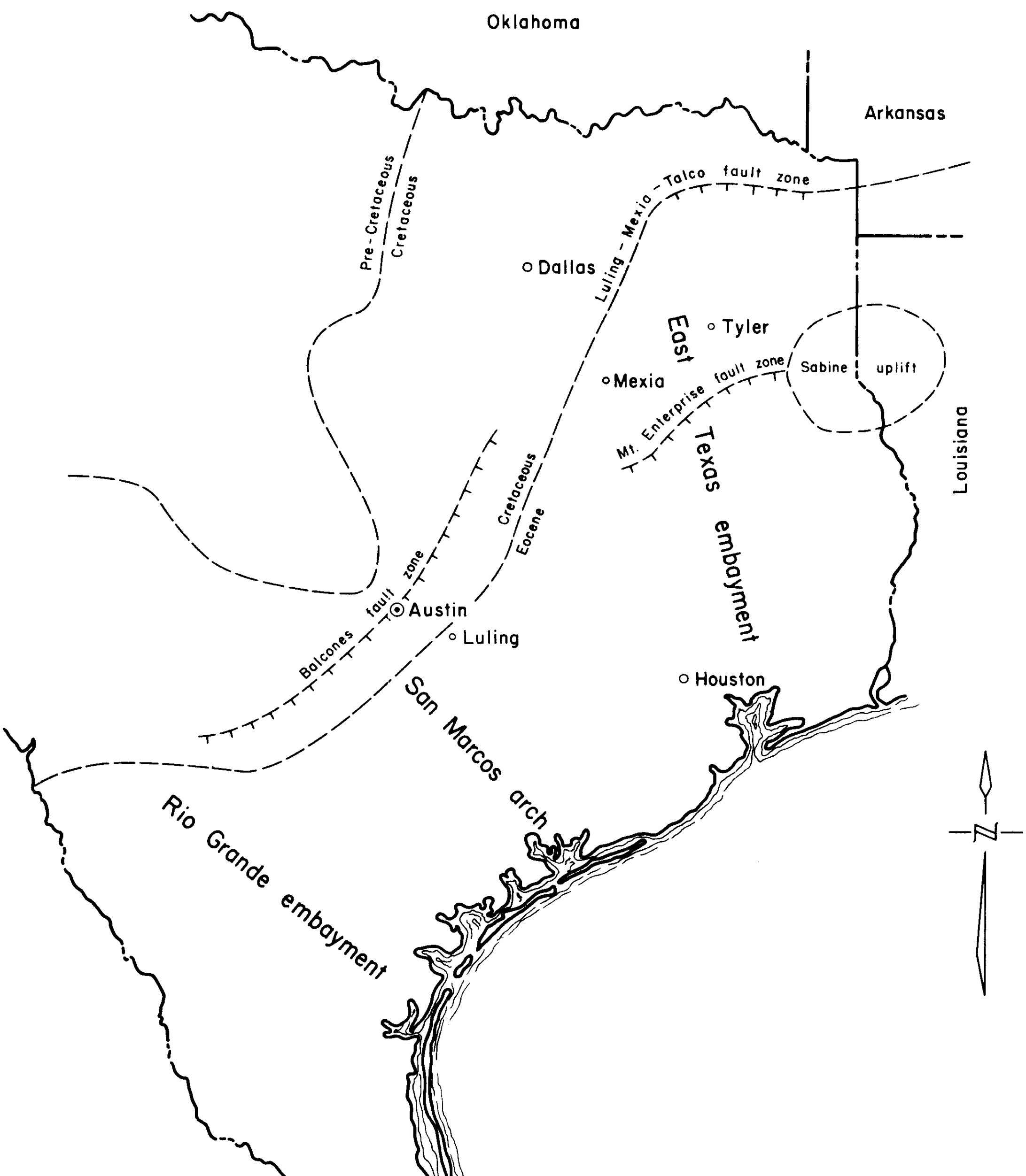

Figure 4

Regional Geologic Structure of Eastern Texas

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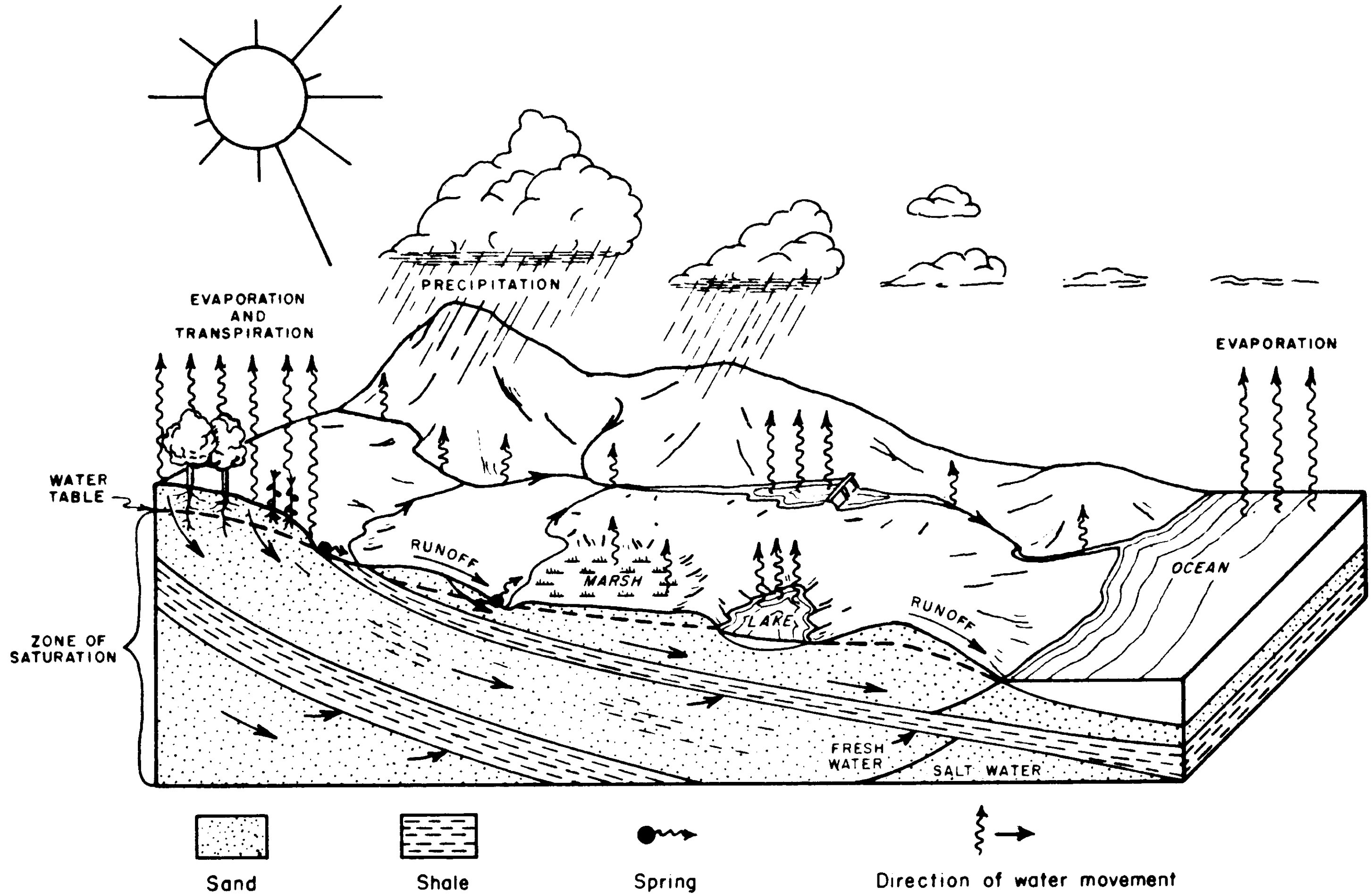

Figure 5

Hydrologic Cycle

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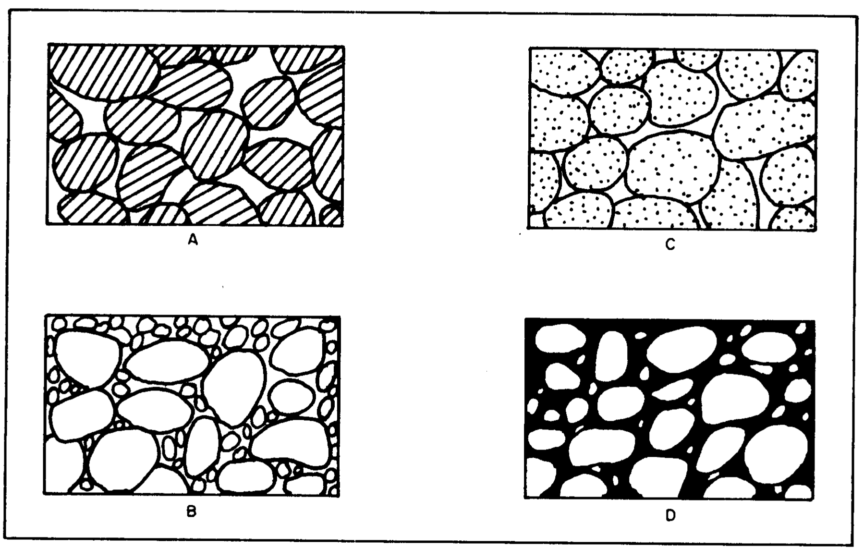
occurring in Leon County, whether surface water or ground water, is derived from precipitation. Moreover, precipitation in this area is derived for the most part from water vapor carried inland from the Gulf of Mexico.

Occurrence and General Hydraulics

Ground water is contained in the interstices or voids of pervious strata. Two rock characteristics of fundamental importance in the occurrence of ground water are porosity, the amount of open space contained in the rock, and permeability, which is the ability of the porous material to transmit water. In sedimentary rocks, such as the Tertiary and Quaternary rocks in Leon County, the porosity is a function of the size, shape, sorting, and degree of cementation of the grains. The following diagrams show several of the various types of interstices that occur in sedimentary rocks and the relation of rock texture to porosity.



Adapted from O. E. Meinzer, 1923, The occurrence of ground water in the United States, with a discussion of principles: U.S. Geol. Survey Water-Supply Paper 489, p. 3.

A. Well-sorted sedimentary deposit having high porosity.

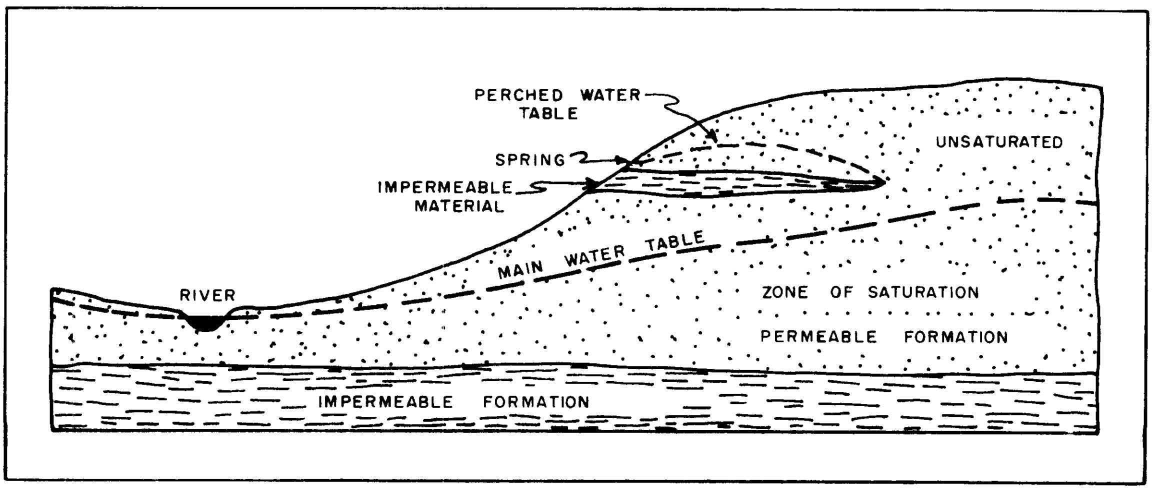
B. Poorly-sorted sedimentary deposit having low porosity.

C. Well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity.

D. Well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter (cementation) in the interstices.

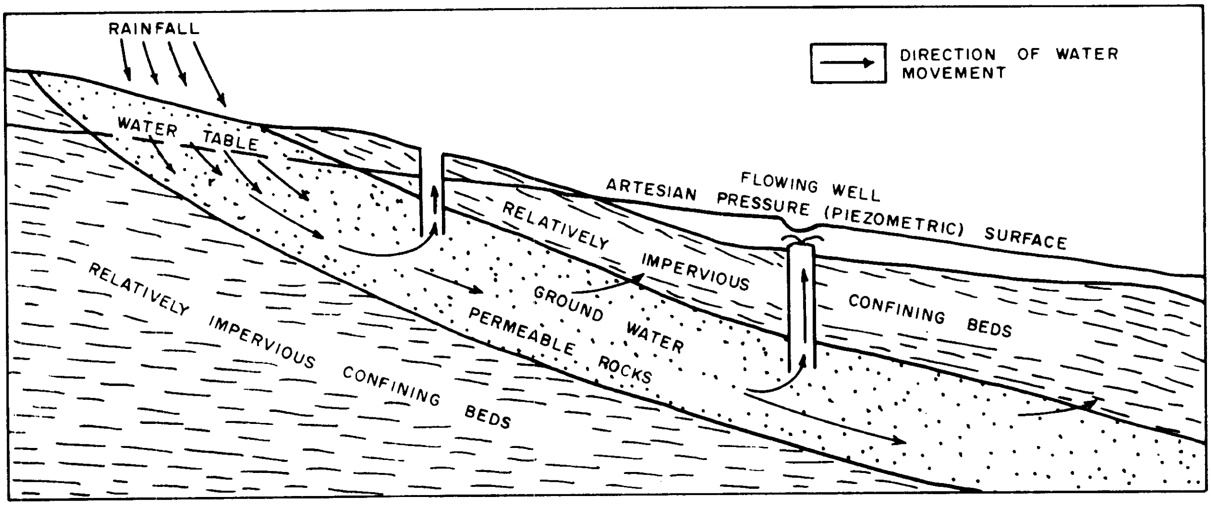
Fine-grained sediments, such as clay and silt, commonly have high porosity, but owing to the small size of the voids they do not readily yield or transmit water. Therefore, in order for a formation to be an aquifer it must be porous, permeable, and water-bearing. An aquifer is defined by Meinzer (1923b, p. 30) as a geologic formation, group of formations, or part of a formation that is water bearing. General usage, however, has restricted the application of the term to those water-bearing units that yield water in sufficient quantities to constitute a usable supply. A geologic unit that is incapable of transmitting significant quantities of water is called an aquiclude. The term "sands" as used in this report refers to distinct layers or beds of sand through which water is most readily transmitted.

Precipitation on the outcrop of an aquifer may take one of many courses in completing the hydrologic cycle. A large percentage of it is evaporated back to the atmosphere directly or is taken up by plants and returned to the atmosphere by transpiration. Some of the water will run off the land surface into streams and thus return to the sea. A small percentage of the rainfall will percolate downward under the force of gravity to a zone in which all rock voids are saturated. This zone is known as the zone of saturation, and the upper surface of the zone is called the water table. Water entering the zone of saturation moves to points of lower elevation, where it is discharged naturally or artificially and is subjected to other phases of the hydrologic cycle. Above the zone of saturation the rock interstices are filled partially by water and partially air. This zone is known as the zone of aeration. Occasionally a local impermeable layer above the water table will intercept the downward percolation of the water, creating a saturated zone above the main water table. This zone is known as a perched water table and is usually of small areal extent. The following diagram illustrates the occurrence of a perched water zone.



Adapted from L. D. Leet and Sheldon Judson, 1954, Physical Geology: New York, Prentice-Hall, Inc., p. 158.

Water in an aquifer may occur under water-table or artesian conditions. In the outcrop area of an aquifer, ground water generally occurs under water-table conditions; that is, the water is unconfined and is at atmospheric pressure. The hydraulic gradient in an unconfined aquifer is the slope of the water table. Downdip from the outcrop or recharge area, ground water occurs under artesian conditions where the water in a permeable stratum is confined between relatively impermeable beds. The water is then under sufficient pressure to rise above the top of the confining bed if the water-bearing stratum is penetrated by a well. Pressure head is expressed as the height of a column of water that can be supported by the pressure. The level to which water will rise in wells completed in an artesian aquifer is called the piezometric surface. When the elevation of the land surface at a well is lower than the elevation of the piezometric surface of an artesian aquifer, a flowing well will occur. Water in the deeper aquifers of Leon County are under greater pressure than the water in the shallow aquifers because the deeper aquifers crop out at higher elevations. Because of this pressure-head differential, there is vertical leakage upward through the confining beds. The loss of water from an artesian aquifer by natural means of discharge downdip causes a loss in hydrostatic pressure, so that the piezometric surface is at a progressively lower elevation in a downdip direction. The hydraulic gradient of an artesian aquifer is determined by the slope of the piezometric surface. The following diagram illustrates typical conditions in which ground water occurs in Leon County.



Adapted from L. D. Leet and Sheldon Judson, 1954, Physical Geology: New York, Prentice-Hall, Inc., p. 161.

The water-producing capability of an aquifer depends upon its ability to store and transmit water. Although the porosity of a rock is a measure of its capacity to store water, not all of this water in storage may be recovered by pumping. Some of the water stored in the interstices is retained because of molecular attraction of the rock particles for water. The coefficient of storage is equal to the amount of water in cubic feet that will be released from or taken into storage by a vertical column of the aquifer having a base 1 foot square when the water level or hydrostatic pressure is lowered or raised 1 foot. In an aquifer under water-table conditions, the coefficient of storage is essentially equal to the specific yield, which is the ratio of the volume of water a saturated material will yield under the force of gravity to the total volume of material drained. In an artesian aquifer, ground water is withdrawn from storage without draining the water-bearing rocks. As water is pumped from the artesian aquifer the hydrostatic pressure is lowered. The weight of the overlying sediments, which were partially supported by the hydrostatic pressure, compresses the water-bearing material and the confining media, and the water expands, causing some water to be released from storage.

The quantity of water the aquifer receives as recharge and the ability of the aquifer to transmit water to the areas of discharge are the principal factors that must be considered in determining the amount of water available for withdrawal on a sustained basis. The coefficient of transmissibility provides an index of an aquifer's ability to transmit water. It is defined as the amount of water in gallons per day that will pass through a vertical strip of the aquifer 1 foot wide under a hydraulic gradient of 1 foot per foot. By using the coefficient of transmissibility, the amount of water that will pass through an aquifer under various hydraulic gradients can be determined. The coefficient of permeability is defined as the quantity of water in gallons per day that will pass through a section of the aquifer 1 foot square under a hydraulic gradient of 1 foot per foot. It may be determined by dividing the coefficient of transmissibility by the thickness of the aquifer, in feet.

The coefficients of storage and transmissibility are determined from pumping tests of wells that screen a water-bearing formation. The term "screen" is used to define the zone or zones in the casing that are open to the aquifer by means of well screens or other similar openings through which water enters the well. A pumping test consists of pumping a well at a constant rate for a period of time and making periodic measurements of water levels in the pumping well and, if possible, in one or more observation wells. The recovery of the water level is also measured after pumping stops. From the data obtained, the coefficients of transmissibility and storage can be calculated by means of certain formulas. In general, the coefficient of storage can be determined if data are obtained from one or more observation wells. The coefficients of transmissibility and storage may be used in computing the effects that pumping from a well will have on water levels in the aquifer at various times and at various distances from the pumped well. The coefficients also can be used in computing the quantity of water that will flow through a given section of the aquifer and in estimating the availability of water from storage. A general indication of the hydraulic characteristics of an aquifer is provided by the specific capacity of a well. The specific capacity of a well is defined as the gallons per minute a well will yield for each foot of water-level drawdown that has occurred at the end of a period of time during which the well has been pumped at a constant pumping rate. However, the type of well construction and the thoroughness of well development also have an effect on the well's specific capacity that is not directly related to the aquifer's hydraulic characteristics.

Recharge, Discharge, and Movement

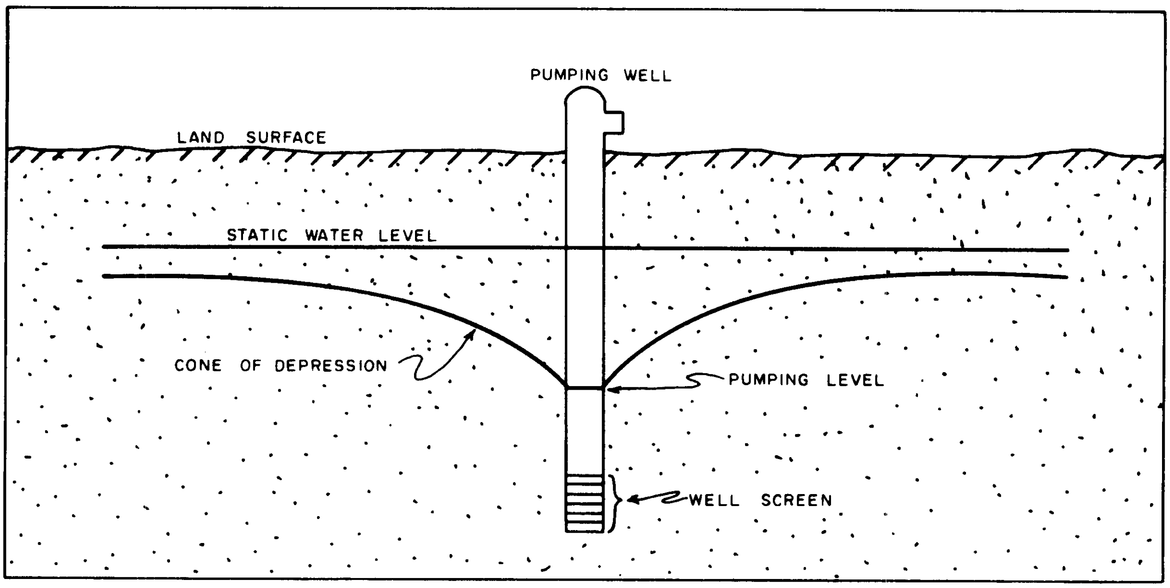
Recharge is the addition of water to an aquifer. The principal source of ground-water recharge in Leon County is precipitation that falls on the outcrop of the various aquifers. In addition, seepage from streams and lakes located on the outcrop and possibly interformational leakage are sources of ground-water recharge. Recharge is a limiting factor in the amount of water that can be developed from an aquifer, as it must balance discharge over a long period of time or the water in storage in the aquifer will eventually be depleted. Among the factors that influence the amount of recharge received by an aquifer are: the amount and frequency of precipitation; the areal extent of the outcrop or intake area; topography, type and amount of vegetation, and the condition of soil cover in the outcrop area; and the ability of the aquifer to accept recharge and transmit it to areas of discharge. On aquifer outcrops where vegetation is dense, the removal of underbrush and non-beneficial plants will reduce evaporation and transpiration losses, making more water available for ground-water recharge.

Discharge is the loss of water from an aquifer. The discharge may be either artificial or natural. Artificial discharge takes place from flowing and pumped water wells, drainage ditches, gravel pits, and other excavations that intersect the water table. Natural discharge occurs as effluent seepage, springs, evaporation, transpiration, and interformational leakage.

Ground water moves from the areas of recharge to areas of discharge or from points of higher hydraulic head to points of lower hydraulic head. Movement is in the direction of the hydraulic gradient just as in the case of surface-water flow. Under normal artesian conditions, movement of ground water usually is in the direction of the aquifer's regional dip. Under water-table conditions, the slope of the water table and consequently the direction of ground-water movement usually is closely related to the slope of the land surface. However, in the case of both artesian and water-table conditions, local anomalies are developed in areas of pumping and some water moves toward the point of artificial discharge. The rate of ground-water movement in an aquifer is usually very slow, being in the magnitude of a few feet to a few hundred feet per year.

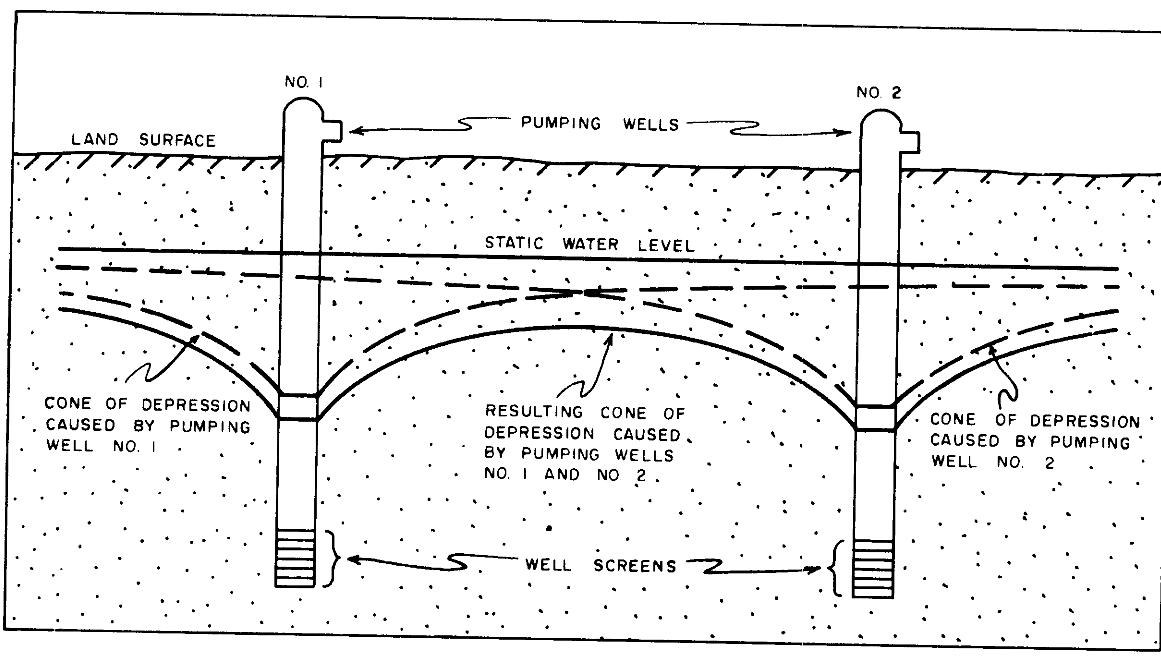
Fluctuations of Water Levels

Changes in water levels are due to many causes. Some are of regional significance whereas others are extremely local. The more significant causes of water-level fluctuations are changes in recharge and discharge. When recharge is reduced, as in the case of a drought, some of the water discharged from the aquifer must be withdrawn from storage and water levels decline. The water levels may be lowered sufficiently to dry up springs or shallow wells. However, when adequate rainfall resumes, the volume of water drained from storage in the aquifer during the drought may be replaced and water levels will rise accordingly. When a water well is pumped, water levels in the vicinity are drawn down in the shape of an inverted cone with its apex at the pumped well. This cone of depression in the water table is illustrated in the following diagram.



The development or growth of this cone depends on the aquifer's coefficients of transmissibility and storage, and on the rate of pumping. As pumping continues the cone expands and continues to do so until it intercepts a source of replenishment capable of supplying sufficient water to satisfy the pumping demand. This source of replenishment can be either intercepted natural discharge or induced recharge. If the quantity of water received from these sources is sufficient to compensate for the water pumped, the growth of the cone will cease and new balances between recharge and discharge are achieved. In areas where recharge or salvageable natural discharge is less than the amount of water pumped from wells, water is removed from storage in the aquifer to supply the deficiency and water levels will continue to decline.

Where intensive development has taken place in ground-water reservoirs, each well superimposes its own individual cone of depression on the cone of neighboring wells. This results in the development of a regional cone of depression. When the cone of one well overlaps the cone of another, interference occurs and an additional lowering of water levels occurs as the wells compete for water by expanding their cones of depression. The effects of interference between pumping wells are illustrated in the following diagram.



The amount or extent of interference between cones of depression depends on the rate of pumping from each well, the spacing between wells, and the hydraulic characteristics of the aquifer in which the wells are completed.

Water levels in some wells, especially those completed in artesian aquifers, have been known to fluctuate in response to such phenomena as changes in barometric pressure, tidal force, and earthquakes. However, the magnitude of the fluctuations are usually very small.

All ground water contains dissolved minerals. The kind and concentration of these depend upon the environment, movement, and source of the ground water. Water has considerable solvent power that dissolves mineral matter from the soil and the component rocks of the aquifer as it passes through them. The amount that is dissolved depends on the solubility of the minerals that are present, the length of time the water is in contact with the rocks, and the amount of dissolved carbon dioxide contained in the water. The concentrations of dissolved minerals in water generally increase with depth and are greater in stratigraphic units where ground-water circulation is restricted. In most stratigraphic units whose sediments were deposited in brackish water, the flushing action of fresh water moving through the aquifers has not been complete throughout the strata. Therefore, at some distance downdip from the outcrop highly mineralized water is encountered.

In addition to natural mineralization of water, the quality of water also can be affected by man. Contamination can occur from the disposal of industrial waste into improperly completed, or faulty, disposal pits and disposal wells. Inadequate plugging of test holes and severe corrosion of well casing permits highly mineralized water to enter and contaminate fresh-water aquifers. The quality of water in an individual water well can be affected by the well's construction, through improper casing or cementing, which allows water of poor quality to enter the well or move into a fresh-water aquifer having a lower hydrostatic head. Contamination also can occur through the improper disposal of wastes into surface streams that provide recharge to ground-water aquifers.

The chemical quality of uncontaminated ground water, unlike that of surface water, remains relatively constant at all times. This, in addition to its relatively constant year-round temperature, makes ground-water supplies highly desirable for many uses.

Standards

The principal mineral constituents found in ground water are calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, silica, iron, manganese, nitrate, fluoride, and boron. Water used for municipal supplies should be colorless, odorless, palatable, and wherever possible be within the limits set by the U.S. Public Health Service (1962) for drinking water used on interstate carriers. Some of these standards, in parts per million, are as follows:

Substance	Concentration (ppm)
Chloride (Cl)	250
Fluoride (F)	(*)
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Total dissolved solids	500

*When fluoride is present naturally in drinking water, the concentration should not average more than the appropriate upper limit shown in the following table:

Annual average of maximum daily air temperatures (°F)	Recommended control limits of fluoride concentrations (ppm)		
	Lower	Optimum	Upper
50.0 - 53.7	0.9	1.2	1.7
53.8 - 58.3	.8	1.1	1.5
58.4 - 63.8	.8	1.0	1.3
63.9 - 70.6	.7	.9	1.2
70.7 - 79.2	.7	.8	1.0
79.3 - 90.5	.6	.7	.8

The above limits are desirable for municipal use, but it is realized that many supplies that cannot meet these standards must be used for the lack of a more suitable supply. Many supplies failing to meet all these standards have been in use for long periods of time without any apparent ill effects on the user. Maxcy (1950, p. 271) states that water having a nitrate content in excess of 45 ppm should be regarded as unsafe for infant feeding. The presence of large quantities of nitrate may indicate organic pollution. Water containing more than 0.3 ppm iron and manganese combined is likely to cause objectionable staining of laundered clothes and plumbing fixtures.

Hardness of water is an important factor in domestic, municipal, and industrial supplies. The principal constituents causing hardness of water are calcium and magnesium. Water hardness is expressed in parts per million as calcium carbonate. An increase in hardness causes an increase of soap consumption in washing and laundering processes, and the formation of scale in boilers and other equipment. A generalized classification for hardness, which is useful as an index to the analyses of water, is as follows: less than 60 ppm, soft; 61 to 120 ppm, moderately hard; 121 to 220 ppm, hard; and more than 200 ppm, very hard.

The tolerance in chemical quality of water for industrial use varies widely for different industries and different processes. One of the major items of concern to most industries is the development of water supplies that do not contain corrosive or scale-forming constituents that affect the efficiency of their boilers and cooling systems. Hardness, along with excessive amounts of silica and iron, cause scale deposits that clog lines and reduce efficiency of heat-exchange apparatus. Suggested water-quality tolerances for a number of industries (Moore, 1940, p. 271) are presented by Hem (1959, p. 253).

There are a number of factors involved in determining the suitability of water for irrigation purposes. The type of soil, adequacy of drainage, types of crops, climatic conditions, and the quantity of water used all have an important bearing on the continued productivity of irrigated soils. According to a report by the U.S. Salinity Laboratory Staff (1954, p. 69), the characteristics of water that are important in determining its suitability for irrigation are: (1) total concentration of soluble salts, expressed in terms of specific conductance, (2) the relative proportion of sodium to the other principal cations (magnesium, calcium, and potassium), expressed as percent sodium or sodium-adsorption ratio (SAR), (3) residual sodium carbonate (equivalents per million of carbonate in excess of calcium and magnesium), and (4) concentrations of boron or other elements that may be toxic to crops.

Treatment

Many waters of substandard quality can be made usable by various treatment methods. These include dilution (blending of poor and good quality waters to achieve an acceptable quality), softening, aeration, filtering, cooling, and the addition of various chemical additives. The limiting factor in water treatment is one of economy. Treatment processes for ground water need not be designed to handle a large variation in quality as the chemical quality of uncontaminated ground water remains relatively constant at all times.

OCCURRENCE AND AVAILABILITY OF GROUND WATER

All tables and plates referred to in this section are located in Appendices A and B respectively at the end of this report. The principal aquifers in Leon County are the Carrizo-Wilcox aquifer, the Queen City aquifer, and the Sparta aquifer.

Carrizo-Wilcox Aquifer

The Carrizo Formation and Wilcox Group are two separate geologic units having their own distinct geologic and hydrologic characteristics. The sands of the Carrizo Formation overlie the sands and shales of the Wilcox Group. In places shale separates the sand beds of the two geologic units, and in other places the shale is missing and the sand of the Carrizo is in direct contact with upper sand beds of the Wilcox. Because the shale is absent in many places, the two units are hydraulically connected, and therefore are considered in this report as one aquifer. The Carrizo-Wilcox aquifer is the primary source of ground water in Leon County.

Geologic Characteristics

The Wilcox Group includes three formations; the Seguin, Rockdale, and Sabinetown. Rocks of the Wilcox Group crop out in a belt 20 miles wide, all of which lies northwest of Leon County except for a 2-mile strip across the northwest corner of the county (Plate 1). The Wilcox Group ranges in thickness from approximately 1,500 feet in the northwest corner of the county to approximately 3,300 feet in the southeast corner where the base of the Wilcox is approximately 4,900 feet below the land surface. The Sabinetwon and Seguin, the upper and lower formations of the Wilcox, respectively, are chiefly calcareous shale and sandy shale that do not contain usable amounts of ground water. The Rockdale Formation constitutes about 80 percent of the Wilcox Group. Its composition ranges from lignitic shale to quartz sand. Approximately 50 percent of the formation's thickness is sand. The Rockdale Formation is made up of alternating beds of sand, sandy shale, and shale whose thickness and stratigraphic positions vary greatly from well to well. The beds of sand usually are white to gray in color, loosely cemented, and made up of fine-grained quartz, and which often contain some silicified wood, lignite particles, clay balls, and lentils of blue-gray clay. The upper part of the Rockdale Formation in and near the outcrop area is chiefly a lignitic shale that contains beds of lignite coal ranging from a few inches to about 12 feet in thickness.

The Carrizo Formation crops out in a belt 2 to 4 miles wide in the northwest part of the county. It ranges in thickness from 100 to 210 feet. The Carrizo Formation is a uniform, well-sorted quartz sand or poorly cemented sandstone that contains only a few very thin beds of shale. In general, the sand is medium-grained near the base grading upward into a fine-grained sand.

In Leon County, the Carrizo Formation and the Wilcox Group have a total thickness ranging from about 1,800 feet at the edge of the outcrop to about 3,500 feet in the southeast corner of the county. However, the Wilcox does not contain usable quality water throughout its total thickness in the southeastern part of the county, as illustrated on Plate 2. Plate 5 shows the approximate altitude of the base of fresh water in Leon County. The Wilcox sands contain water of less than 3,000 ppm dissolved solids throughout its thickness except in the area southeast of a line between Normangee and the confluence of Upper Keechi Creek and the Trinity River. The areal extent of the aquifer includes all of Leon County with the exception of the small area above the Marquez salt dome in the northwest part of the County, as shown on Plate 4. The sands of the Wilcox Group and the Carrizo Formation make up approximately 50 percent of the aquifer's total thickness. The net sand thickness of the aquifer ranges from zero over the Marquez salt dome to more than 1,600 feet in the east-central part of the county. Plate 7 shows the net sand thickness of the Carrizo-Wilcox aquifer where it contains less than 3,000 ppm dissolved solids.

As shown by the contours on Plate 6, the top of the Carrizo-Wilcox aquifer in Leon County generally dips to the southeast. The dip of the beds west of Farm Road 39 and near the outcrop generally ranges between 50 and 100 feet per mile. The rate of dip in the eastern part of the county is a little less, generally from 25 to 75 feet per mile. Also, in the northeastern part of the county there are several elongated structural highs and a circular shaped high above the Oakwood salt dome that interrupt the regional pattern of dip. The depth to the top of the aquifer ranges from the zero in the outcrop area to approximately 1,400 feet in the southeast corner of the county. The depths to the top of the aquifer shown on Plate 6 are only approximate because of the irregularities in the land surface. In the southeastern part of the county the aquifer contains usable quality water to a depth of approximately 3,900 feet below the land surface.

Occurrence and Movement of Ground Water

Water occurs under water-table conditions in the outcrop area of the Carrizo-Wilcox aquifer. However, shale layers in the Wilcox part of the aquifer are of sufficient extent and thickness that artesian conditions also exist locally in the lower sands of the Wilcox Group within the outcrop area. In other words, wells completed in the lower sands of the aquifer may have water levels that rise above the water levels in the shallower Wilcox sands or in the Carrizo, in the outcrop area. Downdip from the outcrop area, the water in the Carrizo-Wilcox aquifer is confined between the relatively impermeable Midway Group and Reklaw Formation, and artesian conditions exist in the aquifer.

In the outcrop of the Carrizo-Wilcox aquifer, the water generally moves from the higher elevations toward the lower elevations of the creeks and river. Downdip from the outcrop the hydrostatic head of the ground water is controlled by the altitude of the water surface in the outcrop area. In Leon County, east of Farm Road 39, the water in the aquifer generally moves eastward and southeastward from the higher elevations along the watershed drainage divide between the Navasota and Trinity Rivers. West of Farm Road 39, the direction of movement is generally to the south-southwest. The piezometric surface ranges from an elevation of approximately 450 feet in the outcrop area to approximately 240 feet along the Trinity River. The hydraulic gradient averages approximately 5 feet per mile in the downdip area, away from the immediate influence of the many variations within the outcrop area. Contours on the piezometric surface in the Carrizo-Wilcox aquifer are shown on Plate 7. These contours were constructed from the few available water-level measurements in the county, and should be used with caution is estimating the water-level elevation in any particular locality.

Recharge and Discharge

Recharge to the Carrizo-Wilcox aquifer is from precipitation on its outcrop area. Most of the area that contributes water to the aquifer in Leon County lies in Freestone and Limestone Counties, a small part of Robertson County, and the northwest corner of Leon County. The outcrop is about 22 miles wide in the area that contributes recharge to the aquifer and covers approximately 850 square miles. The loose sandy soils of the Carrizo Formation and Wilcox Group absorb much of the approximately 40 inches of rainfall a year, and very little is lost to runoff. Even though much of the rainfall is returned to the atmosphere by transpiration of the dense vegetation on the outcrop, large quantities of water reach the zone of saturation.

Ground water is discharged naturally from the Carrizo-Wilcox aquifer through springs and seeps, and by evapotranspiration in the outcrop area. Ground water discharged naturally from the aquifer in the outcrop furnishes water to the Navosota River and to tributaries of the Trinity River. Downdip where the aquifer is under artesian conditions, natural discharge occurs by means of upward leakage through the Reklaw Formation.

Flowing wells and pumping from wells constitute the artificial discharge from the Carrizo-Wilcox aquifer in Leon County. The towns of Buffalo, Jewett, Normangee, Marquez, and Oakwood obtain their municipal water supply from wells completed in the Carrizo-Wilcox aquifer. In addition, numerous domestic and livestock wells are scattered throughout the county, and four irrigation wells along the Trinity River obtain water from the aquifer. Flowing wells occur in the Alligator and Upper Keechi Creek bottoms and the Trinity River bottom, where the elevation of the land surface is lower than the hydrostatic head of the aquifer.

Water Levels

The depth to water in wells that penetrate the Carrizo-Wilcox aquifer ranges from 0 to about 150 feet below the land surface. Water levels in excess of 100 feet below the land surface generally occur in the vicinity of the watershed divide between the Navasota and Trinity Rivers because of the higher surface elevations. The water levels throughout most of the rest of the county are less than 100 feet below the land surface. Plate 7 shows the areas where the elevation of the piezometric surface is sufficiently higher than the land surface so that wells in the area completed in the Carrizo-Wilcox aquifer generally flow. There is sufficient artesian pressure in the aquifer to cause the water level at well 38-43-202 to rise 68 feet above the land surface if casing were extended to this height.

There is little information on previous water levels in the Carrizo-Wilcox aquifer. Water-level measurements from the few wells on which past records are available indicate that there has been little or no decline in the water levels other than minor seasonal fluctuations. The water levels will decline in the vicinity of pumping wells, but will recover after pumping has ceased. Although past water-level measurements are not available to show it, water levels in the outcrop area can be expected to lower during periods of drought and expected to recover during periods of average or above average rainfall.

Water-Bearing Characteristics

The Carrizo Formation is a massive, well-sorted, homogeneous sand that is poorly cemented and contains only minor amounts of shale. Because of this, the Carrizo Formation has relatively high coefficients of permeability and transmissibility, whereas the Wilcox Group consists of lenticular beds of sand, clay and lignite, and has lower and varying coefficients of permeability. However, because of its thickness, the Wilcox also generally has a high coefficient of transmissibility.

Pumping tests were conducted on two wells completed in the Carrizo part of the aquifer, one at the city of Oakwood (well 38-26-102) and the other at the Cauble Ranch (well 38-43-101). Coefficients of transmissibility of 30,000 gpd/ft (gallons per day per foot) and of permeability of 338 gpd/ft^2 were obtained on the city of Oakwood well, and coefficients of transmissibility of 31,000 gpd/ft and of permeability of 480 gpd/ft^2 for the Cauble well. Although these two tests are rather consistent, tests on other wells throughout east Texas indicate these coefficients are slightly higher than the average.

No pumping tests were conducted on wells in Leon County that were completed in the Wilcox part of the aquifer. However, from pumping tests conducted on wells in Anderson and Freestone Counties, it is possible to obtain an indication of the coefficients of transmissibility and permeability that can be expected in Leon County. Coefficients of transmissibility from tests conducted on wells at the cities of Elkhart, Fairfield, and Palestine ranged from about 5,000 gpd/ft at Fairfield to 19,000 gpd/ft at Palestine. The wide range of transmissibility was caused by different amounts of sand being screened and by changes in the permeability which ranged from 40 gpd/ft^2 at Fairfield to 145 gpd/ft^2 at Elkhart. At the city of Fairfield, several sand beds near the middle of the Wilcox Group were screened, totaling 133 feet. In the city of Elkhart well, approximately 105 feet of massive sand was screened, between the depths of 905 and 1,010 feet, in the upper section of the Wilcox. The coefficient of transmissibility of 19,000 gpd/ft at the city of Palestine was an average of tests conducted on four wells in which the coefficients of transmissibility ranged from 14,000 to 24,000 gpd/ft. These wells screened large sections of sand in the middle and lower parts of the Wilcox. The coefficient of permeability obtained on the Elkhart well was much higher than the average obtained on numerous other wells in east Texas. It can be expected that the coefficients of permeability in Leon County would be more on the order of those obtained in the Fairfield wells. By using an average coefficient of permeability of 40 gpd/ft^2 times the net sand thickness of the Wilcox Group immediately downdip from the outcrop area (approximately 750 feet of sand), a coefficient of transmissibility of 30,000 gpd/ft is obtained for the Wilcox part of the aquifer in Leon County.

In general, coefficients of transmissibility on the order of 25,000 to 30,000 gpd/ft can be expected from the Carrizo part of the aquifer in areas downdip from the outcrop, except in the immediate vicinity of the salt domes. Similar coefficients of transmissibility can be obtained from the Wilcox part of the aquifer if all of the sand beds are screened. However, this is not always practical for a single well, and in many places the lower part of the Wilcox contains water of poorer quality than the remainder of the aquifer.

Coefficients of storage were not obtained on any of the pumping tests of wells completed in the Carrizo-Wilcox aquifer in Leon County. From coefficients of storage obtained on pumping tests on other wells in east Texas completed in the aquifer and from coefficients of storage in artesian aquifers in general, a coefficient of about 0.0002 probably can be expected for the aquifer in Leon County.

A distance-drawdown graph has been prepared based on coefficients believed to be the most applicable for the aquifer in the county. Figure 6 shows the amount that water levels would be lowered at various distances from a pumped well after the well has pumped for various periods of time. The distances are measured along a line parallel with the outcrop and passing through the pumped well. The pumped well is located approximately 15 miles from the outcrop area and pumps at a rate of 700 gpm (gallons per minute). A coefficient of transmissibility of 25,000 gpd/ft was used to prepare this graph, inasmuch as most wells completed in the area will either screen the Carrizo sand or the Wilcox sands separately. The coefficient of storage used was 0.0002.

Chemical Quality of Water

The quality of water in the Carrizo-Wilcox aquifer is suitable for most purposes with little or no treatment, except when iron or hydrogen sulfide is encountered. Water from the sands of the aquifer in and near the outcrop area usually contains objectionable amounts of iron. However, sands without large amounts of this element usually can be found at deeper depths. The Carrizo-Wilcox aquifer in a few isolated cases contains hydrogen sulfide gas. This occurs in wells 38-25-702 and 39-63-801. The water in these wells has a dark color and slight odor. The source of the hydrogen sulfide is probably from lignite beds that are in contact with the water-bearing sands. This gas, as well as iron, can be removed by aeration and filtration.

The quality of water in the aquifer gradually worsens with depth until in the southern part of the county the lower sands of the Wilcox Group no longer contain usable quality water. Plate 5 shows the altitude of the base of water containing less than 3,000 ppm dissolved solids. This base of fresh water generally coincides with the base of the Wilcox Group except in the southeastern part of the county where the lower sands contain water of more than 3,000 ppm dissolved solids. (See Plate 2.)

Of the 17 wells completed in the Carrizo-Wilcox aquifer from which analyses were obtained, excluding well 39-40-701 which is suspected of receiving some water from shallower beds, the analyses of the wells sampled have the following range of constituents: dissolved solids, 143 to 591 ppm; iron, 0 to 2.7 ppm; sulfate, 0 to 179 ppm; chloride, 5 to 78 ppm; and hardness, 2 to 186 ppm. The other constituents analyzed were all within the limits set by the U.S. Public Health Service. Complete analyses for all of the sampled wells are listed in

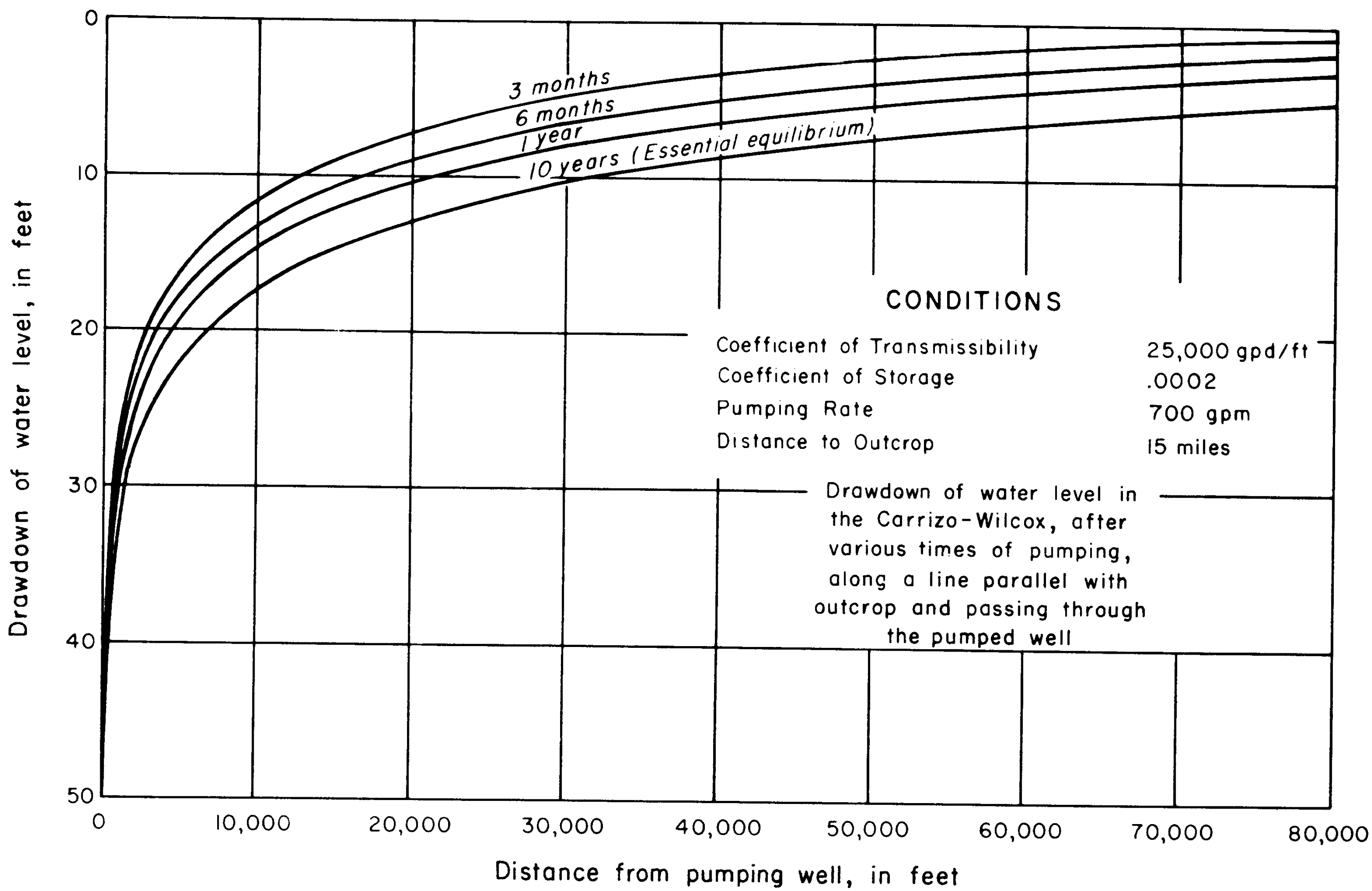


Figure 6

Distance-Drawdown Curves, Carrizo-Wilcox Aquifer, Leon County

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Table 3. Plate 4 shows the areal extent of the Carrizo-Wilcox aquifer and some of the chemical constituents of the sampled wells.

Utilization and Development

The Carrizo-Wilcox aquifer is a source of water for all of the towns in Leon County except Centerville, which obtains its supply from the Queen City aquifer. In addition to the ground-water withdrawals for municipal use, four irrigation wells and two wells classified as industrial wells produce from the aquifer, as well as numerous domestic and livestock wells located mostly in the northern half of the county.

Approximately 281 acre-feet of water was pumped from the Carrizo-Wilcox aquifer in 1960 for municipal purposes in Leon County. The usage by cities is as follows: Buffalo, 123 acre-feet; Normangee, 42 acre-feet; Oakwood, 55 acre-feet; Jewett, 37 acre-feet; and Marquez, approximately 24 acre-feet. The Texas Board of Water Engineers (1960, p. 15) estimated the irrigation pumpage in Leon County in 1958 to be approximately 267 acre-feet. The water was used to irrigate approximately 200 acres of land. Although there are four irrigation wells in the county, only three were active in 1958. These are wells 38-26-201, 38-26-202, and 38-43-101. The wells are used only to supplement rainfall during rain-deficient years; therefore, irrigation pumpage will vary greatly from year to year. Pumpage for the two wells classified as industrial is believed to be quite small. Well 39-40-501 is used to fill a lake when springflow and surface runoff are not sufficient. In 1958 this well was inoperative. Well 39-63-801 is used to fill a swimming pool in the southwest corner of the county. In general, the development and pumpage from this aquifer is very small in relation to the quantity of water moving through the aquifer.

The yields of wells producing from the Carrizo-Wilcox aquifer vary greatly from well to well, depending on the needs of the well owner. In other words, wells are constructed in such a manner as to supply only the amount of water needed. The well yields of the six municipal wells producing from the aquifer range from 40 to 150 gpm. The yields of the three irrigation wells range from 350 to 900 gpm and well 38-43-101 was reported to have been tested at 1,650 gpm at the time of completion.

The only specific capacity measured on a Carrizo-Wilcox well in Leon County was at the city of Oakwood, well 38-26-102, which is completed in the Carrizo part of the aquifer. The specific capacity in this well was 11.3 gpm per foot of drawdown. The specific capacities are dependent upon the well construction as well as the transmissibility of the aquifer.

Wells completed in the Carrizo-Wilcox aquifer range in depth from about 25 feet in the outcrop to as much as 1,209 feet in well 39-64-701 at the city of Normangee. Casing diameters in the drilled wells range from 3 to 12 inches at the surface with some wells being reduced in size to as small as 2 inches at the bottom. The casings of the major wells range from 6-5/8 to 12 inches in diameter at the surface and many of the wells have casing that is lapped or swedged to liners and screens ranging from 4 to 9 inches in diameter. The dug wells generally have 36-inch concrete casing. Most of the domestic and livestock wells are equipped with electric-powered jet pumps of $\frac{1}{2}$ to 2 horsepower. The city wells all have turbine pumps and are electrically powered with motors ranging from 3 to 25 horsepower. The irrigation wells have turbine pumps with gasoline engines ranging from 25 to 90 horsepower.

Development in the Wilcox part of the aquifer is primarily confined to the northwest part of the county. Further to the southeast, where the Carrizo no longer contains undesirable amounts of iron, most wells do not penetrate below the Carrizo part of the aquifer because it occurs at a shallower depth than the Wilcox, and the Carrizo can produce the desired quantities of water with a minimum amount of screen or slotted pipe. There has been very little development of the Carrizo-Wilcox aquifer in the southeast part of the county, in that generally good quality water can be obtained from the shallower aquifers. The development of the Carrizo-Wilcox aquifer is far below its potential and offers the best source of available water in the county.

Ground Water Available for Development

The amount of water available from the Carrizo-Wilcox aquifer determined during this study is an estimate based on pumpage under assumed conditions, and is related primarily to the ability of the aquifer to transmit water from the outcrop to areas of pumping. It is not possible to determine precisely the amount of water that is present beneath the earth's surface, or the quantity that may be produced. However, if certain aquifer conditions are known, it is possible to estimate the order of magnitude of water available. It is known that the amount of water that will move through a segment of an aquifer is dependent upon the coefficient of transmissibility, the hydraulic gradient, and the width of the segment perpendicular to the flow. The relationship of the above factors is expressed by the formula $Q = TIL$, in which Q is the quantity of water in gallons per day, T is the coefficient of transmissibility, I is the gradient in feet per mile, and L is the segment of the aquifer under consideration. This equation can be used to determine the amount of water moving through the aquifer under present water-level gradients and to predict the quantity that would move through the aquifer under assumed conditions.

With the present water-level gradients, approximately 10,000 acre-feet of water annually is moving through the aquifer and is being discharged downdip either naturally or artificially.

Under future conditions of development, the rate of flow through the aquifer may be greatly increased owing to increased gradients caused by pumping. For the purpose of estimating the amount of water available for development from the Carrizo-Wilcox aquifer, a future gradient is assumed, based on a static water level drawn down to the top of the aquifer where the aquifer is 400 feet below land surface. Because of the aquifer's great thickness and extensive outcrop area, gradients that would be established between the outcrop and the line where the top of the Carrizo is 400 feet below the land surface, by the development of the entire aquifer, will differ greatly for the upper and lower sands of the aquifer. The lower sands of the Wilcox Group crop out at great distances from the assumed 400-foot line; therefore, their gradients will be low in comparison to the Carrizo Formation and the upper Wilcox sands. For the purpose of computing the quantity of water available under the assumed conditions, a gradient equal to the dip of the top of the aquifer was used for the Carrizo Formation. An average gradient between the dip of the top of the aquifer and the lowest sand was used for the Wilcox part of the aquifer. Under the foregoing assumed conditions, it is estimated that on the order of 61 million gallons of water per day or 68,000 acre-feet per year would be transmitted from the outcrop area of the Carrizo-Wilcox aquifer to the areas of pumpage. Of this total, approximately 37 million gallons per day or 41,000 acre-feet per year would move through the Carrizo part of the aquifer, and 24 million gallons per day or 27,000 acre-feet per year would move through the Wilcox part of the aquifer.

Recharge to the Carrizo-Wilcox aquifer appears to be more than adequate to supply the quantity of water that would be moving through the aquifer under the assumed conditions of development. The outcrop area of the Carrizo-Wilcox aquifer from which the recharge is supplied for pumpage in Leon County covers approximately 540,000 acres, most of which lies outside of Leon County to the northwest. Therefore, less than 2 inches of the 40 inches of annual precipitation would be required to supply the 68,000 acre-feet of water that can be transmitted by the aquifer. This amounts to about 4 percent of the total annual rainfall.

Conditions are favorable for further development in the Carrizo-Wilcox aquifer throughout most of Leon County, although both quantity and quality problems may occur in developing water from the aquifer in the immediate vicinity of salt domes. In order to obtain the maximum quantity of water available in the Wilcox part of the aquifer, it will be necessary to screen all of the water-bearing sands of the Wilcox Group. This requires large amounts of screen, and in the southern part of the county the quality of water in the lower part of the Wilcox is not so good or desirable as that in the upper part of the aquifer. It must also be realized that increased development from the aquifer in adjoining counties will affect, or can influence, the total quantity of water that can be obtained on a sustained basis from the Carrizo-Wilcox aquifer in Leon County. Although the quantity of water available is large, it is possible to overdevelop the aquifer in local areas by intensive pumpage.

Queen City Aquifer

Geologic Characteristics

The outcrop area of the Queen City Formation is approximately 6 miles wide in the western part of the county and more than 16 miles wide in the eastern part of the county (Plate 1). The Queen City Formation is predominantly a sand with numerous shale layers occurring at varying levels and locations. The sand beds are thin to massive and interbedded with lenses of shale and sandy shale. The shale and sandy shale lenses interfinger with the sands; gradations from the sand to shale occur both laterally and vertically. The sands are chiefly a fine-grained, slightly lignitic, micaceous quartz sand, which is usually cross-bedded. The lignite in the Queen City Formation is disseminated rather than in distinct beds. The Queen City Formation also contains several glauconitic sand layers and ironstone layers, which weather to a bright red. These beds are lenticular and usually cannot be traced for any distance. Downdip from its outcrop area, the Queen City ranges in thickness from about 250 to 400 feet, with the sand beds making up approximately 60 to 70 percent of the Queen City's total thickness. Plate 9 shows the net sand thickness of the Queen City aquifer.

As shown by the contours on Plate 8, the top of the Queen City aquifer in Leon County generally dips to the southeast. The dip of the beds ranges from about 40 to 80 feet per mile with the steeper dips occurring in the southeastern part of the county. The depth to the top of the aquifer ranges from zero in the outcrop area to approximately 800 feet below the land surface in the southeastern corner of the county. The depths to the top of the aquifer shown on Plate 8 are only approximate because of irregularities in the land surface.

Occurrence and Movement of Ground Water

The Queen City aquifer contains usable quality water throughout its extent in Leon County. Water in the outcrop area of this aquifer generally occurs under water-table conditions. However, numerous impermeable shale layers within the formation create both perched water zones and localized artesian conditions. Local artesian conditions in the lower sands of the Queen City aquifer within the outcrop area are quite common in Leon County. The artesian pressure is sufficient to cause Queen City wells to flow in the Alligator and Upper Keechi Creek bottoms. The areas of local flowing wells within the outcrop area are not shown on Plate 9 because of their limited extent and erratic occurrence. Downdip from the outcrop area the water in the Queen City aquifer is confined between the relatively impermeable Reklaw and Weches Formations, and artesian conditions exist throughout the aquifer's downdip extent.

The water in the outcrop area of the Queen City aquifer generally moves from the higher elevations along the drainage divides to the lower elevations of the creeks and rivers. Downdip from the outcrop, the hydrostatic head of the ground water is controlled by the altitude of the water surface in the aquifer's outcrop area. In Leon County the water in the aquifer generally moves eastward and southeastward from the Trinity-Navasota River watershed drainage divide toward the Trinity River. West of Farm Road 39, the direction of movement is to the south and southwest. The piezometric surface ranges from an elevation of approximately 490 feet in the outcrop area to less than 200 feet along the Trinity River. The hydraulic gradient averages approximately 10 feet per mile in the downdip area away from the immediate influence of the many variations that occur within the outcrop area. Contours on the piezometric surface in the Queen City aquifer are shown on Plate 9. These contours were constructed from the few available water-level measurements in the county, and should be used with caution in estimating the water-level elevation in any particular locality.

Recharge and Discharge

Recharge to the Queen City aquifer is derived from precipitation in its outcrop area. The Queen City outcrop in Leon County covers approximately 500 square miles or almost half of the county. The Queen City outcrop forms a northeast-trending belt, which is about 6 miles wide west of Farm Road 39. East of Farm Road 39 the outcrop widens rapidly to more than 16 miles. The loose sandy soil formed on the Queen City outcrop has a high infiltration rate, which allows much of the approximately 40 inches of annual rainfall to be absorbed by the soil with very little of it being lost to runoff. Although most of the precipitation falling on the Queen City outcrop is absorbed by the soil, large quantities of this water are returned to the atmosphere by transpiration of the dense vegetation that occurs on the outcrop area.

Ground water from the Queen City aquifer is discharged naturally through numerous seeps and springs and by evapotranspiration in the outcrop area. Ground water being discharged naturally from the aquifer in the outcrop area furnishes water to the Navasota and Trinity Rivers and their tributaries. Downdip, where the aquifer is under artesian conditions, natural discharge from the aquifer occurs by means of upward leakage through the overlying Weches Formation.

Flowing and pumped wells constitute the artificial discharge from the Queen City aquifer in Leon County. Most of them are small domestic and livestock wells scattered throughout the outcrop area and for a short distance downdip. The town of Centerville also obtains its supply of water from the Queen City aquifer. The flowing wells occur in the outcrop area in the Alligator and Upper Keechi Creek bottoms where the elevation of the land surface is lower than the hydrostatic head in the lower sands of the aquifer. There are also several flowing Queen City wells downdip from the outcrop area, near the Trinity River.

Water Levels

The depth to water in the wells that penetrate the Queen City aquifer ranges from 0 to approximately 165 feet below the land surface. The water levels throughout most of the county are less than 100 feet below the land surface with depths exceeding 100 feet only in the vicinity of the watershed divide between the Navasota and Trinity Rivers because of the higher surface elevations. The depths to water of the wells measured during this investigation are listed in Table 2. In addition to the flowing wells caused by local artesian conditions, in Alligator and Upper Keechi Creek bottoms, Plate 9 shows the areas where the elevation of the piezometric surface is sufficiently higher than the land surface so that wells in the area generally flow when completed in the Queen City aquifer.

There is little information on previous water levels in the Queen City aquifer from which to determine water-level fluctuations. Based on the small amount of available data, it appears that water levels in the Queen City aquifer have changed very little over the years except for minor natural fluctuations and the possible lowering of water levels in the vicinity of the Centerville wells. The water level in well 38-41-701 at Centerville was reported to be 32 feet at the time the well was drilled in 1939. In 1959 the water level in this well was measured to be 83.1 feet below the land surface. This decline is not excessive for an artesian aquifer, and is necessary to produce gradients sufficient to transmit the amount of water being pumped from the aquifer in this area. The water levels in the outcrop area can be expected to lower during periods of drought, and can be expected to recover during the periods of average or about average rainfall.

Water-Bearing Characteristics

The heterogeneous character of the sediments and the lenticular nature of the beds of the Queen City aquifer contribute to the relatively low transmissibility of the aquifer. The coefficients of transmissibility calculated from data obtained on pumping tests of the Centerville wells were approximately 2,700 gpd/ft and 2,300 gpd/ft respectively for wells 38-41-701 and 38-41-702. Both of these wells screen approximately 50 feet of sand near the bottom of the aquifer. Based on the sand thickness at the screened interval, the coefficients of permeability for the two tests averaged 50 gpd/ft^2. Higher coefficients of transmissibility could be obtained if all of the sand beds in the aquifer were screened in a well. By using an average coefficient of permeability of 50 gpd/ft^2 times the net sand thickness of the Queen City aquifer at the southern edge of the outcrop (approximately 200 feet), a coefficient of transmissibility of approximately 10,000 gpd/ft can be expected in Leon County if the entire sand thickness is screened.

A distance-drawdown graph has been prepared assuming that most of the aquifer is screened. Figure 7 shows the amount that water levels would be lowered at various distances from a pumped well after the well has pumped for various periods of time. The distances on the graph were measured along a line parallel with the outcrop and passing through the pumped well, which is located 8 miles from the outcrop area and pumps at a rate of 250 gpm. A coefficient of transmissibility of 8,000 gpd/ft and a coefficient of storage of 0.0002 were used in preparing this graph.

Chemical Quality of Water

The water from the Queen City aquifer in Leon County is generally suitable for most purposes with little or no treatment. In some places, especially in and near the outcrop area, there are high concentrations of iron that make the water undesirable for domestic use, without aeration and filtration or some other iron removal treatment. The iron content of the water generally can be expected to be greater in wells in the vicinity of the Weches Formation outcrop.

Analyses of water from only three Queen City wells were obtained during this investigation. The analyses of the wells sampled had the following ranges of constituents: total dissolved solids, 101 to 393 ppm; iron, 0.05 to 0.14 ppm; sulfate, 0.2 to 116.8 ppm; chloride, 5.5 to 32 ppm; and hardness, 56 to 151 ppm. The other constituents analyzed were all within the limits set by the U.S. Public Health Service. Complete analyses for these three wells are listed in Table 3. The areal extent of the Queen City aquifer and some of the chemical constituents of the sampled wells are shown on Plate 4.

Utilization and Development

The development of the Queen City aquifer has been extremely small, with the only major pumpage from the aquifer being from two municipal wells at the city of Centerville. The total pumpage from these two wells in 1960 was 107 acre-feet. In addition to the municipal pumpage, hundreds of domestic and livestock wells and some flowing wells discharge water from the aquifer in the outcrop area and for a short distance downdip.

The yields of wells producing from the Queen City aquifer are generally very small in that the quantity of water needed is small. The two wells at the city of Centerville are producing from the basal sand in the Queen City Formation. The wells are approximately 360 feet deep, and both have 8-inch casing at the surface, which is reduced to 4-inch casing in the lower part of the wells. The wells are completed with 48 feet of 4-inch diameter screens, which screen approximately 50 feet of sand in the lower part of the aquifer. The wells have shaft-driven turbine pumps, powered by 10-horsepower electric motors. Well 38-41-701 has a yield of 67 gpm and a specific capacity of 2.0 gpm per foot of drawdown. Well 38-41-702 has a reported yield of 130 gpm.

The domestic and livestock wells that are drilled generally have casings ranging from 3 to 9 inches in diameter, some of which are reduced in size to as small as 2 inches in the lower part of the well. The dug wells generally have 36- to 39-inch diameter concrete casings. Most of the wells are equipped with electrically powered jet pumps of $\frac{1}{4}$ to $1\frac{1}{2}$ horsepower. The wells range in depth from about 13 feet in the outcrop to as much as 633 feet in well 38-42-702.

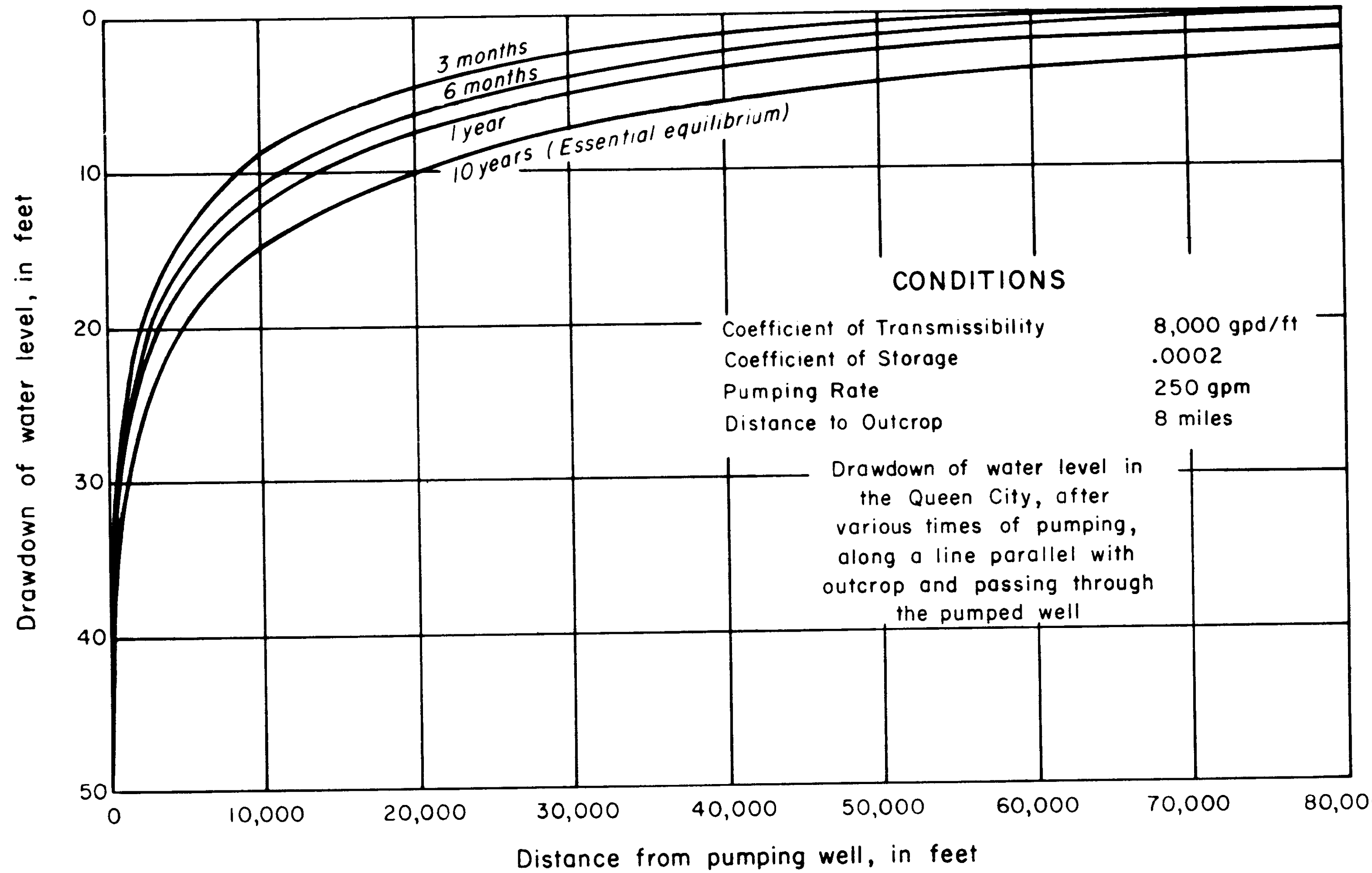

Figure 7

Distance-Drawdown Curves, Queen City Aquifer, Leon County

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Because the Queen City aquifer has a relatively low transmissibility, greater drawdowns are required to obtain large amounts of water than are necessary in the Carrizo-Wilcox aquifer. The drawdowns that can be expected at various distances from a well pumping at a rate of 250 gpm are illustrated by the distance-drawdown curves on Figure 7. Yields up to as much as 250 gpm can be anticipated from the Queen City aquifer if all of the available sand beds are screened. Care should be taken in the development of a water supply in the Queen City aquifer to insure proper spacing of the wells so that the cones of depression from the individual wells will not overlap excessively and cause severe water-level declines in the immediate area of pumpage.

The Queen City aquifer is capable of supplying water for small municipalities and industries throughout the aquifer's extent in Leon County. There has been very little development of Queen City wells in the southeastern part of the county, as water of good quality can be obtained from the Sparta aquifer at shallower depths. The development of the Queen City aquifer in Leon County is far below its potential.

Ground Water Available for Development

The amount of water available from the Queen City aquifer, determined during this study, is an estimate based on pumpage under assumed conditions similar to that used in determining the availability of water from the Carrizo-Wilcox aquifer. Under the present water-level gradients, approximately 3,300 acre-feet of water is estimated to be moving through the aquifer each year and discharged downdip either naturally or artificially. Assuming that conditions of pumpage occur so that the static water level is drawn down to the top of the aquifer where it is 400 feet below the land surface, approximately 16,500 acre-feet of water would be transmitted annually from the outcrop of the aquifer to the areas of pumpage in Leon County.

Recharge to the Queen City aquifer in Leon County appears to be more than adequate to supply the quantity of water that would be moving through the aquifer under the assumed maximum conditions of development. Of the approximately 320,000 acres of Queen City outcrop in Leon County, only the rainfall that falls on approximately 200,000 acres contributes water to the area of assumed development in Leon County. The rainfall that falls on the remaining part of the outcrop in Leon County would be utilized in supplying water to development of the aquifer in Houston and Madison Counties. Less than 1 inch of the 40 inches of annual precipitation would be required as recharge to the aquifer in order to supply the 16,500 acre-feet of water that can be transmitted by the aquifer. This amounts to only about 2.5 percent of the total annual rainfall.

Further development of the Queen City aquifer is favorable throughout the southern part of Leon County. Development is also possible in a large part of the outcrop area in which the sands are thick enough to yield the desired quantities of water. Low transmissibility is the main problem of developing water from the Queen City aquifer. This limits the quantity of water that can move through the aquifer to points of discharge under hydraulic gradients that are within the economic limits of development. For optimum development of the Queen City aquifer, well fields throughout the southern half of Leon County are required.

Sparta Aquifer

Geologic Characteristics

The Sparta Formation crops out in a northeast-trending belt, 3 to 10 miles in width, across the southern part of the county (Plate 1). The Sparta Formation consists principally of fine- to medium-grained, round to subangular quartz sand, which is gray to buff in color. The lower part of the aquifer is a massive unconsolidated sand with minor amounts of shale. The upper part of the Sparta Formation in Leon County is usually a shaley glauconitic sand or sandstone. Downdip from its outcrop area, the Sparta Formation ranges in thickness from 200 to 330 feet, and the sand beds make up approximately 75 percent of the total thickness. The net sand thickness of the Sparta aquifer ranges from a feather edge along the northwestern extent of the outcrop to approximately 250 feet in the southeastern part of the county. Plate 11 shows the net sand thickness of the Sparta aquifer in Leon County.

The Sparta Formation dips to the southeast at a rate of approximately 50 feet per mile downdip from the outcrop area, and there is very little variation in regional dip. The depth to the top of the aquifer ranges from zero in the outcrop area to approximately 360 feet in the southeastern corner of the county. The approximate altitude of and depth to the top of the Sparta aquifer in Leon County are shown on Plate 10.

Occurrence and Movement of Ground Water

The Sparta aquifer contains usable quality water throughout its extent in Leon County. Water in the outcrop area occurs under water-table conditions. Downdip from the outcrop area the water in the aquifer is confined between the relatively impermeable Weches Formation underlying the Sparta and the Cook Mountain Formation overlying the Sparta, and water occurs under artesian conditions.

In the outcrop area of the Sparta aquifer the water generally moves from the higher elevations toward the lower elevations along the creeks and rivers. Downdip from the outcrop area and west of Farm Road 39, water moves in a southerly direction. East of Farm Road 39, the water moves to the southeast and east. The piezometric surface ranges from an elevation of approximately 540 feet in the outcrop area to less than 200 feet along the Trinity River in the southeastern part of the county. Based on the few available water-level measurements in Leon County and in the adjoining counties, the hydraulic gradient is approximately 10 feet per mile in the downdip area, away from the immediate influence of the many variations that occur in the outcrop area. The water-level gradients in and near the outcrop area are somewhat steeper and more variable, in both rate and direction. Contours on the piezometric surface in the Sparta aquifer are shown on Plate 11. These contours are constructed from the few available water-level measurements, and should be used with caution in estimating the water-level elevation in any particular locality.

Recharge and Discharge

Recharge to the Sparta aquifer is derived from precipitation on its outcrop area. The Sparta outcrop in Leon County covers approximately 235 square miles in the southern part of the county. The width of the outcrop area ranges from 3 to 10 miles. The sand of the Sparta Formation weathers to a loose sandy soil, which has only minor amounts of vegetation. The sandy soil is very permeable, and allows much of the rainfall to be absorbed, thus recharging the aquifer; very little is lost to runoff.

Ground water is discharged naturally from the Sparta aquifer by springs and seeps and by evapotranspiration in the outcrop. Downdip from the outcrop where the aquifer is under artesian pressure, natural discharge from the aquifer occurs by means of upward leakage through the confining beds. The artificial discharge from the Sparta aquifer in Leon County is from numerous small domestic and livestock wells located both in the outcrop area and a short distance downdip. There are no known flowing Sparta wells in Leon County.

Water Levels

The depth to water in wells that penetrate the Sparta aquifer ranges from about 10 feet to about 65 feet below the land surface. The depths to water in wells measured during this investigation are listed in Table 2. Although there are no wells completed in the Sparta aquifer that flow, there is a small area in the southeastern corner of the county along the Trinity River in which the artesian pressure should be sufficient to cause any well completed in this area to flow. Plate 11 shows the area where the elevation of the piezometric surface in the Sparta aquifer is sufficiently higher than the land surface so that wells completed in the area would probably flow.

There is very little information on previous water levels in the Sparta aquifer from which to determine water-level fluctuations. However, because of the small quantities of water being withdrawn in the county, it would not be expected that pumpage has caused any noticeable fluctuations in the water levels. In and immediately downdip from the outcrop area, variations in transpiration as well as in rainfall cause changes in the water levels. It is believed that these fluctuations are sometimes quite large. In periods of prolonged drought, some of the shallow dug wells in the outcrop area may dry up. However, these wells will recover during periods of average or about average rainfall.

Water-Bearing Characteristics

The lower part of the Sparta Formation is a massive, unconsolidated sand with only minor amounts of shale, whereas the upper part of the aquifer consists of interbedded sand and shaley sand. Because of the relatively well-sorted and clean nature of the lower part of the aquifer, the Sparta aquifer has high permeability and generally high transmissibility. As there were no large-capacity wells producing from the Sparta aquifer in Leon County, pumping tests in the county were not available for this aquifer. However, pumping tests conducted on a well in Houston County and another in Madison County had coefficients of transmissibility of 16,500 gpd/ft and 21,000 gpd/ft, respectively. The pumping test on the well located in Houston County had an average coefficient of permeability of approximately 110 gpd/ft^2. The well in Madison County, which screened a 50-foot sand section in the lower part of the aquifer, had a coefficient of permeability of 450 gpd/ft^2. The average coefficient of permeability for the Sparta aquifer in Leon County probably would range between 100 and 200 gpd/ft^2. If the entire sand thickness of the Sparta aquifer were screened in a well, coefficients of transmissibility between 20,000 and 40,000 gpd/ft could be expected from large-capacity wells completed in the southeastern corner of Leon County.

A distance-drawdown graph has been prepared based on coefficients believed to be the most applicable in Leon County if the entire aquifer were screened. Figure 8 shows the amount that the water levels would be lowered at various distances from a pumped well after the well has pumped for various periods of time. The distances on the graph are measured along a line parallel with the outcrop area and passing through the pumped well, which is located 8 miles from the outcrop and pumping at a rate of 700 gpm. A coefficient of transmissibility of 20,000 gpd/ft and a storage coefficient of 0.0002 were used to prepare the graph.

Chemical Quality of Water

The water from the Sparta aquifer in Leon County is generally suitable for most purposes, with little or no treatment required except for excessive iron in and near the outcrop area. There are high concentrations of iron in the water in many places, which make the water unusable for domestic purposes without first treating the water. Water was obtained from only two Sparta wells during the investigation for analyses. In these wells, the iron content was 0.56 and 0.76 ppm. The analysis of water obtained from well 39-63-601 contained 1,840 ppm dissolved solids, most of which was sodium and chloride. These constituents are excessively high in comparison with other water samples obtained from the Sparta aquifer in adjoining areas, and it is suspected that this well may be contaminated. The other well sampled in Leon County, well 38-50-402, contained 266 ppm dissolved solids, 30 ppm chloride, and 51 ppm sulfate. The complete analyses on these 2 wells are listed in Table 3. The areal extent of the Sparta aquifer and some of the chemical constituents of the sampled wells are shown on Plate 4.

Utilization and Development

The Sparta aquifer in Leon County is virtually undeveloped. There are no municipal, industrial, or irrigation wells in the county producing from this aquifer. The only pumpage from the aquifer is that of domestic and livestock wells located in and near the outcrop area. The yields of wells presently completed in the Sparta aquifer are small, because the quantity of water needed is small. The dug wells generally have 24- to 36-inch diameter brick or concrete casing, whereas the drilled wells have from 3- to 4-inch diameter iron casing. The wells range in depth from about 14 to 238 feet. Most of the wells are equipped with jet pumps powered by electric motors of small horsepower.

In areas in which the iron concentrations are high, some corrosion and encrustation of well screens may occur. Wells using slotted pipes or screens that have improperly sized openings are likely to pump sand owing to the unconsolidated nature of the sand of the Sparta aquifer.

If wells completed in the Sparta aquifer are properly constructed and maintained, yields up to as much as 700 gpm can be expected in the southeastern corner of Leon County. Because of the relatively high transmissibility of the aquifer, large amounts of water could be withdrawn from the aquifer with relatively small drawdowns, as illustrated by Figure 8. The Sparta aquifer is capable of supporting additional pumpage throughout its extent in Leon County.

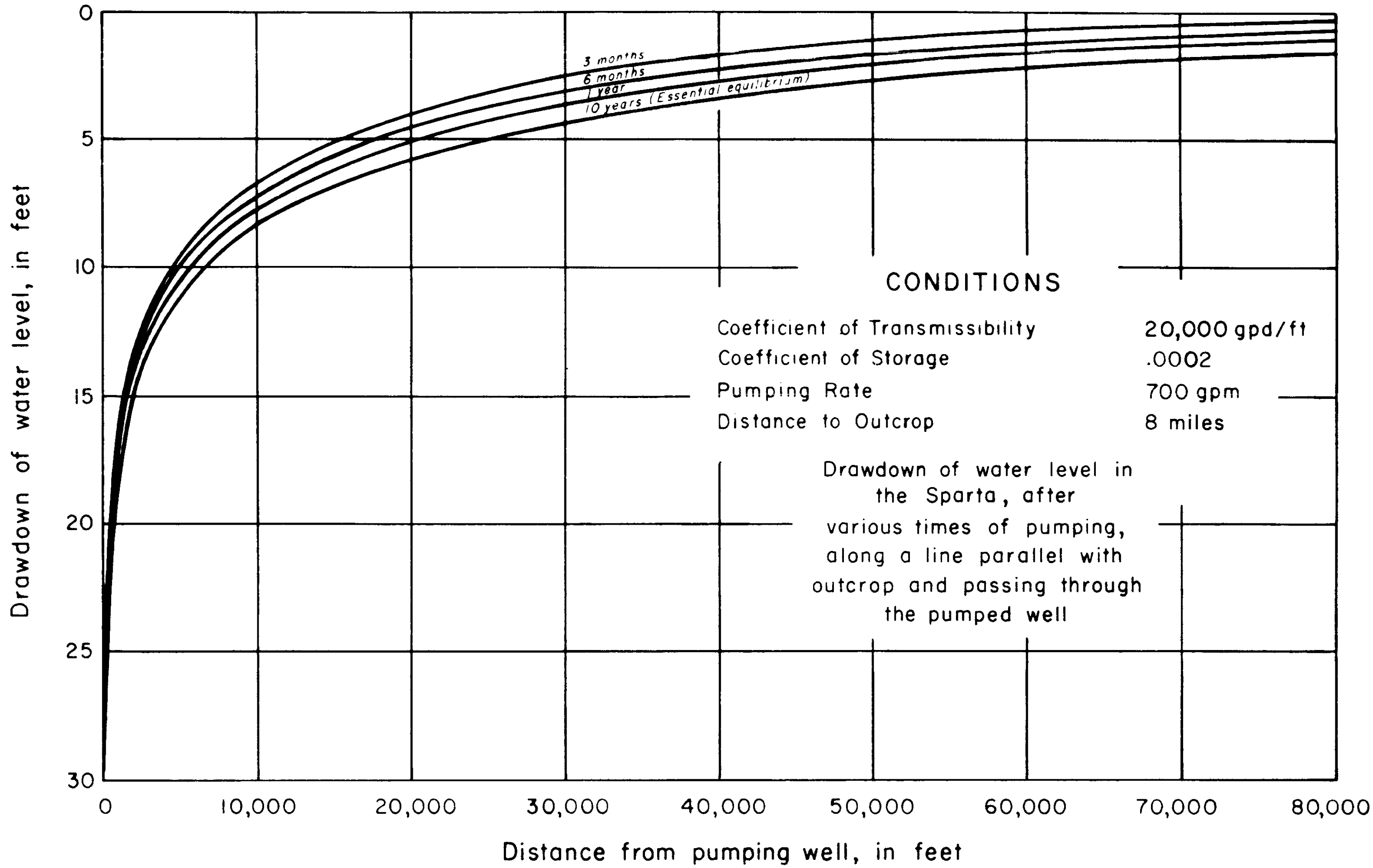

Figure 8

Distance-Drawdown Curves, Sparta Aquifer, Leon County

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However, the best area for possible large-scale development is in the southeastern corner of the county, downdip from the outcrop area.

Ground Water Available for Development

The amount of water available from the Carrizo-Wilcox and Queen City aquifers was determined on the basis that assumed conditions of pumpage would occur, which would cause the static water level to be drawn down to the top of the aquifers where they were 400 feet below the land surface. The line along which the top of the Sparta aquifer occurs at 400 feet below the land surface is south of Leon County, in Houston and Madison Counties. Any change in the assumptions for computing the availability from the Sparta aquifer would be misleading when compared with the Queen City and Carrizo-Wilcox aquifers. Therefore, no estimate of the quantity of water that could be developed in Leon County has been made. It is assumed that most of the development of this aquifer will take place in Houston and Madison Counties, with the approximately 235 sqaure mile outcrop area in Leon County furnishing water for the development of the aquifer downdip.

Although the largest development of the Sparta will probably take place south of Leon County, it is possible to obtain substantial quantities of water in the southeastern corner of Leon County. In addition, water supplies can be developed in the outcrop areas where the sands are sufficiently thick to yield the desired quantities of water.

CONCLUSIONS

Large quantities of water are available for development from the three principal aquifers in Leon County. These aquifers are the Carrizo-Wilcox, the most prolific of the three, the Queen City, and the Sparta. Approximately 75.4 million gallons per day or 84,500 acre-feet per year of ground water is estimated to be available from the Carrizo-Wilcox and Queen City aquifers, with additional undetermined quantities available from the Sparta aquifer. Of this total, approximately 68,000 acre-feet of water is available annually from the Carrizo-Wilcox aquifer and 16,500 acre-feet per year available from the Queen City aquifer. In the process of establishing the assumed conditions of pumpage for which availability was computed, additional water would be released from artesian storage from the aquifers.

The quantity of water presently being pumped in Leon County is very small. Approximately 655 acre-feet per year of ground water is being pumped from the aquifers in Leon County for municipal and irrigation purposes. In addition undetermined quantities of water are being produced from domestic and livestock wells, and small quantities are being used for commercial purposes. Of the total quantity of water pumped, 388 acre-feet per year is being used for municipal purposes. All of the pumpage for municipal purposes is from the Carrizo-Wilcox aquifer, except for 107 acre-feet which is pumped from the Queen City aquifer. Approximately 267 acre-feet of water per year is being pumped for irrigation, all from the Carrizo-Wilcox aquifer.

Ground water in Leon County, particularly downdip from the outcrop areas, should be suitable for most municipal, industrial, and agricultural uses. Where undesirable constituents are found, they may be removed by various treatment methods. Whenever iron is encountered in a sand, it is generally possible to produce iron-free water by drilling to deeper sands in the area.

The possibility of irrigation from the principal aquifers in Leon County appears to be very good, with the Carrizo-Wilcox aquifer offering the best potential. The outcrops of the Marquez Member of the Reklaw Formation, the outcrop of the Cook Mountain Formation, and many of the stream valleys provide relatively flat land, which should be suitable for irrigation. It is possible to obtain large yielding wells in the Carrizo-Wilcox aquifer, and although the wells would be of considerable depth in the southern part of the county, the water levels are relatively shallow and would not require excessive pumping lifts.

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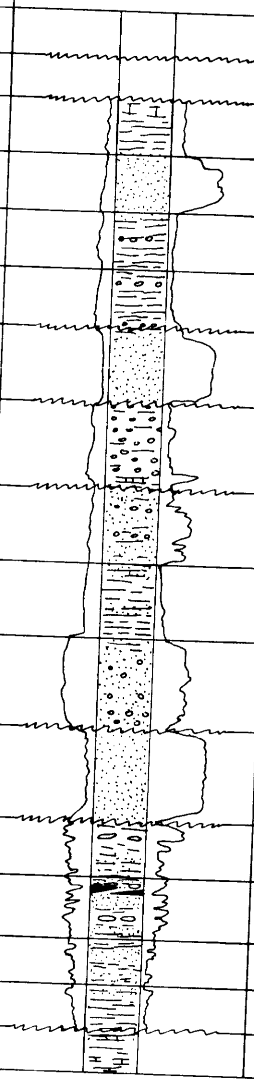
APPENDIX A

TABLES OF BASIC DATA

1. Geologic units and their water-bearing characteristics in Leon County
2. Records of selected wells in Leon County
3. Chemical analyses of water from selected wells in Leon County
4. Oil tests used as data-control points in Leon County

Table 1.--Geologic units and their water-bearing characteristics, Leon County

System	Series	Group	Formation and member	Approximate thickness (feet)	Generalized electrical and lithological log (not to scale)	Character of rocks	Water-bearing properties
Quaternary	Recent and Pleistocene		Alluvium and terrace deposits			Gravel, silt, and clay; confined to stream valleys.	Yields small quantities of water to shallow domestic wells.
Tertiary	Pliocene		Upland gravels			Unconsolidated, pebble-sized, siliceous gravel.	Beds are too thin to contain a usable amount of water.
	Eocene	Claiborne	Cook Mountain Formation: Mount Tabor Member	120±		Brown shale and marl with impure limestone.	Not known to yield water to wells in Leon County.
			Cook Mountain Formation: Spiller Member	90±		Gray to brown lignitic argillaceous sand.	Yields small quantities of water to shallow domestic wells.
			Cook Mountain Formation: Landrum Member	110±		Brown marl and shale with glauconitic marl and limestone lenses; numerous gypsum crystals.	Yields only small quantities of highly mineralized water.
			Cook Mountain Formation: Wheelock Member	90±		Gray-green to blue-gray thin-bedded, fossiliferous marl with beds of glauconitic marl.	Not known to yield water to wells in Leon County.
			Sparta Formation	200-330		Upper member when present is slightly shaly, glauconitic sand; lower member is gray, well-bedded, loose sand.	Yields moderate quantities of good quality water.
			Weches Formation	30-100		Black-green clay with iron sulfide nodules; calcareous glauconite with iron concretions; glauconitic calcareous marl with white lime nodules.	Not known to yield water to wells in Leon County.
			Queen City Formation	250-400		Fine-grained, slightly lignitic sand with thin, gray, lignitic shale beds, and a few glauconitic sand beds.	Yields moderate quantities of good quality water to domestic and municipal wells.
			Reklaw Formation: Marquez Member	70-240		Chocolate-brown shale with thin sand layers.	Yields only small quantities of rather highly mineralized water.
			Reklaw Formation: Newby Member	20-85		Yellow friable sandstone with layers of red-brown ferruginous glauconitic sandstone.	Yields small quantities of varying quality water in local areas.
			Carrizo Formation	100-210		Well-bedded, loose or friable, fine to medium grained quartz sand.	Yields large supply of water to municipal, domestic, and irrigation wells. Water of good quality downdip, with increase of iron toward outcrop.
		Wilcox	Sabinetown Formation	0-50		Calcareous shale and argillaceous sand with purple concretions.	Yields large supply of water to municipal and domestic wells. Water of varying quality.
			Rockdale Formation	350-3,000		Lignitic shale and fine grained sand with lignite beds and silicified wood fragments.	
			Seguin Formation	50-200		Gray calcareous shale and sandy shale.	
		Midway	(Undivided)	800±		Dark gray calcareous shale with thin sand streaks.	Not known to yield water to wells in Leon County.
Cretaceous	Gulf	Navarro and Taylor	(Undivided)	800+		Dark gray shale and chalky marl.	Not known to yield water to wells in Leon County.



Symbols: Sand, Shale, Marl, Glauconite, Lignite and Concretions, Unconformity

Table 4.--Oil tests used as data-control points in Leon County

Well	Operator	Lease and well
38-19-701	Carter-Gragg Oil Co.	A. W. Johnson No. 4
25-501	M. G. Hansboro	Richardson No. 1
601	Hamman & Meehan	Dunlap No. 1
801	Wynne Drilling Co.	Brown No. 1
901	Humble Oil & Refining Co.	Mrs. M. Harrod No. 1
26-501	Carter-Gragg Oil Co	Emma Dora Carter No. 3
502	(Confidential)	--
702	Humble Oil & Refining Co.	Gas Unit No. 11
703	Humble Oil & Refining Co.	Lena Heller No. 1
704	Humble Oil & Refining Co.	John Hanna No. 1
801	Carter-Gragg Oil Co.	E. H. Richmond No. 1
802	Fisher & Davidson	J. Emanuel No. 1
901	B. G. Byars	Fannie Coleman No. 1
902	Azalea	De Vaughn No. 1
27-401	Danciger Oil Co.	J. B. Knight No. 1
33-201	Carlson & Heller	Coats Estate No. 1
305	Fisher & Davidson	Lee No. 1
306	Humble Oil & Refining Co.	Gas Unit No. 2 Well No. 1
401	Lone Star Producing Co.	Recknow No. B-2
502	Shell - Lone Star	W. L. Tandy No. 1
701	J. F. Corley	Thomason No. 1
702	Shell, Penn, & Black	W. M. Phillips No. 1
804	Lone Star Producing Co.	Yarborough No. 1
34-106	Humble Oil & Refining Co.	Gas Unit No. 4
107	Humble Oil & Refining Co.	Lester Foran No. 1
108	Humble Oil & Refining Co.	Unit No. 5 Well No. 1
109	Humble Oil & Refining Co.	Unit No. 6 Well No. 1
110	Humble Oil & Refining Co.	S. W. Oakwood Gas Unit No. 10
111	Humble Oil & Refining Co.	Oakwood Gas Unit No. 3
201	American Liberty	Mullinax & Thrash No. 1
302	Carter & Lipsey	Kaemmer No. 1
303	Humble Oil & Refining Co.	K. Holley No. 1
304	Lone Star Producing Co.	L. L. Haley No. 1
305	Humble Oil & Refining Co.	T. O. Harris Heirs No. 2
306	Humble Oil & Refining Co.	Leone Plantation Inc. No. 1
35-701	Carter-Gragg Oil Co.	B. F. Phillips No. 1-A
41-101	Christie Mitchell	Hubbard No. 1
201	Christie Mitchell	W. B. Stevens No. 1
202	Lone Star Producing Co.	Page Estate No. C-1
501	Globe & McGarlane	J. B. Carter No. 1
601	Perryman & Greer	R. C. Burleson No. 1
703	Hunt Oil Co.	D. A. Sullivan No. 1
42-101	Hudson	G. Gresham No. 1
102	Shell Oil Co.	J. & O. Smith No. 1
303	General Crude	Shelly Smith No. 1
501	Allerton Miller	S. L. Leathers No. 1
704	R. Lacy, Inc.	L. T. Nierth No. 1
43-106	Barnwell	Swift Estate No. 1

Table 4.--Oil tests used as data-control points in Leon County--Continued

Well	Operator	Lease and well
38-43-107	General Crude	E. F. Swift No 1
108	Laan Tex Oil Co.	E. F. Swift No. 1
401	Magnolia Oil Co.	Swift Estate No. 1
402	Hassie Hunt	Swift No. 1
49-202	British American Oil Producing Co.	E. T. Sherman No. B-1
301	John W. Pace	Sherman Unit No. 1
302	Gibson Drilling Co. & J. W. McFarlane	Maude Wakefield Albrecht No. 1
602	Rancho Oil Co.	T. Z. Shadix No. 1
701	D. H. Byrd	Elizabeth L. Nash No. 1
801	Raymond Hedge, et al.	Mary Jackson Brewster No. 1
50-601	D. H. Byrd	J. M. Leathers No. 1
701	Delta Drilling Co.	Moore No. 1
801	Harvey Park	F. C. Wilson No. 1
57-101	Byrd - Frost Inc.	J. L. Nash No. 1
201	V. M. Harrison	Nash No. 1
58-301	Hunt Oil Co.	L. A. Wakefield No. 1
39-40-302	G. M. Jordan	P. Van Winkle No. 1
504	N. A. Lindsay	J. L. White No. 1
903	Sun Oil Co.	T. E. Harcrow No. 1
46-801	Humble Oil & Refining Co.	Jewell Martin No. 1
47-604	Sun Oil Co.	M. Golie No. 1
48-102	W. L. Pickens	Mary Black No. 1
801	Byrd - Frost Inc.	R. H. Simmons No. 1
901	Gate City Development Co.	Sam Bain No. 1
55-901	United North & South	Ray Oden No. 1
56-101	Humble Oil & Refining Co.	L. J. Craig No. 1
801	Falcon Oil Corp. and James Papadakis	Ester Willman, et al, No. 1
64-101	Daniels Oil Co.	Cox Estate No. 1
201	C. Bell	Browne - Carson No. 1
202	Cooper, et al.	Lynch No. 1-A
403	H. A. Baker	C. M. Wells No. 1
404	Harry Williams	B. H. Henry No. 1
405	Albert Plummer	Lula Henry No. 1
501	H. W. Hawker	C. H. Mills Estate No. 1

APPENDIX B

DESCRIPTIVE PLATES

PLATE 1

Geologic Map of Leon County, Showing Locations of Selected Wells

This map shows the location and extent of the outcrops of the geologic units in Leon County. The Carrizo-Wilcox outcrop is present only in the northwest corner of Leon County with most of the outcrop occurring northwest of the county. The outcrops of progressively younger formations occur in a southeastward direction from the Carrizo-Wilcox outcrop. The small circular outcrops of Cretaceous rocks and rocks of the Midway Group, northwest of Marquez, are located above the Marquez salt dome which has pushed these older rock units to the surface.

The location of the 121 water wells inventoried during this investigation and the location of the 82 oil tests used as control points on the various maps and cross sections are shown on this map. The symbols used on this map designate the type of well, and the numbers next to the symbol are the last three digits of the well number as explained in the section on the well-numbering system. Data obtained on the water wells shown on this map are listed in Table 2, and the oil tests used as control points are given in Table 4.

PLATE 2

Generalized Geologic Section A-A', Leon County

From well 39-47-604 to well 38-58-301, this section generally follows the dip of the geologic units and shows the general position and thicknesses of the geologic units present. The effects of the Marquez salt dome on the base of the Wilcox Group can be seen in the vicinity of well 39-46-801, as the line of cross section passes on the north flank of the dome.

The curve on the left hand side of each of the control wells in this section is the "self-potential" curve of an electric log of the well. The curve on the right side of the control well is the "64-inch normal" resistivity curve of the electric log. In addition to the control wells, the structure contours on the top of the various aquifers (Plates 6, 8, and 10) were used between the control points in preparing this cross section.

PLATE 3

Generalized Geologic Section B-B', Leon County

This geologic section is drawn generally along the strike of the geologic formations. Between well 39-48-901 and well 38-34-110 the section passes along the south flank of an elongated structural high. The structural contours on the top of the various aquifers in the county were also used in preparing this cross section. The base of usable quality water along this section is the base of the Wilcox Group.

PLATE 4

Areal Extent of Principal Aquifers and the Chemical Quality of Their Water, Leon County

This map outlines the areas in which water can be obtained from the three principal aquifers in Leon County. Water can be obtained from all three aquifers, the Carrizo-Wilcox, Queen City, and Sparta aquifers, where indicated by overlapping patterns on the map. None of the three aquifers are present in the white area above the Marquez salt dome.

The 23 wells from which water samples were analyzed are shown on the map in the same color as the aquifer from which they produce. The parts per million concentration of dissolved solids, iron, sulfate, and chloride also are shown on the map. Excluding well 39-40-701, suspected of receiving some water from shallower beds, and well 39-63-601, which indicates possible contamination, the analyses have the following range of constituents: dissolved solids, 101 to 661 ppm; iron, 0.0 to 2.7 ppm; sulfate, 0.0 to 179; chloride, 5 to 78; hardness, 2 to 186. The complete analyses for all of the sampled wells are listed in Table 3.

PLATE 5

Approximate Altitude of Base of Water Containing Less Than 3,000 ppm Dissolved Solids, Leon County

This map illustrates the altitude of the base of fresh water (3,000 ppm dissolved solids) in Leon County. The base of fresh water was calculated from the self-potential curve of the electric logs. Except for the southeast part of the county, this map is essentially the same as the base of the Wilcox Group because water containing 3,000 ppm or less dissolved solids occurs throughout the Wilcox Group. Further downdip, in the southeast part of the county, the lower part of the Wilcox Group contains water with more than 3,000 ppm dissolved solids. The deepest that fresh water occurs in Leon County is approximately 3,570 feet below sea level or approximately 3,900 feet below the land surface in the southeast part of the county. In the same general area, the base of the Wilcox Group occurs at a depth of about 4,860 feet below the land surface. The relationship of the fresh water to the base of the Wilcox Group is shown on Plate 2. The effects that the Oakwood and Marquez salt domes have had on the altitude of the base of fresh water and the base of the Wilcox Group is shown by the circular highs in grids 38-25-7 and 39-46-8, respectively.

PLATE 6

Approximate Altitude of and Depth to Top of the Carrizo-Wilcox Aquifer, Leon County

This illustration is a structural contour map drawn on the top of the Carrizo Formation. The top of the Carrizo ranges from about 450 feet above sea level in the northwest part of the county down to more than 1,100 feet below sea level in the southeast corner of the county. The dip of the top of the aquifer generally ranges between 25 and 100 feet per mile with the steeper dips occurring near the outcrop and west of Farm Road 39.

The depths to the top of the aquifer, as shown by the various patterns, range from zero in the outcrop to approximately 1,400 feet in the southeast corner of the county. These depths are only approximate because of the irregularities in the land surface.

PLATE 7

Isopachous Map of Net Sand in the Carrizo-Wilcox Aquifer Containing Water Having Less Than 3,000 ppm Dissolved Solids, and Altitude of the Piezometric Surface in the Aquifer, Leon County

This illustration shows the net sand thickness, not the total thickness, of the Carrizo-Wilcox aquifer where it contains water with less than 3,000 ppm dissolved solids. In other words, the shale beds contained in the aquifer have been excluded in order to show the accumulative total of the sands. The net sand thickness in the Carrizo-Wilcox aquifer, except over the salt domes, ranges from approximately 700 feet in the outcrop area to more than 1,600 feet in the eastern part of the county.

The contour lines on the map are the altitude of the piezometric surface of water levels in the Carrizo-Wilcox aquifer. The piezometric surface ranges from an elevation of approximately 450 feet in the outcrop area to approximately 240 feet along the Trinity River. The hydraulic gradient averages approximately 5 feet per mile in the downdip area away from the immediate influence of the many variations that occur within the outcrop area. These contours were constructed from the few available water-level measurements in the county and should be used with caution in estimating the water-level elevation in any particular locality.

Also shown is the area, in the eastern part of the county, where the piezometric surface of the Carrizo-Wilcox aquifer is sufficiently higher than the land surface so that wells completed in the aquifer will generally flow.

PLATE 8

Approximate Altitude of and Depth to Top of the Queen City Aquifer, Leon County

The contours on this map illustrate the altitude of the top of the Queen City aquifer downdip from the outcrop area. The altitude ranges from more than 500 feet above sea level in the vicinity of the intersection of State Highway 7 and Farm Road 39 to more than 600 feet below sea level in the southeast corner of the county. The dip of the beds ranges from about 40 to 80 feet per mile, with the steeper dips occurring in the southeast part of the county.

The depths to the top of the Queen City aquifer are shown by the various patterns. The depth to the top of the aquifer ranges from zero in the outcrop area to approximately 800 feet below the land surface in the southeast corner of the county. The depths to the top of the aquifer shown on this map are only approximate because of the irregularities in the land surface.

PLATE 9

Isopachous Map of Net Sand in the Queen City Aquifer Containing Water Having Less Than 3,000 ppm Dissolved Solids, and Altitude of the Piezometric Surface in the Aquifer, Leon County

The patterns on this map represent the net sand thickness in the Queen City aquifer, not the total thickness. The Queen City aquifer ranges in thickness from about 250 to 400 feet downdip from the outcrop with the sands making up approximately 60 to 70 percent of the aquifer's total thickness. The net sand thickness of the Queen City aquifer ranges from a feather edge at the northern extent of the aquifer's outcrop to more than 200 feet in the southern part of the county.

The contour lines on the map are drawn on the altitude of the piezometric surface of water levels in the Queen City aquifer. The elevation of the piezometric surface ranges from approximately 490 feet in the outcrop area to less than 200 feet along the Trinity River. The hydraulic gradient averages approximately 10 feet per mile in the downdip area away from the immediate influence of the many variations that occur within the outcrop area. These contours were constructed from the few available water-level measurements in the county and should be used with caution in estimating the water-level elevation in any particular locality.

Also shown, in the eastern part of the county, is the area where the elevation of the piezometric surface in the Queen City aquifer is sufficient to cause wells completed in the aquifer to flow. The Queen City aquifer has numerous shale layers between the sand beds which, in some cases, are impervious enough to confine the sand beds and create local artesian conditions, even within the outcrop area. There are wells completed in the Queen City aquifer in the Upper Keechi and Alligator Creek bottoms which flow as a result of such local artesian conditions within the outcrop area of the aquifer.

PLATE 10

Approximate Altitude of and Depth to Top of the Sparta Aquifer, Leon County

The contours on this map illustrate the elevation of the top of the Sparta aquifer downdip from its outcrop. The elevation of the top of the Sparta aquifer ranges from more than 400 feet above sea level just north of Normangee to almost 200 feet below sea level in the southeast corner of the county. The top of the aquifer dips toward the southeast at a rate of approximately 50 feet per mile.

The patterns on the map indicate the general depth to the top of the aquifer, which ranges from zero in the outcrop area to approximately 360 feet below the land surface in the southeast corner of the county. The depths to the top of the aquifer are only approximate because of the irregularities in the land surface.

PLATE 11

Isopachous Map of Net Sand in the Sparta Aquifer Containing Water Having Less Than 3,000 ppm Dissolved Solids, and Altitude of the Piezometric Surface in the Aquifer, Leon County

The patterns on this map show the net sand thickness of the Sparta aquifer. The total thickness of the Sparta aquifer, including shales, ranges in thickness from 200 to 330 feet downdip from its outcrop area, and the sand beds make up approximately 75 percent of the Sparta's total thickness. The net sand thickness in the Sparta aquifer ranges from a feather edge along the northwest extent of the outcrop to approximately 250 feet in the southeast part of the county.

The contour lines on the map illustrate the altitude of the piezometric surface of water levels in the Sparta aquifer. The piezometric surface ranges from an elevation of approximately 540 feet in the outcrop area to less than 200 feet in the southeast part of the county. The hydraulic gradient averages approximately 10 feet per mile in the area downdip from the outcrop. These contours were constructed from the few available water-level measurements in the county and should be used with caution in estimating the water-level elevation in any particular locality.

The map shows the area, near the Trinity River, where the elevation of the piezometric surface in the Sparta aquifer is sufficiently higher than the land surface so that wells in the aquifer will probably flow.