GROUND-WATER RESOURCES OF LA SALLE AND McMULLEN COUNTIES, TEXAS

TEXAS WATER COMMISSION

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By

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GROUND-WATER RESOURCES OF LA SALLE AND MCMULLEN COUNTIES, TEXAS

ABSTRACT

La Salle and McMullen Counties are in the central part of southern Texas. The report area is in the Nueces River Basin, and the low relief is typical of the central part of the West Gulf Coastal Plain. The average annual precipitation is a little more than 20 inches; the two-county area is in the semiarid climatic belt.

The economy of La Salle and McMullen Counties is based on agriculture and the production of oil and gas. Cattle ranches occupy almost all the area of the counties. Cultivated land includes about 20,000 acres not irrigated, about 3,000 acres irrigated with ground water, and about 1,000 acres irrigated with surface water. The production of oil and gas is the only industry in the two-county area. All the water for public supply, domestic, and industrial uses, and most of the water for livestock and irrigation uses is obtained from wells; the rest is obtained from small reservoirs and the intermittent flow of streams.

The estimated uses of ground water in La Salle and McMullen Counties in 1962 in acre-feet were as follows: irrigation, 4,000; domestic and livestock, 1,600; public supply, 770; and industrial, 56.

The water-bearing formations in La Salle and McMullen Counties range in age from Eocene to Recent. The rocks consist mainly of alternating beds of sand and clay or shale, which crop out in belts that roughly parallel the coast. The formations dip to the southeast at an angle slightly greater than the slope of the land surface, and most of the formations thicken in the same direction.

The Carrizo Sand is the most important aquifer in the two-county area. The Carrizo supplies large quantities of water for irrigation, public supply, and industrial uses. Moderate to large quantities of water are obtained from the other principal aquifers, the Queen City Sand Member of the Mount Selman Formation and the Sparta Sand. Other formations supply only small quantities of water for domestic and livestock needs.

The source of ground water in La Salle and McMullen Counties is precipitation on the land surface in these counties and in adjoining areas on the north and west. The water moves through the sand aquifers from areas of recharge to areas of discharge at a slow rate, perhaps a few hundred feet per year. The artificial discharge of ground water is from wells, and the only apparent natural discharge is the water evaporated from the soil or transpired by plants.

Hydrographs of water levels for the period 1959 to 1962 or 1963 in 11 observation wells tapping the Carrizo Sand show declines caused chiefly by ground-water withdrawals in heavily irrigated areas to the north and northwest of the report area.

The chemical quality of water from wells in La Salle and McMullen Counties ranges from fresh to moderately saline. The Carrizo Sand contains the largest quantity of fresh to slightly saline water in the report area.

Aquifer tests in eight wells in La Salle County and other information indicate that the Carrizo Sand is, by far, the largest potential source of ground water in the two-county area. Computations indicate that the Carrizo could transmit water at the rate of 90,000 acre-feet per year without excessive drawdowns of water levels. However, recharge to the part of the Carrizo Sand supplying La Salle and McMullen Counties is estimated at only 50,000 acre-feet per year, and an estimated 130,000 acre-feet was used in 1961 principally for irrigation in the heavily pumped areas adjoining La Salle and McMullen Counties on the west and north. In effect, the withdrawals for irrigation in the areas to the west and north are already intercepting much more than the recharge to La Salle and McMullen Counties. It is unlikely that large quantities of water will be developed from the Carrizo Sand in the two-county area because of the great depth to the top of the formation and the doubtful quality of much of the water for irrigation.

The potential ground-water development from the other two principal aquifers could not be evaluated quantitatively. However, yields up to about 1,000 gpm (gallons per minute) might be obtained from the Queen City Sand Member of the Mount Selman Formation in much of La Salle County and the northwestern part of McMullen County. The Sparta Sand probably is capable of yielding as much as 400 gpm to wells in the western two-thirds of La Salle County. The water from both aquifers is of doubtful quality for irrigation. However, the water from the Sparta, especially that above a depth of about 800 feet, is of better quality than the water from the Queen City.

The other geologic formations in the two-county area are capable of yielding only small quantities of water, and most of the water is saline.

GROUND-WATER RESOURCES OF LA SALLE AND MCMULLEN COUNTIES, TEXAS

INTRODUCTION

Location and Extent of Area

La Salle and McMullen Counties are in the central part of southern Texas (Figure 1). La Salle County is bordered on the east by McMullen County, on the south and southwest by Webb County, on the west by Dimmit County, on the northwest by Zavala County, and on the north by Frio County. McMullen County is bordered on the north by Atascosa County, on the east by Live Oak County, and on the south by Duval County. Cotulla, the county seat of La Salle County, is 70 miles north of Laredo and 80 miles south-southwest of San Antonio. Tilden, the county seat of McMullen County, is 65 miles south of San Antonio and 85 miles west-northwest of Corpus Christi. The report area includes 2,660 square miles--La Salle County has an area of 1,501 square miles and McMullen County an area of 1,159 square miles.

Purpose and Scope of Investigation

This investigation was a cooperative project of the Texas Water Commission and the U.S. Geological Survey. It was started September 1, 1962 to determine and describe the ground-water resources of La Salle and McMullen Counties. The results of the investigation are described in this report, which includes an analytical discussion of the occurrence and availability of ground water and tabulations of basic data obtained during the investigation. The purpose of this report is to present information and data that can be used as a guide to the development of the available ground-water supplies.

The general scope of the investigation included the collection, compilation, and analysis of data related to ground water in the project area. Included were determinations of the location and extent of the water-bearing formations, the chemical quality of the water they contain, the quantity of water being withdrawn and the effects of these withdrawals on the water levels, the hydraulic characteristics of the important water-bearing formations, and estimates of the quantities of ground water available for development.

The investigation was made under the immediate supervision of A. G. Winslow, district geologist of the U.S. Geological Survey in charge of ground-water investigations in Texas.

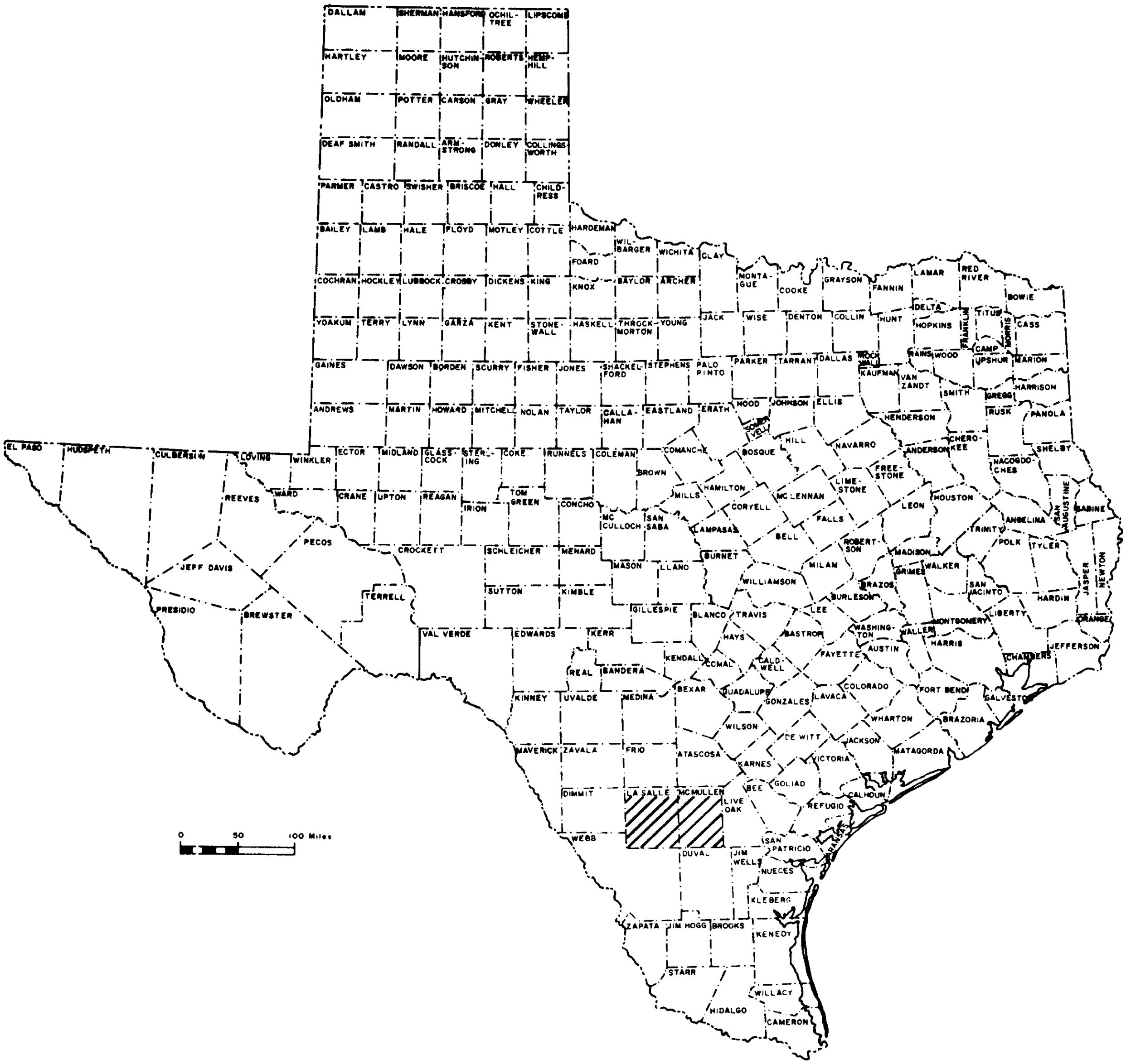

Figure 1

Index Map of Texas Showing Location of La Salle and McMullen Counties

U. S. Geological Survey in cooperation with the Texas Water Commission

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Methods of Investigation

The following items of work were included in the investigation of the ground-water resources of La Salle and McMullen Counties:

1. All public supply, irrigation, and industrial wells, and most of the domestic and stock wells (a total of 252 wells) were inventoried. The locations of the wells inventoried are shown on Plate 1.

2. The electric logs of 292 oil and gas tests were used for correlation and for a study of the water-bearing properties of the formations. The locations of these tests are shown on Plate 1.

3. Quantities of water used for public supply, irrigation, and industry were inventoried, and the quantity of water used for domestic and livestock purposes was estimated.

4. Eight wells were test pumped to determine the hydraulic characteristics of the water-bearing sands.

5. Water levels in wells were measured and available records of past fluctuations of water levels were compiled (Figures 9 and 10).

6. Climatological and streamflow records were collected and compiled (Figures 2 and 3).

7. Analyses of samples of water collected during this and previous investigations were used to determine the chemical quality of the water.

8. Maps showing the extent and thickness of the sands containing fresh to slightly saline water in the Carrizo Sand and in the Queen City Sand Member of the Mount Selman Formation were made from electrical-log data and from the chemical analyses of water samples (Figures 13 and 15).

9. Maps showing the altitudes of the tops of the Carrizo Sand, the Queen City Sand Member of the Mount Selman Formation, and the Sparta Sand were made from electrical-log data (Figures 4, 5, and 6).

10. Four geologic cross sections were made from electrical logs (Plates 2-5).

11. The hydrologic data were analyzed to determine the quantity and quality of ground water available for development.

12. Problems related to the development of ground-water supplies in La Salle and McMullen Counties were studied.

Well-Numbering System

The well-numbering system used in this report is one adopted by the Texas Water Commission for use throughout the State and is based on latitude and longitude. Under this system, each 1-degree quadrangle in the State is given a number consisting of two digits. These are the first two digits appearing in the well number. Each 1-degree quadrangle is divided into $7\frac{1}{2}$-minute quadrangles which are also given 2-digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each 7½-minute quadrangle is subdivided into 2½-minute quadrangles and given a single digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a 2½-minute quadrangle is given a 2-digit number in the order in which it is inventoried, starting with 01. These are the last two digits of the well number. In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefixes for La Salle and McMullen Counties and adjacent counties are as follows:

County	Prefix	County	Prefix
Atascosa	AL	Live Oak	SJ
Dimmit	HZ	McMullen	SU
Duval	JB	Webb	YZ
Frio	KB	Zavala	ZX
La Salle	RX		

Thus, Well SU-78-36-201 (which supplies water for the city of Tilden) is in McMullen County (SU), in the 1-degree quadrangle 78, in the 7½-minute quadrangle 36, in the 2½-minute quadrangle 2, and was the first well (01) inventoried in that 2½-minute quadrangle.

On the geology and well-location map of this report (Plate 1), the 7½-minute quadrangles are shown and numbered in the northwest corner of each quadrangle. The 3-digit number shown with the well symbol contains the number of the 2½-minute quadrangle in which the well is located and the number of the well within that quadrangle. For example, the city of Tilden well is numbered 201 in the quadrangle numbered 7836 in the upper left corner.

Previous Investigations

A report by Duessen and Dole (1916) on ground water in La Salle and McMullen Counties was the first report on the ground-water resources of the project area. This report contains the records of 121 water wells drilled during the period 1893 to 1914, and the chemical analyses of 131 water samples collected in 1913 and 1914.

In response to a request from the War Department, George and Broadhurst (1942) made an investigation of the ground-water resources in western La Salle County, and Sundstrom (1942) investigated the deeper water wells in central and eastern La Salle County. The public water supplies of Cotulla and Fowlerton were included in an inventory of the public water supplies in southern Texas by Broadhurst, Sundstrom, and Rowley (1950, p. 82-84).

A report by Moulder (1957) on the development of ground water from the Carrizo Sand and the Wilcox Group in the southern Texas area included data on La Salle and McMullen Counties. A reconnaissance report on the ground-water resources of the Nueces River Basin by Alexander, Myers, and Dale (1964) included information on La Salle and McMullen Counties.

Two reports on regional geology (Deussen, 1924, and Sellards and others, 1932) include descriptions of the geologic formations in the report area.

Reports on ground-water resources of areas adjacent to La Salle and McMullen Counties include the following, by counties: Atascosa (Sundstrom and Follett, 1950), Atascosa and Frio (Lonsdale, 1935), Dimmit (Mason, 1960), Dimmit, Maverick, and Zavala (Turner and others, 1960), Duval (Sayre, 1937), Live Oak (Anders and Baker, 1961), and Webb (Lonsdale and Day, 1937).

Economic Development

The economy of La Salle and McMullen Counties is based on agriculture and the production of oil and gas. The populations of the counties, cities, and towns in 1960 (U.S. Census data) were as follows: La Salle County, 5,972; Cotulla, 3,960; Encinal, 300; Fowlerton, 300; and Artesia Wells, 50; McMullen County, 1,116; and Tilden, 380. All the water for public supply and domestic use in the two-county area is obtained from wells.

Cattle ranches occupy almost all the area of La Salle and McMullen Counties. In 1959 (U.S. Census of Agriculture data) there were approximately 86,000 cattle and 1,100 horses in the area. Most of the water for livestock supplies is obtained from wells; the rest is obtained from small reservoirs and the intermittent flow of streams. In 1962 about 24,000 acres of land was under cultivation in the two counties, which included about 3,000 acres irrigated with ground water and about 1,000 acres irrigated with surface water. The principal crops grown in the two counties include grain sorghums, vegetables, cotton, peanuts, broomcorn, hay crops, and corn; irrigated crops include peanuts, grain sorghum, vegetables, cotton, and pasture.

The production of oil and gas is the only industry in La Salle and McMullen Counties. The following data on oil and gas produced were tabulated from reports of individual oil and gas reservoirs (The Railroad Commission of Texas, 1963). The production of oil during 1962 and the cumulative production to January 1, 1963 were as follows: La Salle County, 264,000 and 4,700,000 barrels; McMullen County, 925,000 and 13,880,000 barrels. The production of natural gas in both counties in 1962 was 45,000,000 MCF (thousand cubic feet) of gas and 220,000 barrels of hydrocarbon liquids produced with the gas. Oil or gas reservoirs were reported in the following stratigraphic units discussed in this report: Wilcox Group, Carrizo Sand, Queen City Sand Member of the Mount Selman Formation, Sparta Sand, Yegua Formation, and Jackson Group. The petroleum industry uses a small quantity of ground water to repressure three oil and gas reservoirs and for use at compressor stations.

Physiography and Drainage

La Salle and McMullen Counties are in the West Gulf Coastal Plain of Texas (Fenneman, 1938, p. 100). The principal physiographic features of the report area are the wide valleys of the Nueces and Frio Rivers, the terraces along the rivers, and the nearly flat divides of the upland areas. Altitudes range from about 150 feet above sea level where the Nueces and Frio Rivers cross the eastern boundary of McMullen County to about 650 feet in southwestern La Salle County. The upland areas slope gently toward the southeast from an altitude of about 600 feet in northwestern La Salle County to about 500 feet in east-central La Salle County. The altitude of the upland area in southeastern McMullen County is also about 500 feet. A line of hills extends across the upland area in the southeastern corner of McMullen County; the highest hill is about 100 feet above the upland surface.

The most prominent physiographic feature in the report area is the wide valley of the Nueces River which includes a large part of La Salle County and the southern half of McMullen County. The valley is about 20 miles wide, the river channel is about 200 feet below the divide areas, and the land surface slopes toward the river at the rate of about 20 feet per mile. The width of the flood plain and stream terraces along the Nueces River ranges from about 2 miles in western La Salle County to about 5 miles in McMullen County.

The Frio River flows across the northeastern part of La Salle County and the north-central part of McMullen County in a valley less than 15 miles wide and about 150 feet deep. The width of the flood plain and stream terraces along the Frio River ranges from 2 to 3 miles.

Because of their intermittent flow, the Nueces and Frio Rivers are not dependable sources of water for irrigation in La Salle and McMullen Counties. The Nueces River drains an area of 5,260 square miles above the gaging station at Cotulla. The average annual discharge of the Nueces at Cotulla for a 38-year period was 199,100 acre-feet; however, the discharge for the water year October 1961 to September 1962 was only 2,950 acre-feet (U.S. Geological Survey, 1962, p. 353).

The Frio River drains an area of 5,491 square miles above the gaging station at Calliham. The average annual discharge of the Frio at Calliham for a 31-year period was 176,600 acre-feet, but the discharge for the water year October 1961 to September 1962 was only 14,280 acre-feet (U.S. Geological Survey, 1962, p. 367).

Climate

The records of the U.S. Weather Bureau at Dilley, which is 16 miles north-northeast of Cotulla and about 1 mile north of the La Salle-Frio county line, date from 1910 and provide the most complete climatological data for the report area. The average monthly data for precipitation, temperature, and evaporation from 1931 to 1960 are shown on Figure 2. During this period, the average annual precipitation was 22.63 inches. The monthly precipitation was lowest during January, February, March, and November, and highest during May and June. The average annual temperature was 70.9°F, and temperature was lowest in January, February, and December, and highest during June, July, and August. The average annual evaporation was 78.84 inches and evaporation was lowest and highest during the same months as the temperature. The growing season is about 286 days. The approximate dates for the last and first killing frosts are February 22 and December 5. Freezing weather generally is of short duration. The annual precipitation at Dilley during 1931-62, which is shown on Figure 3, ranged from 7.22 inches in 1956 to 36.05 inches in 1958.

Thornthwaite (1952, p. 25-35) classified the climate in conterminous United States by an index of moisture deficiency or surplus which was obtained from comparisons of the potential evapotranspiration with the precipitation. When precipitation is the same as potential evapotranspiration and water is available as needed, the climate is neither dry nor moist and is called subhumid. As the water surplus becomes larger with respect to the potential evaporation, the climate becomes more humid, and, conversely, as the water deficiency becomes larger, the climate becomes more arid. Most of the eastern half of Texas and part of the Texas Panhandle are in the subhumid belt, and the line separating the moist subhumid belt in eastern Texas from the dry subhumid belt

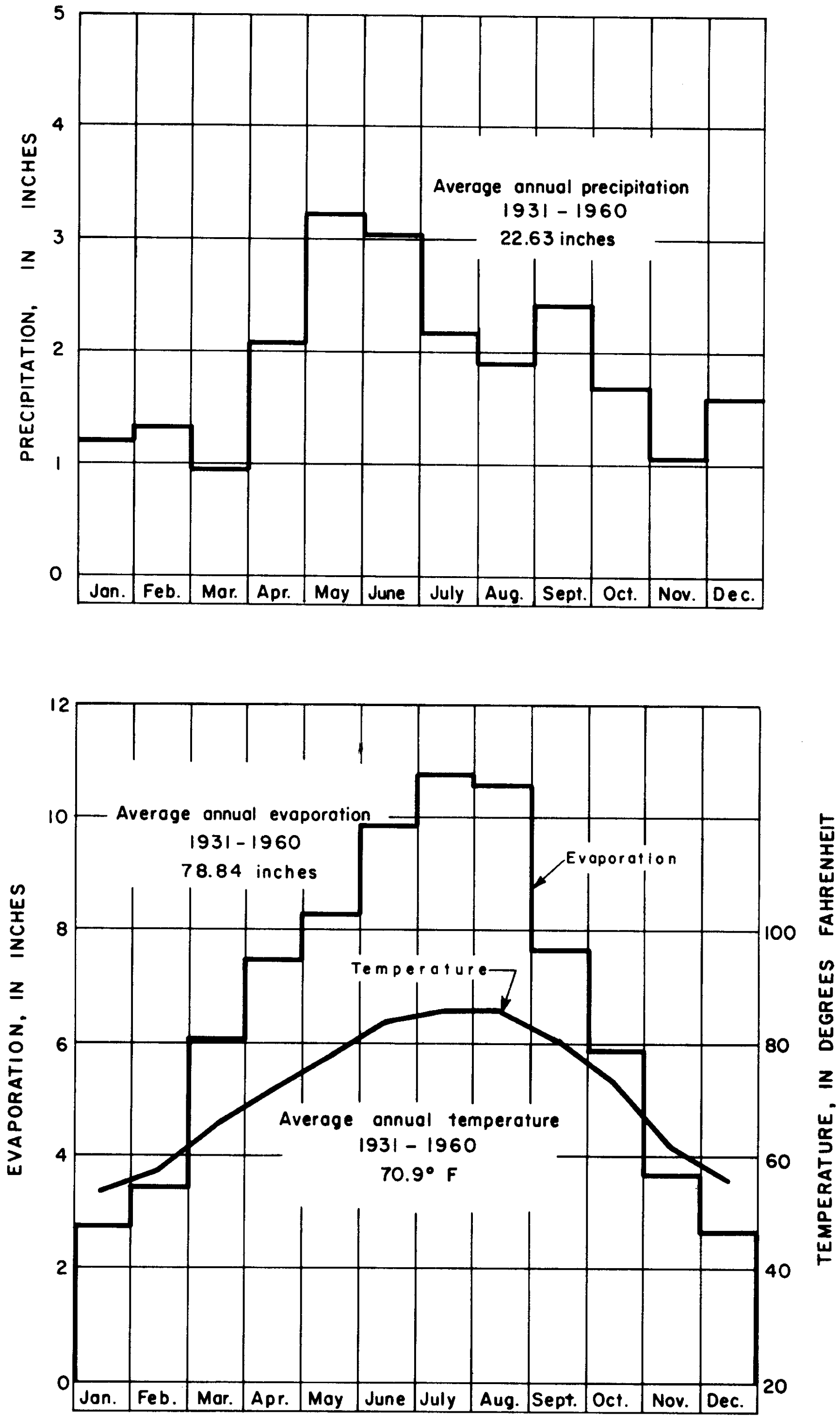

Figure 2
Monthly Precipitation, Evaporation, and Temperature at Dilley, Texas, 1931-60
(From records of the U.S. Weather Bureau)

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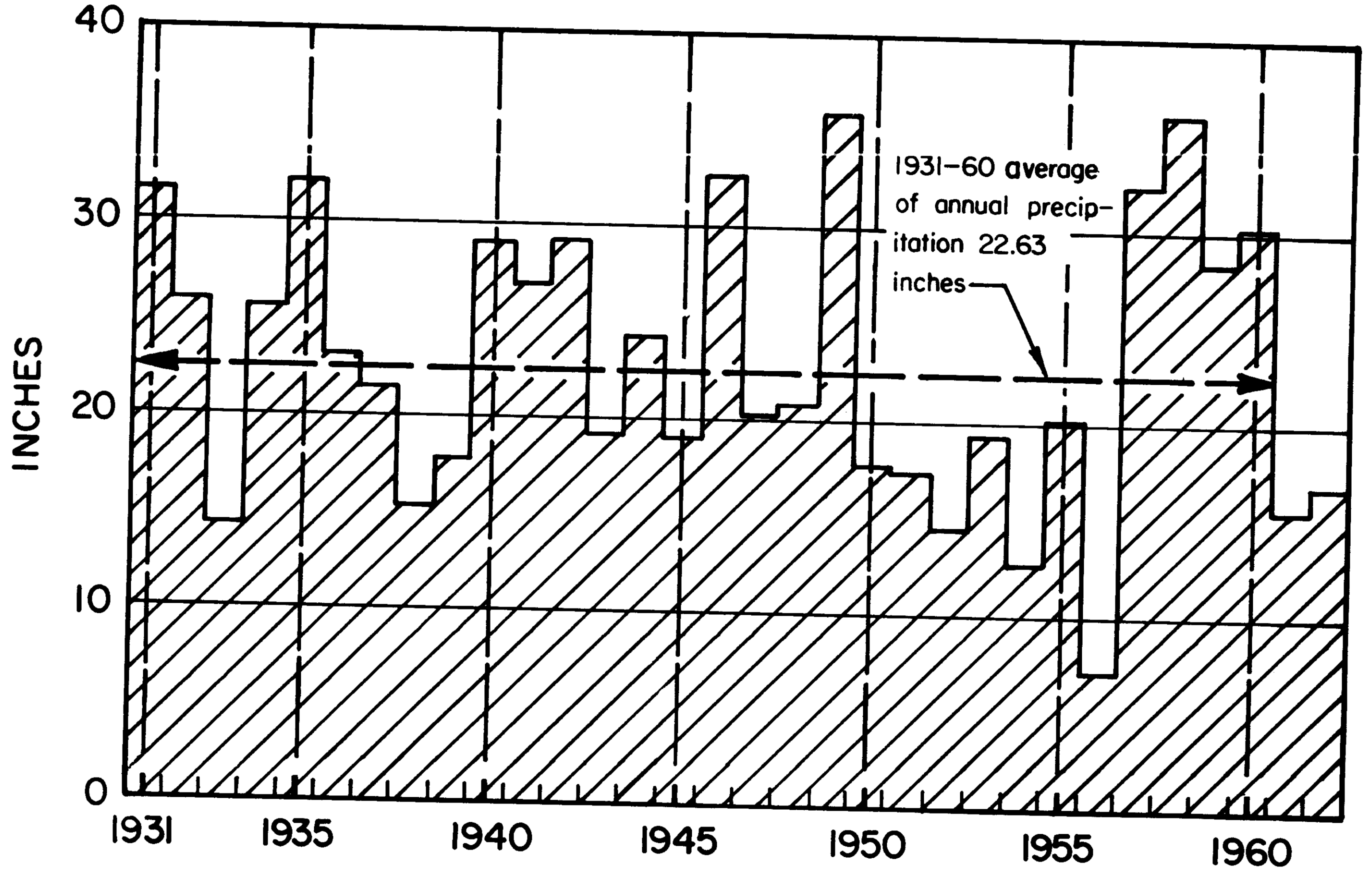

Figure 3

Annual Precipitation at Dilley, 1931-62

(From Records of the U.S. Weather Bureau)

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extends from Port Lavaca, which is 75 miles northeast of Corpus Christi, northward through Dallas. La Salle and McMullen Counties are in the semiarid belt but are close to the boundary line of the dry subhumid belt (Thornthwaite, 1952, fig. 30).

Acknowledgments

The author is indebted to the ranchers in La Salle and McMullen Counties for supplying information about their water wells and for permitting access to their properties, to the well drillers for logs and other information on water wells, and to the officials of the cities and towns and the State and Federal agencies, especially the Soil Conservation Service of the U.S. Department of Agriculture, and the county agricultural agents. Considerable help was received from D. Hoye Eargle, U.S. Geological Survey, and from the officials of the Atlantic Refining Co., Humble Oil and Refining Co., Phillips Drilling Co., Schlumberger Well Surveying Corp., and the Sun Oil Co. Valuable records used in this report had been previously collected by C. C. Mason, formerly of the U.S. Geological Survey, and F. L. Osborne of the Texas Water Commission.

GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

General Geology

The geologic formations discussed in this report range in age from Eocene to Recent. The thickness, lithology, and water-bearing characteristics of the formations are summarized in Table 1. The areal geology and the locations of selected wells are shown on Plate 1. The structure and thickness of the formations are shown on four geologic sections based on electric logs of wells (Plates 2, 3, 4, and 5).

The rocks consist mainly of alternating beds of sand and clay or shale, which crop out in belts that roughly parallel the coast. The oldest geologic unit discussed in this report, the Wilcox Group, crops out about 40 miles west and about 30 to 40 miles north of the La Salle-McMullen county area. East and south of the Wilcox outcrop, progressively younger formations are exposed. The formations dip to the southeast at an angle slightly greater than the slope of the land surface, and most of the formations thicken in the same direction. Ground water occurs under artesian conditions downdip in the Tertiary sands and under water-table conditions in the outcrops of the Tertiary sands and in the alluvial deposits along the major streams.

Physical Characteristics and Water-Bearing Properties of the Geologic Formations

In the descriptions of the water-bearing properties of the formations, the yields of wells are described according to the following rating:

Table 1.--Geologic formations and their water-bearing properties, La Salle and McMullen Counties

System	Series	Group	Geologic unit	Approximate thickness (feet)	Character of rocks	Water-bearing properties
Quaternary	Recent and Pleistocene		Alluvium	0-30	Terrace deposits of clay, sand, and gravel.	Yields small quantities of fresh water to wells.
Tertiary	Pliocene		Goliad Sand	0-50	Sand interbedded with gravel, sandy clay, and clay.	Not known to yield water to wells in the report area.
	Miocene(?) and Miocene		Lagarto Clay and Oakville Sandstone	280±	Clay, sandy clay, and thin beds of sand in upper part. Sand, sandstone, sandy clay, bentonitic clay, and volcanic ash in the lower part.	Yields small quantities of fresh to moderately saline water to wells.
	Miocene(?)		Catahoula Tuff	1,000-1,160	Primarily tuffaceous clay and tuff; locally contains sandy clay, tuffaceous sand and clay, bentonitic clay, and thin beds of sand and conglomerate.	Yields small quantities of slightly to moderately saline water to wells.
	Oligocene(?)		Frio Clay	450	Clay, sandy clay, and some sand. The clay contains bentonite and gypsum.	Not known to yield water to wells.
	Eocene	Jackson		1,140-1,260	Clay, sand, silt, bentonitic clay, and lignite.	Yields small quantities of slightly to moderately saline water to wells.
		Claiborne	Yegua Formation	1,000-1,200	Gypsiferous clay, sand, and thin beds of lignite.	Yields small quantities of slightly to moderately saline water to wells in outcrop.
			Cook Mountain Formation	450-780+	Clay and shale, glauconitic sand, and limestone concretions.	Yields small quantities of slightly saline water to wells in western La Salle County.
			Sparta Sand	150	Sand, medium to fine grained, contains clay beds.	Yields small to moderate quantities of fresh to slightly saline water to wells in western La Salle County.
			Mount Selman Formation: Weches Greensand Member	100-150	Clay, contains glauconite and thin beds of sand.	Not known to yield water to wells in La Salle and McMullen Counties.
			Mount Selman Formation: Queen City Sand Member	1,000-1,360	Sand, medium to fine grained, contains clay.	Yields large quantities of fresh to moderately saline water to wells.
			Mount Selman Formation: Reklaw Member	350-540+	Shale and sand, contains glauconite.	Not known to yield water to wells in La Salle and McMullen Counties.
			Carrizo Sand	600-1,300	Sand, medium to fine grained, contains thin beds of shale.	Yields large quantities of fresh to slightly saline water to wells.
		Wilcox		800-1,500+	Clay, shale, lenticular beds of sand, and discontinuous beds of lignite; clay and shale generally are gypsiferous.	Not known to yield water to wells in La Salle and McMullen Counties.

Description	Yield (gallons per minute)
Small	Less than 50
Moderate	50-500
Large	More than 500

In general, the chemical quality of the water is classified according to the dissolved-solids content, as follows (Winslow and Kister, 1956, p. 5):

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

Tertiary System

Eocene Series

Wilcox Group

The Wilcox Group crops out in a belt from 3 to 10 miles wide along the western boundaries of Dimmit and Zavala Counties, extending across the northwestern corner of Zavala County and the southern parts of Uvalde, Medina, and Bexar Counties. The outcrop area roughly makes an arc 30 to 40 miles west, northwest, and north of the report area. The Wilcox Group is composed of clay, shale, lenticular beds of sand, and discontinuous beds of lignite. The clay and shale generally contain gypsum. The thickness of the Wilcox Group in the report area ranges from about 800 feet to more than 1,500 feet. The depth to the top of the Wilcox ranges from about 3,100 feet in northwestern La Salle County to 9,000 feet in southeastern McMullen County. The electric logs of wells in La Salle and McMullen Counties indicate that the water in the Wilcox Group ranges from moderately to very saline. The Wilcox is not known to yield water to wells in the two-county area.

Claiborne Group

The Claiborne Group includes the Carrizo Sand, the Mount Selman Formation, the Sparta Sand, the Cook Mountain Formation, and the Yegua Formation. The Carrizo Sand is the most important aquifer in the report area; the Queen City Sand Member of the Mount Selman Formation and the Sparta Sand are aquifers of lesser importance. The Sparta Sand is the oldest stratigraphic unit that crops out in La Salle and McMullen Counties.

Carrizo Sand.--The Carrizo Sand overlies the Wilcox Group unconformably and crops out in a belt from 3 to 10 miles wide just east and south of the outcrop of the Wilcox Group. The depth to the top of the Carrizo ranges from about 1,800 feet in northwestern La Salle County to about 8,400 feet in southeastern McMullen County. Much of the Carrizo in the report area consists of light gray, medium- to fine-grained subangular sand and thin beds of shale. The sand generally contains very little calcium carbonate; however, large amounts were found in the drill cuttings from Well RX-77-40-301 in north-central La Salle County.

The thickness of the Carrizo ranges from about 600 feet in northwestern La Salle County to about 1,300 feet in southeastern La Salle County and south-central McMullen County. Part of the variation of the thickness of the Carrizo is due to its unconformable relationship with the Wilcox, but generally the thickness increases downdip (Plates 4 and 5). The base of the Carrizo shown on the cross sections was picked arbitrarily at the points on the electric logs where a sequence of thin sands overlies the alternating thicker shales and sands of the Wilcox. The dip of the top of the Carrizo is southeasterly and ranges from about 25 feet per mile in northwestern La Salle County to about 250 feet per mile in southeastern McMullen County, as shown by the contour map of the top of the Carrizo (Figure 4).

The Carrizo Sand yields large quantities of fresh to slightly saline water to wells. In McMullen County and southeastern La Salle County, the artesian pressure in the Carrizo is sufficient to cause the wells to flow.

Mount Selman Formation.--The Mount Selman Formation lies conformably on the Carrizo Sand and crops out in a belt from 6 to 30 miles wide east and south of the outcrop of the Carrizo Sand. The Mount Selman consists of sand, shale, and clay, and the thickness of the formation ranges from 1,450 to about 2,000 feet, thickening downdip toward the southeast. The depth to the top of the Mount Selman Formation ranges from near the land surface in northwestern La Salle County to about 3,600 feet in south-central McMullen County. The dip of the formation at the base is the same as the underlying Carrizo Sand; at the top it ranges from about 25 feet per mile in northwestern La Salle County to about 200 feet per mile in south-central McMullen County.

The three members of the Mount Selman Formation--the Reklaw, Queen City Sand, and Weches Greensand--can be recognized on electric logs and correlated across the report area (Plates 2, 3, 4, and 5).

The Reklaw Member of the Mount Selman Formation consists of shale and sand containing glauconite. Some of the sand in western and northwestern La Salle County occurs in thick beds; elsewhere in the report area, the beds of sand are thin. The thickness of the Reklaw ranges from 350 to more than 540 feet. The Reklaw is conformable on the underlying Carrizo Sand, and the dip of the Reklaw is about the same as the dip of the top of the Carrizo. The electric logs indicate that most of the water in the Reklaw is moderately to very saline. The Reklaw is not known to yield water to wells in La Salle and McMullen Counties.

The Queen City Sand Member of the Mount Selman Formation conformably overlies the Reklaw. The Queen City consists of medium- to fine-grained sand and shale. In western La Salle County, most of the lower part of the Queen City is composed of sand, and much of the upper part is shale. Elsewhere in the report area, the Queen City is composed of thick sand beds and a few shale beds. The thickness ranges from about 1,000 to 1,360 feet. The dip of the Queen City is southeasterly and ranges from about 25 to 250 feet per mile at the base and from about 25 to 200 feet per mile at the top (Figure 5). The Queen City yields large quantities of fresh to moderately saline water to wells. The water in the Queen City is under sufficient artesian pressure to cause most of the wells to flow.

The Weches Greensand Member, the uppermost member of the Mount Selman Formation, conformably overlies the Queen City Sand Member. The Weches consists of clay that contains large amounts of glauconite and beds of sand and sandy clay. In western La Salle County, the sand beds are relatively thick and comprise most of the thickness of the Weches; elsewhere the sands are thin. The thickness of the Weches ranges from about 100 to 150 feet. The dip is southeasterly and ranges from about 25 feet per mile in northwestern La Salle County to about 200 feet per mile in south-central La Salle County. The Weches Greensand Member is not known to yield water to wells in La Salle and McMullen Counties.

<u>Sparta Sand</u>.--The Sparta Sand, which conformably overlies the Weches Greensand Member of the Mount Selman Formation, crops out in the northwestern corner of La Salle County (Plate 1). The Sparta consists of medium- to very fine-grained subangular sand, with some clay in the lower third of the section. The Sparta is about 150 feet thick throughout most of La Salle and McMullen Counties; however, it pinches out completely in south-central McMullen County. With the exception of the area northwest of Cotulla, the dip of the Sparta is southeastward and ranges from about 25 feet per mile in northwestern La Salle County to about 200 feet per mile in south-central La Salle County (Figure 6). The Sparta yields small to moderate quantities of fresh to slightly saline water to wells in western La Salle County; elsewhere the water is too saline for most uses.

<u>Cook Mountain Formation</u>.--The Cook Mountain Formation unconformably overlies the Sparta Sand and crops out in a belt 5 to 12 miles wide extending across the northern, northwestern, and western parts of La Salle County (Plate 1). The Cook Mountain consists of clay and shale, sand, sandy clay, and limestone concretions. The clay is dark brown, dark gray, and in a few places dark green; the sand is light gray, medium to fine grained, subangular, and contains glauconite. The electric logs of wells in northwestern La Salle County show sands in the lower part of the Cook Mountain that have electrical properties similar to the sands in the underlying Sparta Sand. Elsewhere in the report area, the sands are thin and intercalated with the clays. The thickness of the Cook Mountain ranges from 450 feet in west-central La Salle County to more than 780 feet in south-central McMullen County. The Cook Mountain yields small quantities of slightly saline water to wells in the outcrop area in western La Salle County.

<u>Yegua Formation</u>.--The Yegua Formation, the youngest in the Claiborne Group, unconformably overlies the Cook Mountain Formation and crops out in a belt from 13 to 24 miles wide that extends from southwestern La Salle County to northwestern McMullen County (Plate 1). The Yegua consists of clay that contains gypsum,

sand, and thin beds of lignite. The thickness ranges from 1,000 to 1,200 feet. The Yegua yields only small quantities of slightly to moderately saline water to wells in the outcrop area.

Jackson Group

The Jackson Group, the youngest group of Eocene age, conformably overlies the Yegua Formation and crops out in a belt from 11 to 16 miles wide that extends from southeastern La Salle County to northeastern McMullen County (Plate 1). The upper part of the Jackson consists of tuffaceous sand, bentonitic clay, and a small amount of lignite; the lower part consists of clay, bentonitic clay, sandy or silty clay, thin sand beds, and a small amount of lignite. The thickness of the Jackson ranges from 1,140 to 1,260 feet. The Jackson yields only small quantities of slightly to moderately saline water to wells.

Oligocene(?) Series

Frio Clay

The Frio Clay, which unconformably overlies the Jackson Group, crops out in a belt from 3 to nearly 6 miles wide that extends from southwestern to northeastern McMullen County (Plate 1). The Frio consists of clay, sandy clay, and some sand. The clay contains bentonite and gypsum. The Frio is about 450 feet thick. It is not known to yield water to wells.

Miocene(?) Series

Catahoula Tuff

The Catahoula Tuff, which unconformably overlies the Frio Clay, crops out in a belt 6 to 10 miles wide extending from south-central to east-central McMullen County (Plate 1). The Catahoula consists mainly of tuffaceous clay and tuff; locally, it contains sandy clay, tuffaceous sand and clay, bentonitic clay, and thin beds of sand and conglomerate. The thickness of the Catahoula ranges from about 1,000 to 1,160 feet. The Catahoula Tuff yields small quantities of slightly to moderately saline water to wells.

Miocene and Miocene(?) Series

Lagarto Clay and Oakville Sandstone

In Karnes County about 30 miles northeast of the report area, Anders (1960, p. 27) described the Lagarto Clay (Miocene(?)) as lying unconformably on the Oakville Sandstone (Miocene) and the Oakville unconformably on the Catahoula Tuff. The Lagarto and Oakville, which are not differentiated in this report, crop out in a belt from 3 to 7 miles wide extending across the southeastern corner of McMullen County (Plate 1). These units are composed of clay, sandy clay, calcareous clay, and thin beds of sand in the upper part, and medium- to coarse-grained sand and sandstone, sandy clay, bentonitic clay, and small amounts of volcanic ash in the lower part. The total thickness of the Lagarto and Oakville in the report area is about 280 feet. The unit yields small quantities of fresh to moderately saline water to wells.

Pliocene Series

Goliad Sand

The Goliad Sand, which unconformably overlies the Lagarto Clay and Oakville Sandstone, crops out in the southeast corner of McMullen County (Plate 1). The Goliad consists of coarse- to fine-grained sand interbedded with gravel, sandy clay, and clay; it contains caliche at the outcrop. The Goliad is about 50 feet thick. It is not known to yield water to wells in the report area.

Quaternary System

Pleistocene and Recent Series

Alluvium

The principal alluvial deposits in La Salle and McMullen Counties are the flood-plain and stream-terrace deposits which occur in belts from 2 to 5 miles wide along the Nueces and Frio Rivers. The alluvium is not shown on the geologic map (Plate 1). The stream-terrace deposits, which are composed of clay, sand, and gravel about 30 feet thick, yield small quantities of fresh water to wells.

GROUND-WATER HYDROLOGY

The following discussion concerns the general principles of ground-water hydrology as they apply to the La Salle-McMullen county area. For a more comprehensive discussion of these and other hydrologic principles, the reader is referred to Meinzer (1923a, 1923b), Meinzer and others (1942), Todd (1959), Tolman (1937), and Wisler and Brater (1959); and for non-technical discussions, Leopold and Langbein (1960) and Baldwin and McGuinness (1963).

Source and Occurrence of Ground Water

The source of ground water in La Salle and McMullen Counties is precipitation on the land surface in these counties and in adjoining areas on the north and west. Most of the water from precipitation is evaporated at the land surface, transpired by plants, or retained by capillary forces in the soil; only a small part migrates downward by gravity through the zone of aeration or essentially dry sediments until it reaches the zone of saturation where the rocks are saturated with water. In the zone of saturation, water is contained in the interstices or pore spaces between the rock particles, such as sand grains and gravel. Sand is the dominant type of sediment composing the aquifers in the report area. The upper surface of the zone of saturation is the water table.

Water-bearing rock units, or aquifers, are classified into two types--water table, or unconfined aquifers, and artesian, or confined aquifers. Unconfined water occurs where the upper surface of the zone of saturation is under atmospheric pressure only and the water is free to rise or fall in response to the changes in the volume of water in storage. Water-table conditions occur in the outcrops of the Tertiary sands in and around La Salle and McMullen Counties and in the alluvial deposits along the major streams. A well penetrating an aquifer under water-table conditions becomes filled with water to the level of the water table.

Confined water occurs where an aquifer is overlain by sediments of lower permeability that confine the water under a pressure greater than atmospheric. Such artesian conditions occur downdip from the outcrops of the Tertiary aquifers in the report area. A well penetrating sands under artesian pressure becomes filled with water to a level above the top of the aquifer, and, if the pressure head is large enough to cause the water in the well to rise to an altitude greater than that of the land surface, the well will flow. Flowing wells are more common at lower altitudes, especially in the valleys of the larger streams. The level or surface to which water will rise in artesian wells is called the piezometric surface. Although the terms water table and piezometric surface are synonomous in the outcrop areas, the term piezometric surface as used in this report is applicable only in artesian areas.

Recharge, Movement, and Discharge of Ground Water

Aquifers may be recharged by either natural or artificial processes. Natural recharge results from the infiltration of precipitation, either where it falls or from runoff enroute to a water course and from the infiltration of water from streams and lakes. Any subsequent transfer of water from one aquifer to another is not a primary source of recharge but only an incident of underground water movement. Artificial-recharge processes include infiltration of irrigation water, industrial waste water, and sewage. Improperly treated waste water and sewage may contaminate the supply of fresh ground water, especially at shallow depths.

Many factors govern the rate of natural recharge--the type of soil, the duration and intensity of rainfall, the slope of the land surface, and the presence or absence of a cover of vegetation are among the most important. In general, the greater the precipitation on the outcrop area of an aquifer, the greater the recharge, but the duration and intensity of rainfall are also factors of considerable importance. A given amount of rainfall during a short period usually results in less recharge than the same amount of rainfall during a longer period. Also, the rates of recharge can be greater during the winter months when plant growth is at a minimum and evaporation rates are low (Figure 2).

The sandy soil and generally poor cover of vegetation on the outcrop of the Carrizo Sand are favorable to recharge. Based on data on recharge in the Winter Garden district (Turner and others, 1960, p. 62-65), the recharge to the part of the Carrizo Sand supplying La Salle and McMullen Counties is estimated at 50,000 acre-feet per year. However, the discharge from the Carrizo (mostly for irrigation) in the area between the outcrop and La Salle and McMullen Counties was estimated as 130,000 acre-feet in 1961 (Alexander, Myers, and Dale, 1963, table 15), which indicates an overdraft of approximately 80,000 acre-feet. The overdraft, which has occurred for a number of years, is probably the major factor contributing to the decline of artesian pressure in the Carrizo in La Salle and McMullen Counties (Figures 9 and 10), where the withdrawals from the Carrizo are relatively small--an estimated 4,300 acre-feet in 1962 (Table 4).

In La Salle and McMullen Counties, ground water moves through the sand aquifers from areas of recharge to areas of discharge at a slow rate, perhaps a few hundred feet per year. The force of gravity is responsible for the initial infiltration and the downward movement of the water to the zone of saturation. After reaching the zone of saturation, the movement of the water generally has a large and almost horizontal component in the direction of decreasing pressure head generally toward the southeast in the direction of the dip of the aquifers. However, the movement is rarely uniform in direction or velocity. The flow is greatest along routes of least resistance, such as unconsolidated sand, and least in masses of sediment having relatively low permeability, such as cemented sand or clay. Except where heavily pumped, the deep aquifers, such as the Carrizo Sand, are under greater artesian pressure than the overlying aquifers, such as the Sparta Sand. In response to the differences in pressure, water may move slowly upward from the deep aquifers through the less permeable confining beds to the overlying aquifers (Winslow, Doyel, and Wood, 1957, p. 387); another possibility is the upward movement of the water along fault planes. The samples of fresh water from three wells tapping the Queen City Sand Member of the Mount Selman Formation in northern McMullen County (SU-78-20-801, SU-78-26-502, and SU-78-36-203 in Table 6) are comparable in mineral content to samples of the fresh water from the underlying Carrizo Sand, and they indicate possible upward movement of water from the Carrizo.

The water in the aquifers in the report area is discharged both naturally and artificially. The only apparent natural discharge is the water evaporated from the soil or transpired by plants; no perennial springs were reported in La Salle and McMullen Counties. The artificial discharge of ground water is from flowing or pumped wells, which is described in a following section on the development of the ground-water resources.

Hydraulic Characteristics of the Aquifers

When water is discharged from an aquifer through a well, a hydraulic gradient in the water table or piezometric surface is established toward the well. When a well is pumped or allowed to flow, the level of the water table or piezometric surface is lowered; the difference between the discharging level and the static level (water level before pumping or before start of flow) is the drawdown. The water table or piezometric surface surrounding a discharging well assumes more or less the shape of an inverted cone which is called the cone of depression.

The rate at which water is transmitted by an aquifer depends on the ability of the aquifer to transmit water and the hydraulic gradient. The amount of water released from storage depends chiefly on the elasticity and compressibility of the sands and their associated clays, and the expansion of the water as the artesian pressure is lowered.

Formulas have been developed to show the relationship among the yield of a well, the shape and extent of the cone of depression, and the properties of the aquifer--the specific yield, porosity, permeability or transmissibility, and storage. The specific yield is the ratio (expressed as a percentage) of the volume of water a saturated rock will yield by gravity to its own volume.

Porosity is the ratio (in percent) of the aggregate volume of pore space in a rock to its total volume. The permeability of an aquifer is the capacity for transmitting water under pressure and is measured by the coefficient of permeability--the rate of flow in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot (100 percent). The coefficient of transmissibility is the rate of flow in gallons per day through a vertical strip of the aquifer 1 foot wide and extending the full saturated thickness of the aquifer under a hydraulic gradient of 100 percent.

The coefficient of storage is the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. When artesian conditions prevail, the coefficient of storage is a measure of the ability of the aquifer to yield water from storage by the compression of the aquifer and the expansion of the water as the artesian pressure is lowered. The coefficients of storage in artesian aquifers are small compared to those in water-table aquifers; consequently, when an artesian well starts discharging, a cone of depression is developed through a wide area in a short time. Where water-table conditions prevail, the coefficient of storage is a measure of the ability of the aquifer to yield water from storage by gravity drainage of the aquifer; consequently, the cone of depression extends through a relatively small area. Under water-table conditions, the volume of water attributable to expansion is usually such a negligible part of the total volume of water released from the aquifer that the coefficient of storage is considered the same as the specific yield.

Formulas based on the hydraulic characteristics of an aquifer indicate that within limits the discharge from a well varies directly with the drawdown--that is, doubling the drawdown will double or nearly double the amount of discharge. The discharge per unit of drawdown (gallons per minute per foot), or specific capacity, is of value in estimating the probable yield of a well.

The yield of a well usually is measured in gallons per minute or gallons per hour. Yield depends on the ability of the aquifer to transmit water, the thickness of the water-bearing material, the construction of the well, the size and efficiency of the pump, and the allowable drawdown.

Aquifer tests were made in eight wells in La Salle County to determine the ability of the aquifers to transmit and store water; no tests were made in McMullen County. The results of the tests are given in Table 2. The data from the tests were analyzed using the Theis non-equilibrium method as modified by Cooper and Jacob (1946, p. 526-534) and the Theis recovery method (Wenzel, 1942, p. 94-97). The coefficients of transmissibility determined from tests of 5 wells tapping the Carrizo Sand ranged from 8,200 to 46,000 gpd (gallons per day) per foot, and from tests of 3 wells tapping the Sparta Sand, the coefficients of transmissibility were 1,100, 1,500, and 3,500 gpd per foot. A coefficient of storage of 0.00019 was obtained from the test of one well tapping the Carrizo Sand. The discharge rates of the 8 wells tested ranged from 22 to 1,000 gpm (gallons per minute), and the specific capacities ranged from 0.3 to 20.4 gpm per foot.

The coefficients of transmissibility and storage may be used to predict future drawdown of water levels caused by pumping. Figure 7 shows the theoretical relation between drawdown or decline of water level and the distance from the center of pumping for different coefficients of transmissibility. The calculations of drawdown are based on a withdrawal of 1 mgd (million gallons per day) for 1 year, a storage coefficient of 0.0002, and coefficients of

Table 2.--Results of aquifer tests in La Salle County

Geologic source	Well	Producing interval (depth, in feet)	Average discharge during test (gpm)	Coefficient of trans-missibility (gpd/ft)	Specific capacity (gpm/ft)	Coef-ficient of storage	Water temper-ature (F°)	Remarks
Carrizo Sand	RX-77-30-801	1,800 - 2,051	--	46,000	20.4	0.00019	104	Drawdown in observation well.
Do.	RX-77-30-802	1,740 - 2,030	1,000	35,000	17.7	--	104	Recovery of pumped well.
Do.	RX-77-39-401	2,100 - 2,483	165	8,200	3.7	--	107	Do.
Do.	RX-77-56-801	3,400 - 3,500	110	9,100	3.0	--	126	Do.
Do.	RX-78-25-801	2,500 - 3,000	155	29,000	6.3	--	115	Do.
Sparta Sand	RX-77-46-803	300 - 600	570	3,500	2.0	--	80	Do.
Do.	RX-77-55-701	700 - 800	22	1,500	1.6	--	86	Recovery of flowing well.
Do.	RX-77-62-701	340 - 580	110	1,100	.3	--	85	Recovery of pumped well.

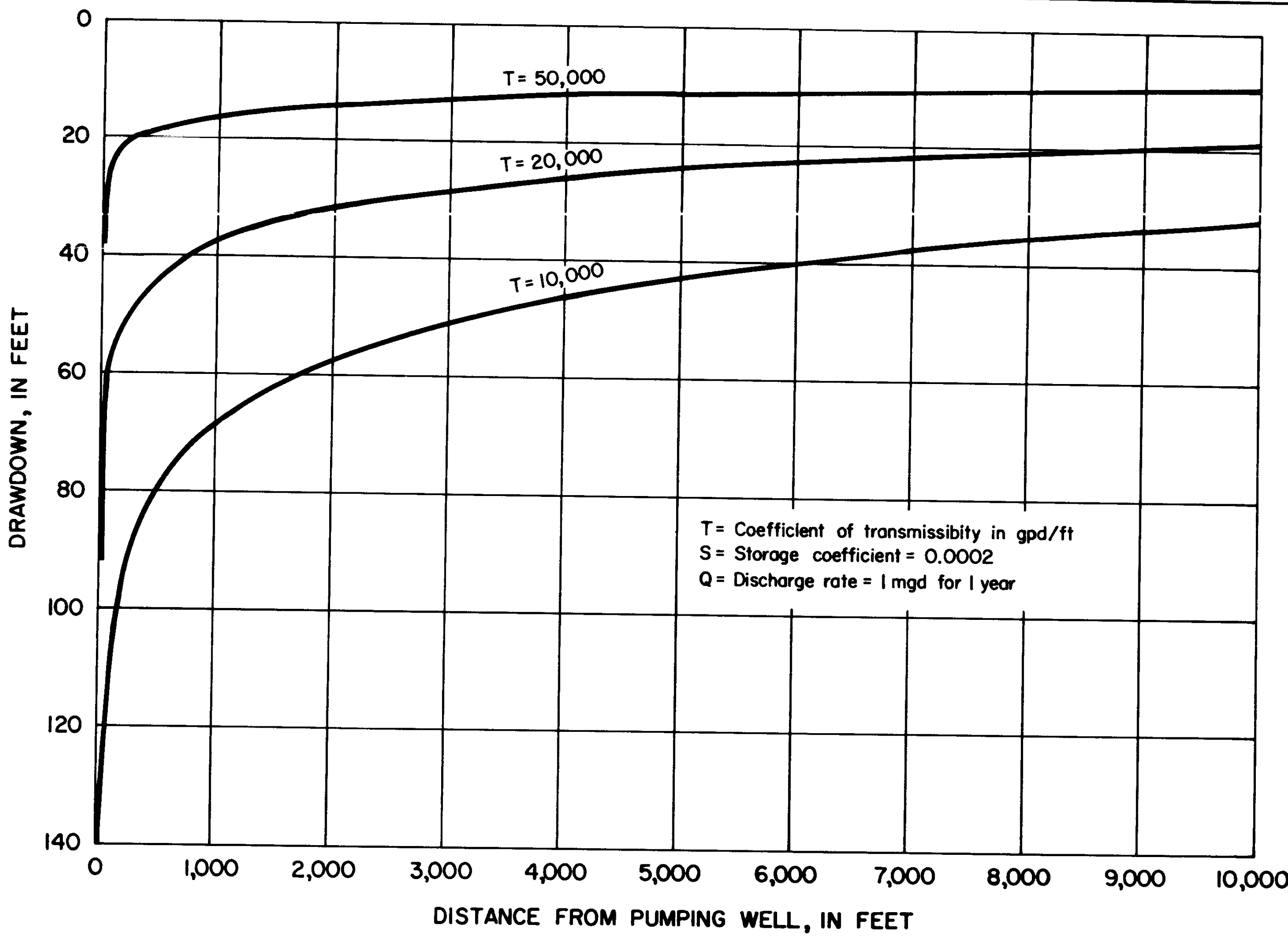

Figure 7

Relation of Drawdown to Transmissibility in an Infinite Aquifer

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transmissibility of 10,000, 20,000, and 50,000 gpd per foot. The figure shows that the amount of drawdown will increase with the decrease in the value of the coefficient of transmissibility. For example, at a point 5,000 feet from the discharging well, the drawdown would be 11 feet 1 year after the start of pumping, if the coefficient of transmissibility is 50,000 gpd per foot; 24 feet, if the coefficient of transmissibility is 20,000 gpd per foot; and 43 feet, if the coefficient of transmissibility is 10,000 gpd per foot.

Figure 8 shows the relation of drawdown to time as a result of pumping from an artesian aquifer of infinite areal extent. Pumping is assumed to be at a constant rate of 1 mgd (million gallons per day), the storage coefficient is 0.0002, and the coefficient of transmissibility is 25,000 gpd per foot. The figure shows that the rate of drawdown decreases with time. For example, at a point 1,000 feet from the pumped well, the drawdown will be 12 feet after 1 day of pumping, 19 feet after 10 days, about 23 feet after 30 days, 30 feet after 1 year, 38 feet after 10 years, 43 feet after 50 years, and 45 feet after 100 years. The dashed line on Figure 8 is the equilibrium curve for the situation where the pumped well is 25 miles from the outcrop of the aquifer. For example, after the effect of pumping has reached the outcrop, the discharge of 1 mgd will result in a drawdown of 36 feet at a point 1,000 feet from the pumped well, and the drawdown will remain indefinitely at 36 feet if the rate of recharge equals the transmission capacity of the aquifer.

Pumping from wells drilled close together may create cones of depression that intersect, thereby causing additional lowering of the piezometric surface or water table. The intersection of cones of depression, or interference between wells, will result in lower pumping levels (and increased pumping costs) and may cause serious declines in yields of the wells. If the pumping level is lowered below the top of the well screen, that part of the aquifer will become dewatered, and the yield of the well will decrease with the decrease in the thickness of the saturated part of the aquifer. The proper spacing of wells to minimize interference can be determined from the aquifer-test data.

Development of Ground Water

In 1962, about 5.7 mgd, or 6,400 acre-feet, of ground water was used in La Salle and McMullen Counties. Table 3 shows the amount of water used for public supply, industrial, irrigation, and domestic and stock uses in 1962. In addition to the amount shown in the table, approximately 50,000 gpd (56 acre-feet per year) of ground water was lost from uncontrolled flowing wells.

The use of ground water from the principal aquifers in La Salle and McMullen Counties in 1962 is shown in Table 4. The table does not include the pumpage from the less important water-bearing formations, most of which would be for domestic and stock use.

Records of 252 water wells were obtained during the ground-water investigation of La Salle and McMullen Counties (Table 5). Of these, 166 wells were used for domestic and stock purposes, 8 for public supply, 4 for industrial purposes, 31 for irrigation, and 43 wells were not being used. The inventory included most of the domestic and stock wells, and all the public supply, industrial, and irrigation wells. Locations of the water wells inventoried and 292 oil and gas tests are shown on Plate 1.

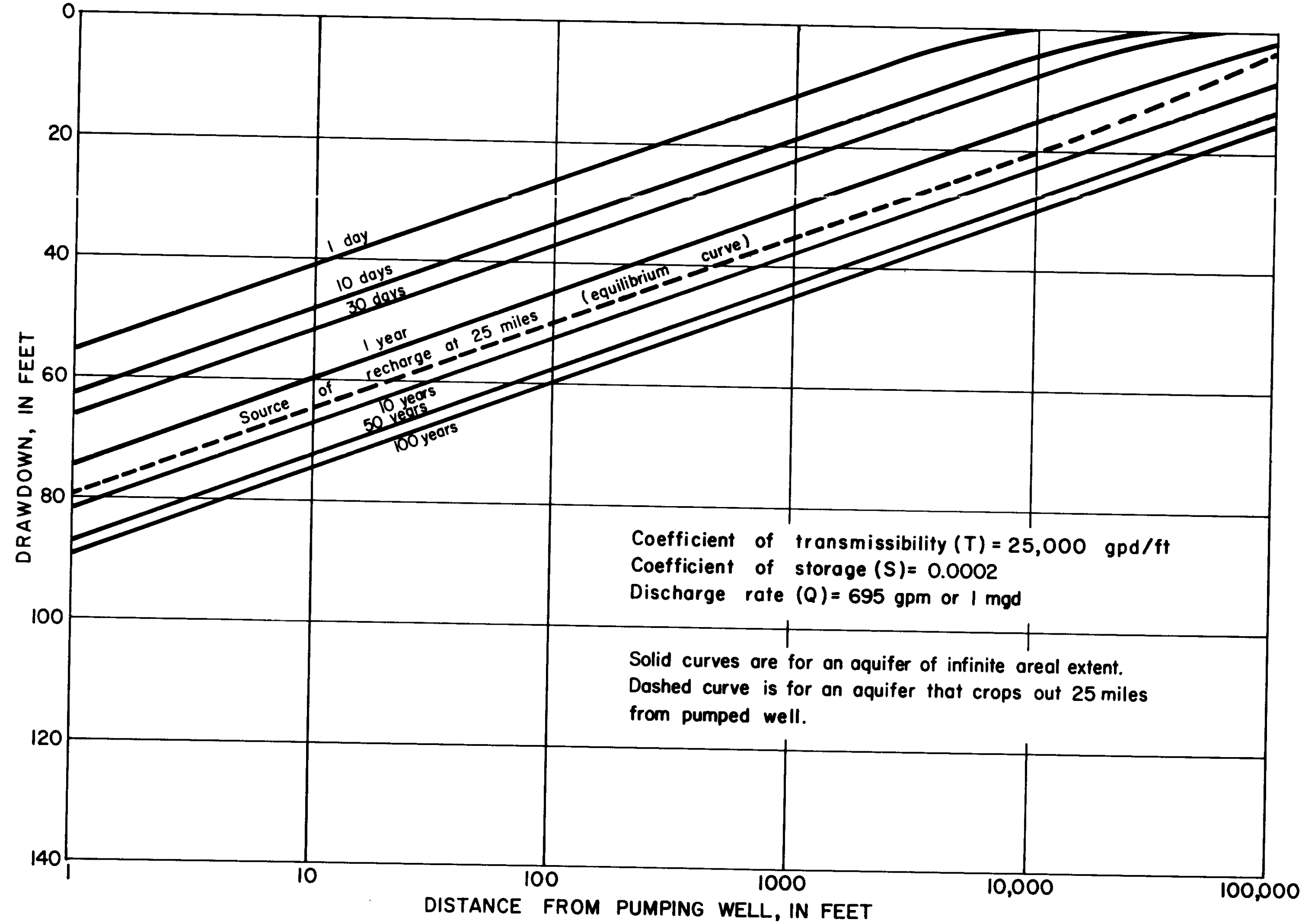

Figure 8

Relation of Drawdown to Time

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Table 3.--Use of ground water in La Salle and McMullen Counties, 1962

Use	La Salle County		McMullen County		Totals*	
	Mgd	Acre-feet	Mgd	Acre-feet	Mgd	Acre-feet
Public supply	0.67	751	0.02	22	0.69	770
Industrial	--	--	.05	56	.05	56
Irrigation	3.57	4,000	--	--	3.60	4,000
Domestic and stock	.85	953	.54	605	1.40	1,600
Totals*	5.10	5,700	.61	680	5.70	6,400

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

Table 4.--Use of ground water from the principal aquifers in La Salle and McMullen Counties, 1962

Geologic source	Public supply		Industrial		Irrigation		Totals*	
	Mgd	Acre-feet	Mgd	Acre-feet	Mgd	Acre-feet	Mgd	Acre-feet
Carrizo Sand	0.62	695	0.05	56	3.12	3,500	3.80	4,300
Queen City Sand Member of Mount Selman Formation	.02	22	--	--	--	--	.02	22
Sparta Sand	.05	56	--	--	.45	500	.50	560

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

Public Supply

Ground water used for public supply in La Salle and McMullen Counties in 1962 amounted to 0.69 mgd, or 770 acre-feet, for the year, which represents about 12 percent of the ground water used for all purposes. The use of water for public supply in 1962 was less than that used during the drought years of 1947-56 when an estimated 1.13 mgd, or 1,300 acre-feet per year, was pumped.

The city of Cotulla used an average of 0.60 mgd in 1962, or about 673 acre-feet for the year, representing about 87 percent of the water pumped for public supply in the report area. The water is obtained from the Carrizo Sand from 3 wells (2,300, 2,370, and 2,483 feet deep); reported discharges were 400, 1,000, and 700 gpm, respectively, and the temperatures of the water were 104°, 107°, and 108°F, respectively.

The city of Tilden in 1962 used an average of 0.02 mgd, or about 22 acre-feet for the year. The water is obtained from the Carrizo Sand from a well 4,250 feet deep which had a reported flow of 1,000 gpm on March 3, 1959. The temperature of the water was 144°F.

The city of Fowlerton in 1962 used an average of 0.02 mgd, or about 22 acre-feet for the year. The water is obtained from the Queen City Sand Member of the Mount Selman Formation from a flowing well 1,857 feet deep. The temperature of the water was 99°F.

The city of Encinal in 1962 used an average of 0.05 mgd, or about 56 acre-feet for the year. The water is obtained from the Sparta Sand from a well 500 feet deep.

Industry

The quantity of ground water used by industry in La Salle and McMullen Counties in 1962 was only a small part of that used for all purposes. A natural gas compressor station about 4 miles south of Tilden used an average of 0.05 mgd, or about 56 acre-feet, for the station and employees' domestic needs. The water was obtained from the Carrizo Sand from a flowing well 4,700 feet deep. The temperature of the water was 148°F.

The only other water used for industrial purposes in 1962 consisted of relatively small quantities of water from three wells used to repressure oil and gas reservoirs.

Irrigation

In 1962, an estimated 4,000 acre-feet (3.57 mgd) of ground water was used for irrigation in La Salle County, which represents about 62 percent of the ground water used for all purposes. No ground water was used for irrigation in McMullen County. The drought from 1947 to 1956 increased the use of ground water for irrigation. Of the 31 irrigation wells inventoried, 5 were drilled before 1947, 20 were drilled during the drought, and 6 were drilled after 1956. The principal crops irrigated from wells include peanuts, grain sorghum, vegetables, cotton, and pasture.

An estimated 2,800 acres in northern La Salle County was irrigated in 1962 from wells tapping the Carrizo Sand. These wells supplied about 3,500 acre-feet of water, which is about 55 percent of the ground water used for all purposes. The depths of the irrigation wells ranged from about 1,900 feet in the northwestern part of the county to about 3,400 feet in the northeastern part; the water levels ranged from above the land surface at flowing wells to more than 150 feet below the land surface. The discharge rates ranged from 30 gpm from a flowing well to about 1,800 gpm from pumped wells; however, only two wells pumped more than 1,000 gpm. The depths to the pumps ranged from 150 to 400 feet below the land surface.

An estimated 400 acres in western La Salle County was irrigated in 1962 from wells tapping the Sparta Sand. These wells supplied an estimated 500 acre-feet of water, which represents about 8 percent of the ground water used for all purposes. The depths of the wells ranged from 500 to about 750 feet; the water levels ranged from 30 to about 130 feet below land surface, and the discharge rates ranged from 110 to 350 gpm. The depths to the pumps ranged from 200 to 450 feet below the land surface.

Domestic and Stock

The estimate of 1.40 mgd, or 1,600 acre-feet, of ground water used in 1962 for domestic and livestock needs was based on agricultural and population census data. The depths of the domestic and stock wells ranged from about 30 feet in dug wells to 5,200 feet in a flowing well that was originally drilled as an oil test. Generally, the depths of the wells supplying domestic and livestock needs are not more than several hundred feet; however, a number of deep oil tests have been plugged back to the Carrizo Sand and converted to water wells for livestock and domestic supplies. (See Table 5.) With the exception of the Frio Clay and the Goliad Sand, which are not known to yield water to wells, the stratigraphic units younger than the Sparta Sand (Table 1) supply a large part of the ground water for domestic and livestock uses.

Changes in Water Levels

Long-term records of water-level fluctuations in wells in La Salle and McMullen Counties are not available; however, since 1959, the Texas Water Commission has maintained a network of water-level observation wells. Hydrographs of water levels in 11 wells tapping the Carrizo Sand in La Salle County and one in McMullen County for the period 1959 to 1962 or 1963 are shown in Figures 9 and 10. Wells RX-78-18-702 and RX-78-26-802, both in northeastern La Salle County, and Well SU-78-28-501 in north-central McMullen County (Figure 10) are in areas where the withdrawals from the Carrizo Sand are very small. The declines of water levels in these wells were caused chiefly by withdrawals in the heavily irrigated areas to the north and northwest. The remaining 9 hydrographs show declines of water levels in 1961 and 1962; the largest declines were in Wells RX-77-29-901, RX-77-31-703, and RX-77-38-201, all in northwestern La Salle County, where withdrawals from the Carrizo are the greatest in the report area. However, even in this area, part of the declines have resulted from withdrawals in neighboring Dimmit, Zavala, and Frio Counties. The rise of water levels in most of the wells during 1959 and 1960 is related to the above-average precipitation during these years (Figure 3), which resulted in less withdrawal of ground water for irrigation than during 1961 and 1962 when precipitation was below average.

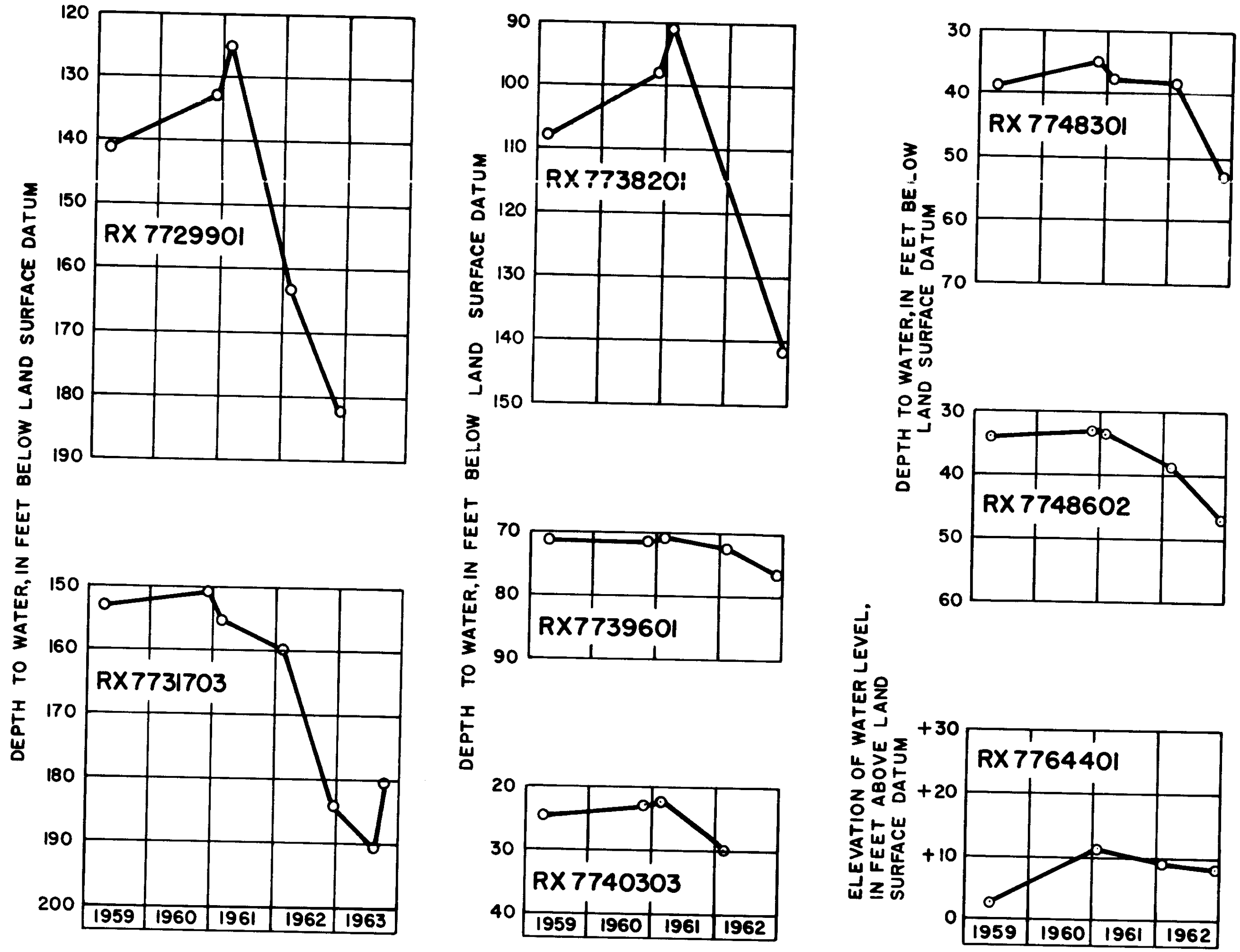

Figure 9

Hydrographs of Water Levels in Wells Tapping the Carrizo Sand in La Salle County

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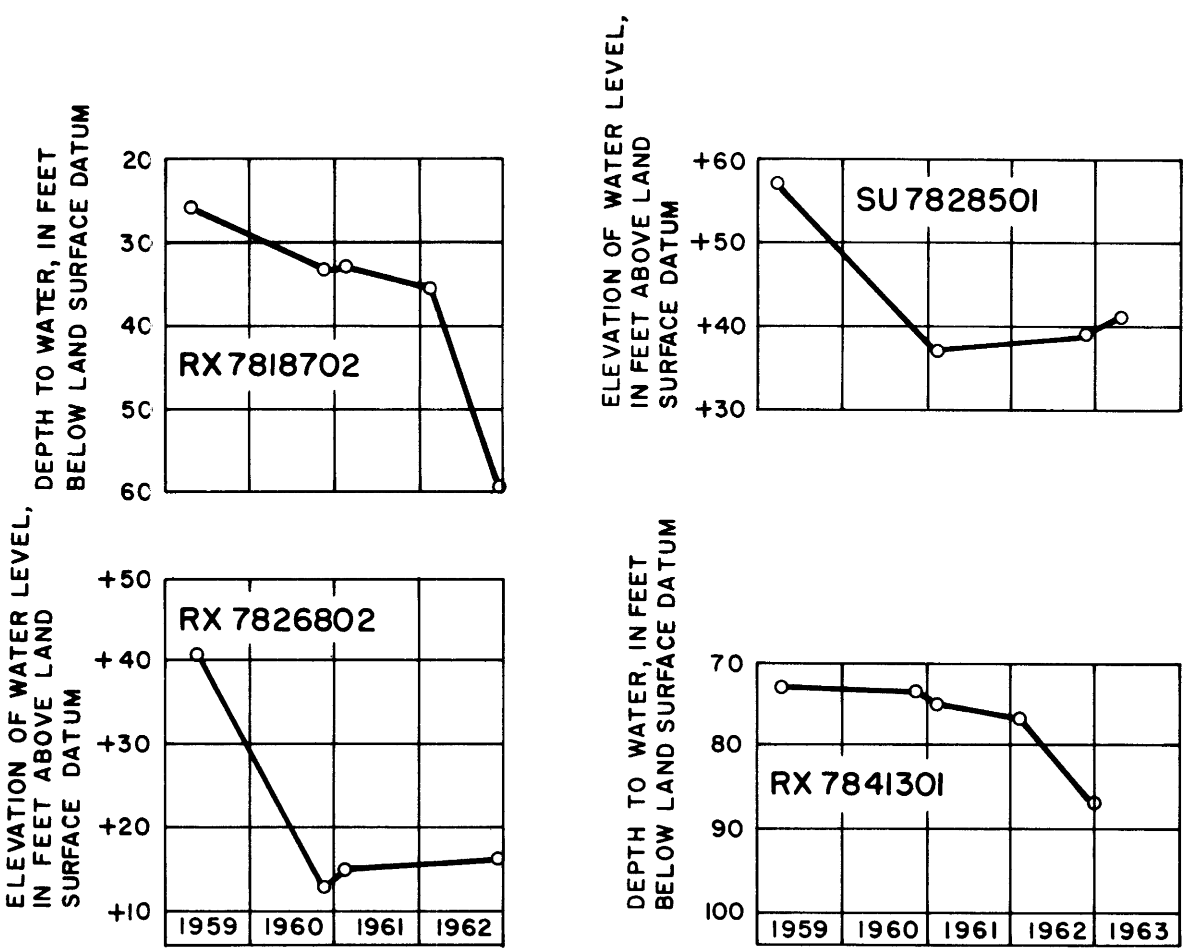

Figure 10

Hydrographs of Water Levels in Wells Tapping the Carrizo Sand in La Salle and McMullen Counties

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Construction of Wells

Almost all the water wells in La Salle and McMullen Counties are drilled wells; the few exceptions are wells about 30 feet deep that were dug in the alluvial deposits of the Nueces and Frio Rivers. The casings used in the drilled wells range in diameter from 4 to 14 inches. Casings from 4 to 6 inches in diameter are the sizes commonly used in wells drilled for domestic and stock supplies; the larger-diameter casings are necessary to accommodate the deep-well turbine pumps that supply larger quantities of water for irrigation, public supply, and industrial needs. In many wells, large-diameter casing is set in the upper part of the hole and the size is reduced in the lower part. In most of the wells, slotted casings are installed opposite the water-bearing sands, but in a few wells, screens are used for this purpose. Gravel packing is uncommon in La Salle and McMullen Counties. A number of unsuccessful oil or gas test wells have been plugged back to the base of the Carrizo Sand and completed as water wells by gun perforating the casing opposite the Carrizo Sand.

QUALITY OF GROUND WATER

The chemical constituents of ground water originate principally from the soil and rocks through which the water has moved; most of the differences in the chemical character of the water in the La Salle-McMullen County area reflect the differences in the mineral content of the geologic formations that have been in contact with the water. Generally, the chemical content of ground water increases with depth. The temperature of ground water near the land surface is generally about the same as the mean air temperature of the region and increases with depth. The chemical analyses of water from 130 wells in the report area are given in Table 6, and the temperatures of the water samples are given in Table 5.

The major factors that determine the suitability of a water supply are the limitations imposed by the contemplated use of the water. Various criteria of water-quality requirements have been developed that include: bacterial content; physical characteristics, such as temperature, odor, color, and turbidity; and chemical constituents. Usually, the bacterial content and the undesirable physical properties can be alleviated economically, but the removal of undesirable chemical constituents can be difficult and expensive. For many purposes, the dissolved-solids content is a major limitation on the use of the water. A general classification of water according to the dissolved-solids content was given in the table on page 13.

The U.S. Public Health Service has established and periodically revises standards of drinking water to be used on common carriers engaged in interstate commerce. The standards are designed to protect the traveling public and may be used to evaluate domestic and public water supplies. According to the standards, chemical constituents should not be present in a public water supply in excess of the listed concentrations shown in the following table, except where other more suitable supplies are not available. Some of the standards adopted by the U.S. Public Health Service (1962, p. 7-8) are as follows:

Substance	Concentration (parts per million)
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 naturally present 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 (obtained for a minimum of 5 years) (°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

For the 5-year period, 1958-62, the annual average of the maximum daily air temperatures at Cotulla ranged from 80.9 to 85.9°F and averaged 82.8°F; for the same period at Tilden the range was from 80.8 to 85.2°F and the average was 82.3°F. Consequently, the recommended control limits of fluoride concentrations in the report area range from 0.6 to 0.8 ppm (parts per million). Of the 64 water samples analyzed for fluoride, 19 contained amounts more than 0.8 ppm. Excessive concentrations of fluoride in water may cause teeth of young children to become mottled; however, optimum concentrations of fluoride may reduce the incidence of tooth decay (Dean, Arnold, and Elvove, 1942, p. 1155-1179). The optimum fluoride level for a given community depends on climatic conditions because the amount of water (and consequently the amount of fluoride) ingested by children is primarily influenced by air temperature.

Concentrations of nitrate in excess of 45 ppm in water used for infant feeding have been related to the incidence of infant cyanosis (methomoglobinemia or "blue baby" disease), a reduction of the oxygen content in the blood constituting a form of asphyxia (Maxcy, 1950, p. 271). High concentrations of nitrate may be an indication of pollution from organic matter, commonly sewage. Of the 118 water samples analyzed for nitrate, only three contained amounts of more than 45 ppm.

Excessive concentrations of iron and manganese in water cause reddish-brown or dark gray precipitates that discolor clothes and stain plumbing fixtures. Iron appears to be a problem in the La Salle-McMullen county area. Of 64 iron determinations, 33 were in excess of 0.3 ppm.

Water having a chloride content exceeding 250 ppm may have a salty taste. Such concentrations are common in La Salle and McMullen Counties especially in the deeper parts of the principal aquifers where the water is slightly or moderately saline.

Sulfate in water in excess of 250 ppm may produce a laxative effect. High concentrations of sulfate are common in much of the slightly and moderately saline water in the two-county area.

Calcium and magnesium are the principal constituents in water that cause hardness. Excessive hardness causes increased consumption of soap and induces the formation of scale in hot water heaters and water pipes. A commonly accepted classification of water hardness is given in the following table:

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

The hardness as calcium carbonate in the 130 water samples ranged from 3 to 2,400 ppm; however, the hardness was less than 60 ppm in samples collected from 45 wells tapping the Carrizo Sand.

Water used for industry may be classified into three categories--process water, cooling water, and boiler water. Process water is the term used for the water incorporated into or in contact with the manufactured products. The quality requirements for this use may include physical and biological factors in addition to chemical factors. Water for cooling and boiler uses should be noncorrosive and relatively free of scale-forming constituents. The presence of silica in boiler water is undesirable because it forms a hard scale or encrustation, the scale-forming tendency increasing with the pressure in the boiler. The following table shows the maximum suggested concentrations of silica for water used in boilers (Moore, 1940, p. 263):

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

The silica content in the water samples from 127 wells in the report area ranged as follows: from 9 to 20 ppm in 43 samples; from 21 to 40 ppm in 50 samples; and from 41 to 108 ppm in 34 samples.

Several factors other than the chemical quality are involved in determining the suitability of water for irrigation purposes. The type of soil, adequacy of drainage, crops grown, climatic conditions, and quantity of water used all have important bearing on the continued productivity of irrigated land.

A classification commonly used for judging the quality of a water for irrigation was proposed in 1954 by the U.S. Salinity Laboratory Staff (1954, p. 69-82). The classification is based on the salinity hazard as measured by the electrical conductivity of the water and the sodium hazard as measured by the SAR (sodium-adsorption ratio). The relative importance of the dissolved constituents in irrigation water is dependent upon the degree to which they accumulate in the soil--more of the mineral content of the water will accumulate in tight soils than in more permeable soils under similar conditions. Sodium can be a significant factor in evaluating quality of irrigation water because a high SAR of the water will cause the soil structure to break down by deflocculating the colloidal soil particles. Consequently, the soil can become plastic, thereby causing poor aeration and low water availibility. This is especially true in fine-textured soils. Wilcox (1955, p. 15) stated that the system of classification of irrigation waters proposed by the laboratory staff "...is not directly applicable to supplemental waters used in areas of relatively high rainfall." Wilcox (1955, p. 16) indicated that generally water may be used safely for supplemental irrigation if its conductivity is less than 2,250 micromhos per centimeter at 25°C and its SAR is less than 14. The SAR value and the conductivity of samples from wells tapping the Carrizo Sand and Sparta Sand are shown in Figure 11.

Another factor used in assessing the quality of water for irrigation is the RSC (residual sodium carbonate) in the water. Excessive RSC will cause the water to be alkaline, and the organic content of the soil will tend to dissolve. The soil may become a grayish black and the land areas affected are referred to as "black alkali." Wilcox (1955, p. 11) states that laboratory and field studies have resulted in the conclusion that water containing more than 2.5 epm (equivalents per million) RSC is not suitable for irrigation. Water containing from 1.25 to 2.5 epm is marginal, and water containing less than 1.25 epm RSC probably is safe. However, it is believed that good irrigation practices and proper use of soil amendments might make it possible to use the marginal water successfully for irrigation. Furthermore, the degree of leaching will modify the permissible limit to some extent (Wilcox, Blair, and Bower, 1954, p. 265). RSC is a serious problem in La Salle and McMullen Counties. Much of the water being used for irrigation has excessive RSC and the condition of "black alkali" has been reported by land owners in the area.

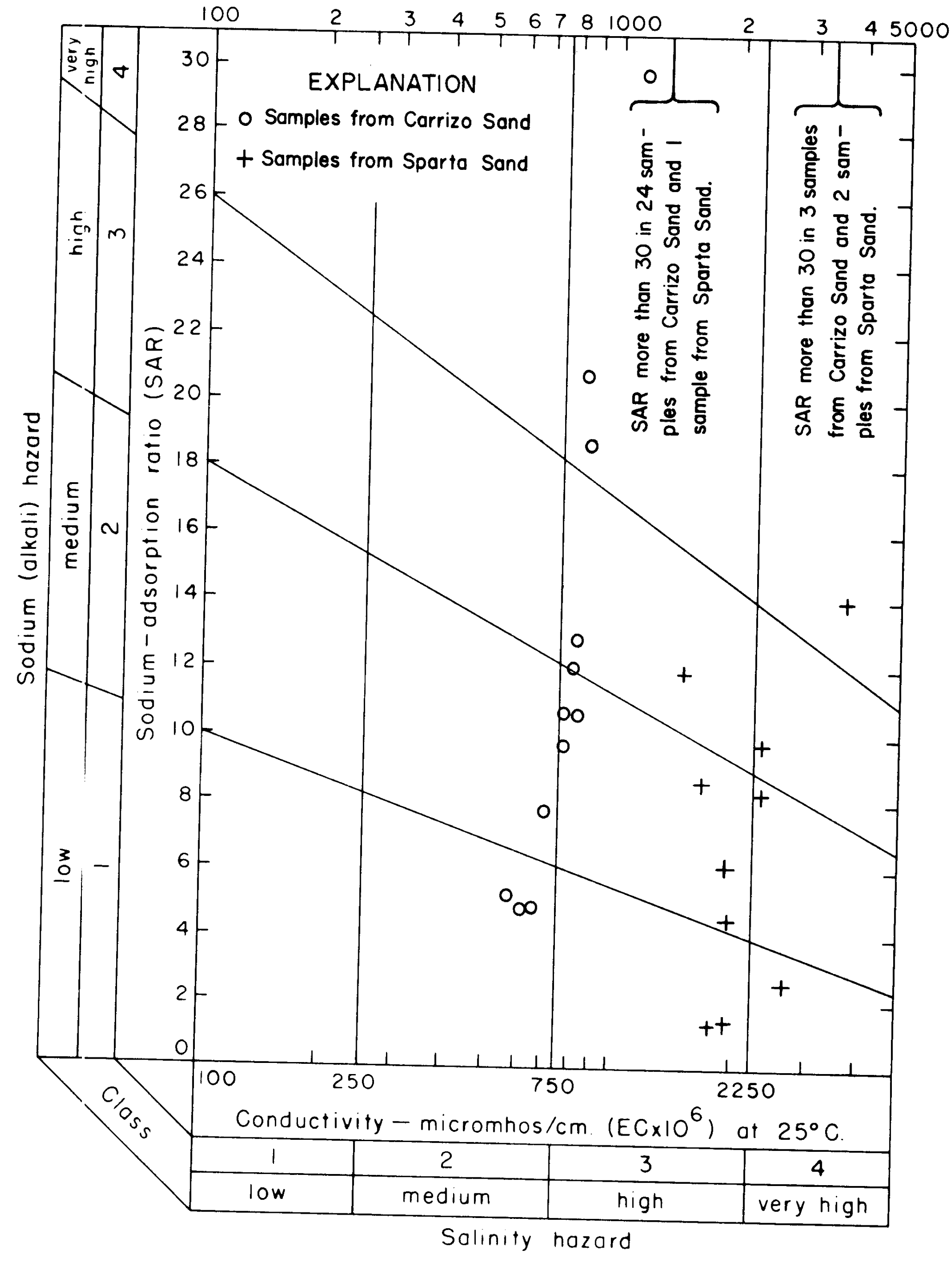

Figure 11

Diagram for the Classification of Irrigation Waters

(After United States Salinity Laboratory Staff, 1954, p. 80)

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An excessive boron content will make water unsuitable for irrigation. Wilcox (1955, p. 11) indicated that a boron concentration of as much as 1.0 ppm is permissible for irrigating sensitive crops; as much as 2.0 ppm for semitolerant crops; and as much as 3.0 for tolerant crops. Crops sensitive to boron include most deciduous fruit and nut trees and navy beans; semitolerant crops include most small grains, potatoes and some other vegetables, and cotton; and tolerant crops include alfalfa, most root vegetables, and the date palm. Boron does not seem to be a significant problem in La Salle and McMullen Counties. Of 33 boron determinations, only 5 were greater than 1 ppm and all were less than 2 ppm.

Carrizo Sand

The water in the Carrizo Sand ranges from fresh to slightly saline throughout La Salle County and in McMullen County, except in the southeastern part where the water is at least moderately saline. Most of the water from the Carrizo is suitable for domestic, stock, and public supplies, and most industrial uses; its use for irrigation is questionable in many instances. Samples of fresh water collected from 36 wells ranging from 2,000 to 4,910 feet in depth contained dissolved solids ranging from 375 to 956 ppm, sulfates from 0.0 to 109 ppm, and chlorides from 22 to 153 ppm. Samples of slightly saline water from 12 wells contained dissolved solids ranging from 1,070 to 2,980 ppm, sulfates from 0.2 to 125 ppm, and chlorides from 103 to 970 ppm. The high concentrations of chloride probably represent leakage from overlying saline-water aquifers.

Much of the water from the Carrizo Sand is of doubtful suitability for irrigation, according to the classification of the U.S. Salinity Laboratory Staff (1954). The SAR (sodium-adsorption ratio) of the water samples collected from the Carrizo Sand ranged from 4.9 to 141, and the specific conductance ranged from 587 to 4,910 micromhos. Of the 39 samples for which SAR and specific conductance data are available, only 9 samples (Figure 11) had SAR values less than 14 and specific conductance less than 2,250 micromhos. All of the samples had RSC (residual sodium carbonate) in excess of 2.5 epm. It is apparent that such items as the type of soil, local conditions of drainage, the type of crop, the method of application of water, and the economics of the use of soil amendments need consideration in each instance in La Salle and McMullen Counties where irrigation with water from the Carrizo Sand is contemplated.

Queen City Sand Member of the Mount Selman Formation

The Queen City Sand Member of the Mount Selman Formation contains fresh to slightly saline water in the northwestern part of McMullen County and in all but the southeastern part of La Salle County. In the rest of the report area, the unit contains water that is moderately saline or worse. Of the 12 water samples collected from the Queen City, 3 were classified as fresh, 7 as slightly saline, and 2 as moderately saline. The three samples of fresh water were collected from wells 2,105, 2,300, and 3,500 feet deep in northern McMullen County. The water is soft, low in sulfate and chloride content, and high in sodium and bicarbonate. The samples are similar to the samples of fresh water from the Carrizo Sand, and the two units may be in close hydraulic connection in this area.

The water from the Queen City Sand Member ranges widely in chemical quality. The water is used chiefly for domestic and stock purposes and is acceptable for those purposes only because better supplies are not readily available. Most of the water is classed as unsuitable for public supply; however, the city of Fowlerton uses slightly saline water from the Queen City for its public supply. The water exceeds the U.S. Public Health Service standards only in dissolved solids, chloride, and fluoride contents.

According to the classification of the U.S. Salinity Laboratory Staff, most of the water from the Queen City has high to very high salinity and sodium hazards. The residual sodium carbonate values were excessive in all but two samples. Obviously, the use of water from the Queen City Sand Member for irrigation should be made with caution.

Sparta Sand

The Sparta Sand yields fresh to slightly saline water only in the western two-thirds of La Salle County. Elsewhere in the report area, the water is more saline.

The water from the Sparta Sand generally is harder than the water from either the Carrizo Sand or Queen City Sand Member. This condition is associated with the comparatively shallow depth of occurrence of the Sparta. Where it occurs above about 800 feet, the water is of a better quality for irrigation than the water from the other two aquifers. Most of this relatively shallow water has a high salinity hazard but low to medium sodium hazard (Figure 11), and residual sodium carbonate is negligible. Below about 800 feet, the sodium hazard increases and residual sodium carbonate becomes significant.

Most of the water from the Sparta Sand does not meet the U.S. Public Health Service standards. The dissolved solids content was excessive in most samples, and in many the chloride and sulfate contents were excessive.

Other Formations

The quality of the water in the less important water-bearing formations in La Salle and McMullen Counties ranges widely. All of the samples from the Cook Mountain Formation were slightly saline. The samples from the Yegua Formation, the Jackson Group, and the Catahoula Tuff ranged from slightly to moderately saline. One sample from the Lagarto Clay and Oakville Sandstone was fresh; the rest were slightly or moderately saline. Only two samples were collected from wells tapping the alluvium; both samples were fresh.

Temperature of Ground Water

The temperature of ground water near the land surface generally is about the same as the mean air temperature of the region, which is about 72°F at Encinal. The increase of the temperature of the water with depth in the Carrizo Sand in the report area is at the rate of about 1°F per 100 feet above a depth of about 2,000 feet and about 2°F per 100 feet below 2,000 feet. The average temperature of water samples collected from wells 2,000 feet deep was 94°F, and the temperature of the water from the deepest well measured was 149°F at a depth of 4,800 feet. The temperatures of water samples collected from wells tapping the Queen City Sand Member ranged from 78°F at 500 feet to 118°F at 3,500 feet--a gradient of about 1.3°F per 100 feet of depth. The temperatures of water samples collected from wells tapping the Sparta Sand ranged from 75°F at 145 feet to 85°F at 750 feet, a gradient of about 1.5°F per 100 feet of depth.

AVAILABILITY OF GROUND WATER FOR FUTURE DEVELOPMENT

The availability of water for future development from the aquifers in La Salle and McMullen Counties is dependent on several hydrologic and economic factors. Among the hydrologic factors, the most important are the ability of the aquifers to transmit water, the amount of water in storage, and the rate of recharge to the aquifers. Economic factors include the cost of wells--in some instances this factor is very important because of the great depth to the top of the aquifers. Of importance economically also is the effect of pumping in adjacent areas which may, in time, be the major control on the amount of water that can be economically developed in the La Salle-McMullen county area.

Carrizo Sand

The Carrizo Sand is the principal source of water for the future development of ground water in the La Salle-McMullen county area. Figure 12 shows the extent of the fresh to slightly saline water in the Carrizo Sand and, by contours, the figure shows the approximate depth to the top of the aquifer in the two-county area. The figure emphasizes one of the deterrents to the development of water from the Carrizo--the great depth to the top of the aquifer. Only in the northwest part of La Salle County is the depth less than 2,000 feet, and in southeastern McMullen County, it is as much as 6,000 feet.

Figure 13 shows the thickness of fresh to slightly saline water-bearing sand in the Carrizo Sand throughout the report area. This figure indicates in a general way by the thickness of these sands the areas where the largest yields of wells might be obtained from the Carrizo. The greatest thicknesses, 500 to about 900 feet, occur in a belt trending northeastward from the southwest part of La Salle County to the northwest part of McMullen County. Elsewhere the thickness is at least 300 feet except in southeast McMullen County where the fresh to slightly saline water-bearing section thins to zero. From an inspection of this map and considering the performance of wells in the area, it is likely that yields up to 2,000 gpm (gallons per minute) can be obtained from properly constructed wells tapping the fresh to slightly saline water-bearing section of the Carrizo almost anywhere within the report area.

The Carrizo Sand in the La Salle-McMullen county area contains an estimated 150,000,000 acre-feet of fresh to slightly saline water in storage. This figure itself is not significant, however, because much of the water will not drain freely from the sands.

One of the principal factors in determining the amount of water available from the Carrizo is the ability of the unit to transmit water to wells. In order to estimate the amount of water which might be available from the Carrizo, a set of theoretical computations were made. It was assumed that a line of wells was installed about 25 miles northwest of and parallel to the downdip limit of fresh to slightly saline water in the Carrizo, and it is assumed that the wells were pumped in such a way that the water levels along the line of wells would be lowered to 400 feet below the land surface. Based on the gradient that would be established toward the line of discharge, it was computed that about 90,000 acre-feet of water per year would be transmitted toward the line of discharge. In addition to this, during the period of lowering the water levels to 400 feet, about 50,000 acre-feet of water would be released from storage. This would indicate that the aquifer could be pumped at the rate of at least 90,000 acre-feet indefinitely. However, as indicated on page 24, this probably exceeds the rate of recharge to the aquifer in the La Salle-McMullen county area. In addition, it should be pointed out that in the heavily pumped areas adjoining La Salle and McMullen Counties on the west and north, approximately 130,000 acre-feet of water was used from the Carrizo chiefly for irrigation in 1961; thus, in effect, this irrigation development is already using much more than the actual recharge to the La Salle-McMullen county area. Also, it should be realized that if water levels were lowered excessively in the La Salle-McMullen county area, the hydraulic gradient at the interface between the slightly and moderately saline water would be reversed and ultimately a very slow intrusion of water of higher salinity would occur, especially in the southeastern part of the area.

One of the more important problems concerning the future development of water from the Carrizo Sand in La Salle and McMullen Counties is the decline of water levels caused by the heavy pumping for irrigation in the adjacent areas on the west and north. A part of this decline is shown on the hydrographs of water levels in observation Wells RX-78-18-702, RX-78-26-802, and SU-78-28-501 (Figure 10). The water levels will continue to decline as long as the irrigation development continues to expand.

Another problem is the threat of contamination of the water in the Carrizo Sand from saline-water-bearing sands above or below the Carrizo. Wells tapping the Carrizo are cased through overlying saline-water-bearing sands, and in some of the older wells, the casing may corrode opposite the saline water sands, thus providing an entrance into the well for the saline water. The high concentrations of chloride in samples from several wells tapping the Carrizo Sand probably represent such leakage from overlying saline-water aquifers. For example, a water sample collected from Well RX-77-31-702 on January 13, 1913 contained 118 ppm chloride, and a sample collected 50 years later on May 23, 1963 contained 680 ppm chloride. This same type of contamination has been observed in the Winter Garden area west and northwest of La Salle and McMullen Counties (Turner and others, 1960, p. 75-76).

Another potential source of contamination of the water in the Carrizo Sand is by the movement of brines from underlying salt-water-bearing sands through improperly cased oil wells or from improperly plugged oil tests. In recent years, the Texas Water Commission has made recommendations to the oil operators of the depths to which water-bearing formations are to be protected, and the Oil and Gas Division of the Railroad Commission of Texas is responsible for the protection of the water-bearing formations. No instances of contamination of this type have been observed in the two-county area.

The infiltration of oil-field brine from disposal pits to shallow sand formations in the report area is a potential source of contamination to the water in these shallow aquifers. However, no contamination through the use of disposal pits was reported in La Salle and McMullen Counties. The Carrizo Sand in the report area is too deep to be contaminated from disposal pits.

The Texas Water Commission and the Texas Water Pollution Control Board (1963, p. 95-99, and 102-121) published a statistical analysis of data on oil-field brine production and disposal in Texas for the year 1961 from an inventory conducted by the Texas Railroad Commission. These data show that 443,228 barrels (57.13 acre-feet, or 18.62 million gallons) of brine was produced in 1961 from the oil reservoirs in La Salle County. Of this amount, 49,429 barrels (6.37 acre-feet, or 2.08 million gallons), or 11.2 percent of the total was disposed through injection wells, 393,799 barrels (50.76 acre-feet, or 16.54 million gallons) or 88.8 percent of the total was disposed in pits. These data show that 7,216,199 barrels (930.12 acre-feet, or 303.08 million gallons) of brine was produced in 1961 from the oil reservoirs in McMullen County. Of this amount, 3,847,364 barrels (495.90 acre-feet, or 161.59 million gallons) or 53.3 percent of the total was disposed through injection wells, 2,925,858 barrels (377.12 acre-feet, or 122.89 million gallons) or 40.5 percent of the total was disposed in pits, 381,060 barrels (49.12 acre-feet, or 16.00 million gallons) or 5.3 percent of the total was disposed in surface-water courses, 1,617 barrels (0.21 acre-feet, or 0.07 million gallons) or 0.0 percent of the total was disposed by miscellaneous methods, and 60,300 barrels (7.77 acre-feet, or 2.53 million gallons) or 0.8 percent of the total was disposed by unknown methods.

It is unlikely that large quantities of water will be developed from the Carrizo Sand in the La Salle-McMullen county area chiefly because of the great depth to the top of the formation as shown in Figure 12. Also, the doubtful quality of much of the water for irrigation probably will limit the development.

Queen City Sand Member of the Mount Selman Formation

The Queen City Sand Member of the Mount Selman Formation is available for development in the northwestern part of McMullen County and in all but the southeastern part of La Salle County as shown on Figure 14. The figure also shows that the depth to the top of the member ranges from less than 200 feet in northwestern La Salle County to more than 2,200 feet in southeastern La Salle County.

Figure 15 shows the thickness of the sands in the Queen City that contain fresh to slightly saline water. The map shows a great variation in the thickness of sand within short distances. The thickness ranges from 0 at the downdip limit of the extent of fresh to slightly saline water to a maximum of about 570 feet in the northwestern part of McMullen County. Throughout most of the area, the average thickness is on the order of 300 or 400 feet. Based on the thickness of the sands and the performance of wells in nearby counties, it is probable that yields up to about 1,000 gpm can be obtained from properly constructed wells tapping the Queen City in much of La Salle County and the northwestern part of McMullen County.

Based on the sand thickness, it is estimated that about 100,000,000 acre-feet of fresh to slightly saline water is in storage in the Queen City Sand Member in the two-county area. However, as in the case of the Carrizo Sand, only a very small part of the water is available for development. The data on the physical properties of the Queen City are not sufficient to make computations of the quantity of water available; however, the amount probably is considerably less than that from the Carrizo Sand. The sand beds in the Queen City are more lenticular and generally are not as thick as those in the Carrizo.

Sparta Sand

The Sparta Sand is available for development in the approximate western two-thirds of La Salle County. Throughout the remainder of the two-county area, the formation contains water that is too highly saline for most uses. Figure 16 shows the approximate depth to the top of the unit throughout the fresh to slightly saline water-bearing part of the aquifer. Data are not sufficient to evaluate quantitatively the potential of the Sparta Sand; the data on the ability of the sand to transmit water are meager and the rate of recharge to the unit is not known. However, based on the performance of wells in the two-county area and in adjoining areas, it is probable that yields of as much as 400 gpm can be obtained anywhere within the extent of the fresh to slightly saline water. Because of its relatively shallow depth, the Sparta Sand is a more likely source of water for irrigation than either the Carrizo Sand or Queen City Sand Member of the Mount Selman Formation. In addition, the water at least above a depth of about 800 feet appears to be more suitable for irrigation. On the other hand, the yields obtained from the Sparta will be small compared to those from the other principal aquifers.

Other Formations

The geologic formations younger than the Sparta Sand (Table 1) yield only small quantities of water to domestic and stock wells in La Salle and McMullen Counties. With a few exceptions, the quality of the water from these wells ranges from slightly to moderately saline and is not suitable for public supply, industrial, or irrigation uses. Data are not available to permit a quantitative appraisal of the potential of these units; however, very little additional development is anticipated because of the low yields of wells and generally poor chemical quality of the water.

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