TEXAS WATER COMMISSION

BULLETIN 6409

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE GUADALUPE, SAN ANTONIO, AND NUECES RIVER BASINS, TEXAS

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FOREWORD

The ground-water reconnaissance study is the first phase of the State's water-resources planning concerning ground water as outlined in the progress report to the Fifty-Sixth Legislature entitled "Texas Water Resources Planning at the End of the Year 1958." Before an adequate planning program for the development of the State's water resources can be prepared, it is necessary to determine the general chemical quality of the water, the order of magnitude of ground-water supplies potentially available from the principal water-bearing formations of the State, and how much of the supply is presently being used. To provide the data necessary to evaluate the ground-water resources of Texas, reconnaissance investigations were conducted throughout the State under a cooperative agreement with the U. S. Geological Survey. The ground-water reconnaissance investigations were conducted by river basins so that the results could be integrated with information on surface water in planning the development of the State's water resources. The river basins of the State were divided between the Ground Water Division of the Texas Water Commission and the U. S. Geological Survey for the purpose of conducting and reporting the results of the ground-water investigations.

This bulletin presents the results of the Guadalupe, San Antonio, and Nueces River Basins ground-water reconnaissance investigation. It provides a generalized evaluation of the ground-water conditions in the basin and points out areas where detailed studies and continuing observations are necessary. The additional studies will be required to provide estimates of the quantity of ground water available for development in smaller areas, to provide more information on changes in chemical quality that may affect the quantity of fresh water available for development, and to better determine the affects of present and future pumpage. This report was prepared by personnel of the U. S. Geological Survey.

TEXAS WATER COMMISSION

Joe D. Carter

Joe D. Carter, Chairman

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RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE GUADALUPE, SAN ANTONIO, AND NUECES RIVER BASINS, TEXAS

ABSTRACT

The Guadalupe, San Antonio, and Nueces River Basins, Texas, comprise an area of 27,377 square miles and include all or parts of 39 counties in the southwestern and south-central parts of the State. The Guadalupe Basin includes 5,972 square miles, the San Antonio Basin 4,255 square miles, and the Nueces Basin 17,180 square miles. The three river basins constitute 10.5 percent of the area of Texas and have a population of about 1,000,000 people, about 10.4 percent of the population of the State.

The economy is dependent largely on the availability and quality of ground water for public supply, agriculture, and industry. Surface water supplies only three cities and a small part of the irrigation requirements. The climate of the Guadalupe, San Antonio, and Nueces River Basins ranges from semiarid in the western part of the Nueces Basin to dry subhumid in the eastern and southeastern parts of the Guadalupe Basin. Consequently, the agriculture in a large part of the report area is limited to ranching and irrigation farming where supplies of ground water are available. The larger cities are located in areas where large quantities of fresh ground water are available. The estimated rate of discharge of ground water by major wells and springs in the three-basin area in 1961 was irrigation, 240,000 acre-feet or 220 mgd (million gallons per day); public supply, 150,000 acre-feet (130 mgd); industrial uses, 32,000 acre-feet (29 mgd); and spring flow, 450,000 acre-feet (410 mgd).

The Guadalupe, San Antonio, and Nueces River Basins are in two physiographic sections--the Edwards Plateau of the Great Plains province and the West Gulf Coastal Plain of the Coastal Plain province. The Balcones escarpment, which faces southeastward and separates the two sections, is from 200 to 400 feet high between Hays County and central Uvalde County; farther west the escarpment is less pronounced.

The Edwards Plateau, which includes about 7,300 square miles, is north and northwest of the Balcones escarpment. In the northern part of the Nueces Basin, large areas of the plateau are relatively undissected by stream erosion; however, in the Guadalupe and San Antonio Basins, broad valleys have been cut into the plateau. Only a small amount of land along the streams is suitable for farming; consequently, almost all the Edwards Plateau in the report area is devoted to ranching. The altitude of the plateau ranges from about 2,400 feet on the divides in the northern part of the report area to about 600 feet along the Guadalupe River at New Braunfels.

The West Gulf Coastal Plain, which includes about 20,100 square miles, extends from the Balcones escarpment southeastward to the Gulf of Mexico. Low relief and the gentle gulfward slope of the land surface characterize that part of the section near the Gulf of Mexico; the surface is rolling to moderately hilly near the Balcones escarpment. The altitude of the West Gulf Coastal Plain ranges from about 1,500 feet in central Kinney County to sea level at the mouths of the Nueces and Guadalupe Rivers.

The inner part of the Coastal Plain, which includes the cities of San Antonio, New Braunfels, San Marcos, and Uvalde, is the most densely populated part of the report area. Most of the industries are in or near San Antonio, and most of the irrigation is southwest of San Antonio.

The two major physiographic sections, the Edwards Plateau and the West Gulf Coastal Plain, also form two major hydrologic subdivisions.

The Edwards Plateau hydrologic subdivision consists of beds of limestone, dolomitic limestone, marl, shale, sandstone, and conglomerate, all of Cretaceous age. The rocks dip gently toward the south or southeast. Water occurs under water-table conditions in the Edwards and associated limestones, the only primary aquifer in the Edwards Plateau, and the discharge from springs draining the aquifer contributes to the recharge of the Balcones aquifer in the West Gulf Coastal Plain. Because of their importance elsewhere in the Edwards Plateau, the Edwards and associated limestones are regarded as a primary aquifer, although the only pumpage in the report area is for domestic and livestock uses. All the water for public supply and the small amount used for irrigation are obtained from the secondary aquifers--the Hosston, Sligo, and Travis Peak Formations, and the Glen Rose Limestone of Cretaceous age, and Recent alluvium. Water occurs under water-table conditions in the Recent alluvium and under artesian conditions in the other secondary aquifers. The estimated pumpage in 1961 from major wells in the secondary aquifers was 2,500 acre-feet (2.1 mgd) for public supply and 770 acre-feet (0.7 mgd) for irrigation. The data do not permit an estimate of the potential development of the aquifers in the Edwards Plateau, but it probably is many times the present rate of withdrawal.

The West Gulf Coastal Plain hydrologic subdivision includes the following primary aquifers: The Balcones aquifer, the Carrizo Sand and Wilcox Group, differentiated, and the Gulf Coast aquifer, and the following secondary aquifers: The Queen City Sand Member of the Mount Selman Formation, the Sparta Sand, and the Leona Formation and Recent alluvium. Ground water occurs under artesian conditions in all the primary aquifers and in the Queen City and Sparta; it occurs under water-table conditions in the Leona Formation and Recent alluvium.

The Balcones aquifer in this report refers to that part of the Edwards and associated limestones in which the water is fresh and under artesian pressure. The Balcones aquifer includes about 2,100 square miles in a belt along the inner border of the Coastal Plain. The Balcones aquifer consists of limestone, dolomitic limestone, and marly limestone. The water occurs in a network of channels that have been enlarged by the solvent action of the water on the limestones. The channels generally follow fractures that are associated with and parallel to faults. A large part of the recharge to the Balcones aquifer is seepage from streams that cross the outcrop of the aquifer in the Balcones fault zone. The annual average recharge to the Balcones aquifer during the period 1934-59, which included a 10-year drought, was about 502,000 acre-feet, and the annual average discharge during the same period was about 509,000 acre-feet. The estimated discharge of ground water by major wells and springs in the Balcones aquifer in 1961 was as follows: public supply 130,000 acre-feet (110 mgd), irrigation 61,000 acre-feet (55 mgd), industry 28,000 acre-feet (25 mgd), and spring flow 460,000 acre-feet (410 mgd). The larger springs are at New Braunfels, San Marcos, San Antonio, and near Uvalde. Most of the pumpage for public supply and industrial uses is in the San Antonio area. The quantity of water in storage in the Balcones aquifer may be as much as 15,000,000 acre-feet.

South and southeast of the Balcones aquifer, the Coastal Plain hydrologic subdivision consists chiefly of layers of sand or sandstone alternating with shale or clay. These rocks of Tertiary and Quaternary ages crop out in belts roughly parallel to the coast, dip gently in the gulfward direction, and contain ground water under artesian pressure. Beginning with the Carrizo Sand and Wilcox Group which crops out near the inner border of the Coastal Plain, the aquifers crop out in the gulfward direction in the following order: Queen City Sand Member of the Mount Selman Formation, Sparta Sand, and the Gulf Coast aquifer.

The Carrizo Sand and the sands in the Wilcox Group of Eocene age are interconnected hydrologically. Therefore, they are treated in this report as a single primary aquifer. The Carrizo Sand consists of coarse to fine sand, sandstone, silt, and clay. The Wilcox generally is finer grained, consisting of clay, silt, medium- to fine-grained sandstone, sandy shale, and thin beds of lignite. The thickness of the Carrizo ranges from 200 to 1,000 feet, and the thickness of the Wilcox ranges from 150 to 2,300 feet. The Carrizo Sand yields moderate to large quantities of fresh to slightly saline water which occurs as far downdip as 4,800 feet below sea level in the San Antonio River Basin. The estimated pumpage from major wells tapping the Carrizo and Wilcox in 1961 was for irrigation 170,000 acre-feet (150 mgd), public supply 7,800 acre-feet (7.0 mgd), and industry 1,300 acre-feet (1.2 mgd). Most of the pumpage for irrigation is in the Nueces Basin where the large withdrawals have caused a general decline in the water levels. The pumpage from the Carrizo and Wilcox in 1961 was 180,000 acre-feet (160 mgd) in the Nueces Basin, 2,500 acre-feet (2.2 mgd) in the San Antonio Basin, and 1,300 acre-feet (1.2 mgd) in the Guadalupe Basin. If the water levels were lowered to 400 feet below the land surface along an assumed line of discharge across each basin, the estimated quantities of fresh water available from storage in the Carrizo and Wilcox would be, as follows: Nueces River Basin, 3,200,000 acre-feet; San Antonio Basin, 2,000,000 acre-feet; and Guadalupe River Basin, 3,100,000 acre-feet. Assuming adequate recharge and the water levels at 400 feet, the Carrizo and Wilcox would transmit 62,650 acre-feet per year (about 60 mgd) in the Nueces River Basin, 33,500 acre acre-feet per year (30 mgd) in the San Antonio River Basin, and 52,300 acre-feet per year (46 mgd) in the Guadalupe River Basin.

The Queen City Sand Member of the Mount Selman Formation is a secondary aquifer in the San Antonio and Nueces River Basins. It consists of medium- to fine-grained sand, clay, and shale, and the thickness ranges from 500 to 1,000 feet. The Queen City yields small to moderate quantities of fresh to slighly saline water. The estimated pumpage from major wells tapping the Queen City in 1961 was 760 acre-feet for irrigation in the San Antonio Basin and 780 acre-feet for public supply in the Nueces Basin.

The Sparta Sand is a secondary aquifer in the Guadalupe and Nueces River Basins. It consists of medium- to fine-grained sand and some clay, and maintains a uniform thickness of about 110 feet in the report area. The Sparta yields small to moderate quantities of fresh to slightly saline water in the outcrop area and slightly to moderately saline water downdip. The estimated pumpage from major wells tapping the Sparta in 1961 was 69 acre-feet for public supply in the Guadalupe Basin and 1,400 acre-feet for irrigation in the Nueces Basin.

The Catahoula Tuff, Oakville Sandstone, Lagarto Clay, Goliad Sand, Lissie Formation, and Beaumont Clay are interconnected hydrologically and are considered as a unit and referred to as the Gulf Coast aquifer, one of the primary aquifers in the report area. These stratigraphic units, which consist of sand or sandstone and shale or clay are in the coastward one-half of the Coastal Plain area. The Gulf Coast aquifer has a maximum thickness of about 1,800 feet in the Nueces Basin and about 1,900 feet in the San Antonio and Guadalupe Basins. The Gulf Coast aquifer yields small to large quantities of fresh to moderately saline water. The estimated pumpage from major wells tapping the Gulf Coast aquifer in 1961 was for irrigation 8,700 acre-feet (7.8 mgd), public supply 6,900 acre-feet (6.2 mgd), and industry 2,200 acre-feet (1.9 mgd). The pumpage from the Gulf Coast aquifer in 1961 was 9,100 acre-feet (8.1 mgd) in the Nueces Basin, 2,100 acre-feet (1.9 mgd) in the San Antonio Basin, and 6,600 acre-feet (5.9 mgd) in the Guadalupe Basin. If the water levels were lowered to 400 feet below the land surface along an assumed line of discharge across each basin and the recharge was adequate, the Gulf Coast aquifer would transmit 10,500 acre-feet per year (9.4 mgd) in the Nueces Basin, 723 acre-feet per year (0.6 mgd) in the San Antonio Basin, and 10,000 acre-feet per year (8.9 mgd) in the Guadalupe Basin. The quantity of water released from storage by lowering the water levels to 400 feet would be 11,600,000 acre-feet in the Nueces Basin, 8,340,000 acre-feet in the San Antonio Basin, and 11,600,000 acre-feet in the Guadalupe Basin.

The Leona Formation of Pleistocene age and the Recent alluvium, which have similar hydrologic and geologic characteristics, are considered as a unit--a secondary aquifer in the Guadalupe and Nueces Basins. The Leona Formation, consisting of silt, sand, and gravel from 0 to 80 feet thick, includes the alluvial terraces along the major streams; the Recent alluvium of similar composition and from 0 to 30 feet thick, includes the flood-plain and channel deposits of the present streams. The aquifer yields small to moderate quantities of fresh water. The estimated pumpage from major wells in 1961 was 800 acre-feet in the Guadalupe Basin and 2,100 acre-feet in the Nueces Basin. Most of the pumpage was for irrigation; only a small part was for public supply.

The total discharge in the three basins in 1961 was 910,000 acre-feet, including 20,000 acre-feet pumped for domestic and livestock purposes. The major pumpage was 240,000 acre-feet for irrigation, although springs in the Balcones fault zone area in the Guadalupe River Basin discharged about 380,000 acre-feet and the total spring flow was 450,000 acre-feet. More than 85 percent of the water pumped for irrigation was from wells in the Nueces River Basin, most of which was from the Carrizo Sand and Wilcox Group, undifferentiated. The largest amount of ground water used by industry and public supply was from the Balcones aquifer in the San Antonio River Basin, reflecting the large withdrawals in the metropolitan San Antonio area.

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE GUADALUPE, SAN ANTONIO, AND NUECES RIVER BASINS, TEXAS

INTRODUCTION

Purpose and Scope

The Texas Water Planning Act of 1957, Senate Bill 1, First Called Session of the 55th Legislature, created a Water Resources Planning Division within the Texas Board of Water Engineers (changed to Texas Water Commission, January 1962). The act directed the Board to submit a statewide report of the water resources of Texas and to make recommendations to the Legislature for the maximum development of the water resources of the State. The report entitled, "Texas Water Resources Planning at the End of the Year 1958, A Progress Report to the Fifty-Sixth Legislature," was submitted in 1958. The report states (Texas Board Water Engineers, 1958, p. 78), "...Initial planning for development of the State's water resources will require that reconnaissance ground-water studies be made in much of the State because time is not available to complete the recommended detailed investigations. Studies of this type will be made chiefly to determine the order of magnitude of the ground-water supplies potentially available from the principal water-bearing formations."

To implement the directive of the Legislature, the Texas Board of Water Engineers and the U. S. Geological Survey began a cooperative project in September 1959 entitled, "Reconnaissance ground-water investigations in Texas." The Planning Division of the Texas Board of Water Engineers based its approach to water-resources development planning upon the needs and availability of both surface water and ground water of each river basin and subdivision of a basin. Therefore, the cooperative program between the Ground Water Branch of the U. S. Geological Survey and the Texas Board of Water Engineers was planned by major river basins. The Geological Survey prepared reports on the Red, Sulphur, and Cypress Basins (E. T. Baker and others, 1963), Brazos Basin (Cronin and others, 1963), the upper Rio Grande Basin (Davis and others, 1962), the lower Rio Grande Basin (R. C. Baker, 1962), and the Gulf Coast region (Wood and others, 1963). The Texas Board of Water Engineers prepared reports on the Canadian Basin (Texas Board Water Engineers, 1960), Sabine Basin (B. B. Baker and others, 1963), Neches Basin (B. B. Baker and others, 1963), Trinity Basin (Peckham and others, 1963), Colorado Basin (Mount and others, 1962), and the middle Rio Grande Basin (Brown and others, 1962).

The studies of the river basins were designed to have their principal emphasis on the following items (Texas Board Water Engineers, 1958, p. 78): "...(1) Inventory of large wells and springs; (2) compilation of readily available logs of wells and preparation of generalized cross sections and maps showing subsurface geology; (3) inventory of major pumpage; (4) pumping tests of principal water-bearing formations; (5) measurements of water levels in selected wells; (6) determination of areas of recharge and discharge; (7) compilation of existing chemical analyses of water and sampling of selected wells and springs for additional analyses; (8) correlation and generalized analysis of all data to determine the order of magnitude of supplies available from each major formation in the area and general effects of future pumping; and (9) preparation of generalized reports on principal ground-water resources of each river basin."

Location and Extent of the Area

The Guadalupe, San Antonio, and Nueces River Basins in Texas comprise an area of 27,377 square miles, including all or parts of 39 counties in the southwestern and south-central part of the State. The report area is bordered on the west and southwest by the Rio Grande Basin, on the south and southeast by the Coastal basins and the Gulf of Mexico, on the east by the Lavaca Basin, and on the north and northeast by the Colorado River Basin. The area is irregular, ranging in width from about 190 miles to less than 1 mile and averaging about 100 miles (Figure 1). The area lies between latitude 27°20' and 30°18' N and longitude 96°50' and 100°40' W.

Economic Development and Cultural Features

The Guadalupe, San Antonio, and Nueces River Basins constitute 10.5 percent of the area of Texas and have a population of about 1,000,000 people, about 10.4 percent of the population of the State. Cities having more than 10,000 population (1960 census) are San Antonio, 606,871; Victoria, 33,047; San Marcos, 12,713; New Braunfels, 15,631; and Uvalde, 10,293.

The early settlements at San Antonio, New Braunfels, and San Marcos were located at large springs (Sellards and Baker, 1934, p. 51). Numerous summer camps and "dude ranches" have been developed in the "Hill Country" along spring-fed streams, chiefly in Kerr and Bandera Counties. The "Hill Country," a local name for the dissected border of the Edwards Plateau, is famous also for its hunting facilities for deer, turkey, and other game. San Antonio, founded in 1718, is one of the oldest cities in the southwestern part of the United States. It is the financial, commercial, and cultural center of southern Texas and is one of the important military centers in the United States.

Manufacturing has contributed substantially to the economy of the area. More than 700 manufacturing establishments employ 25,700 people with a payroll in excess of 88 million dollars a year. Much of the manufacturing is concentrated in or near San Antonio and is related to the production of petroleum and natural gas, gravel, brick and tile, and cement. The value of these products is more than 170 million dollars annually.

Agriculture is also an important industry in the area. The Winter Garden district in Dimmit and Zavala Counties and adjacent areas produces large quantities of vegetables that are irrigated with ground water. Livestock raising and dairying are practiced successfully throughout the area.

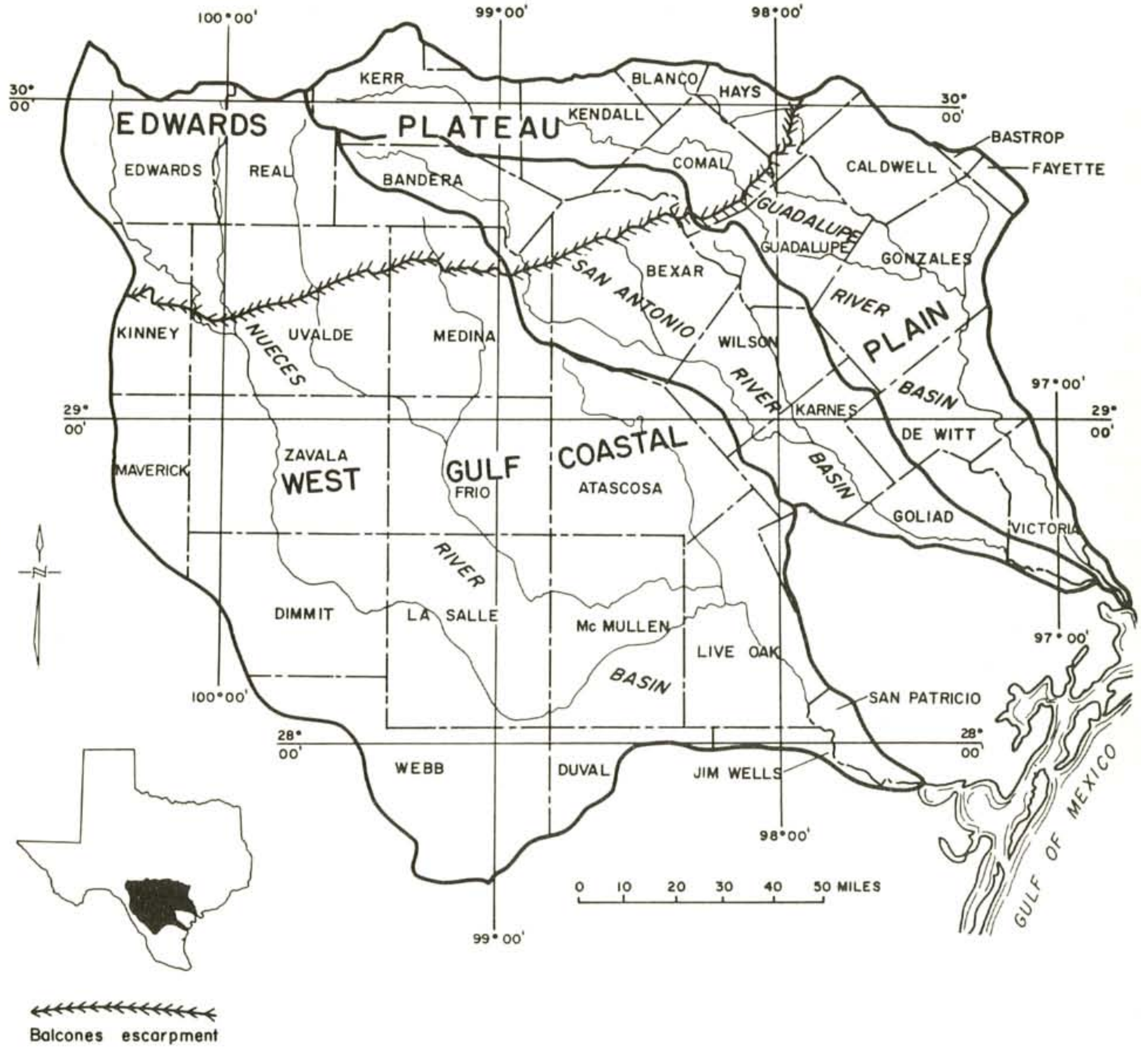

Figure 1

Map of the Guadalupe, San Antonio, and Nueces River Basins, Showing Physiographic Provinces

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

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The Guadalupe, San Antonio, and Nueces River Basins are served by several rail, air, and bus lines, and many hundreds of miles of paved Federal and State highways and secondary roads. Marine shipping also is available to the area through the port of Corpus Christi and the Gulf Intracoastal Canal.

Methods of Investigation

Fieldwork in the Guadalupe, San Antonio, and Nueces River Basins was started in September 1961 and completed in August 1962. Basic data were collected and assembled by O. C. Dale, G. H. Shafer, C. R. Follett, H. B. Harris, and P. L. Rettman of the U. S. Geological Survey. The investigation included an inventory of all the major wells in the area and an inventory of the amount of water pumped during 1961. For the purpose of this report, major wells include public supply, industrial, and irrigation wells that yield more than 50 gpm (gallons per minute). However, all public-supply wells were included in the inventory regardless of capacity. Data also were collected for domestic, livestock, and test wells in selected areas for use as geologic or hydrologic control points. The chemical analyses of 46 water samples collected during the investigation and several hundred other analyses that had been made before the study began were used in delineating areas of usable water and as a guide in interpreting quality of water from electric logs. Records of changes in groundwater levels obtained by periodic measurements of water levels in selected observation wells were used to show the effects of recharge and discharge and other natural or artificial factors. Pumping tests were made to determine the hydraulic characteristics of the aquifers in several localities. The geologic and hydrologic characteristics of many of the aquifers are shown by means of geologic sections, contour maps on the tops of formations, saturated-thickness-of-sand maps, and water-table maps. These maps were prepared from more than 1,000 electric and drillers' logs of wells and several hundred water-level measurements, and served as a basis for evaluating the availability of water, water problems, and the over-all potential of the aquifers. The descriptions of the geologic formations and their water-bearing properties were summarized chiefly from published reports. (See Selected References.)

Well-Numbering System

The numbers assigned to wells and springs in the report conform to the statewide system used by the Texas Water Commission. The system is based on the division of Texas into 1-degree quadrangles bounded by lines of latitude and longitude. Each 1-degree quadrangle is divided into 64 smaller quadrangles, 7-1/2 minutes on a side, each of which is further divided into 9 quadrangles, 2-1/2 minutes on a side. Each of the 89 1-degree quadrangles in the State has been assigned a 2-digit number for identification (Figure 2). The 7-1/2 minute quadrangles are given 2-digit numbers consecutively from left to right, beginning in the upper left-hand corner of the 1-degree quadrangle, and the 2-1/2 minute quadrangles within each 7-1/2 minute quadrangle are similarly numbered with 1-digit numbers. Each well inventoried in each 2-1/2 minute quadrangle is assigned a 2-digit number. The well number is determined as follows: From left to right, the first 2 numbers identify the 1-degree quadrangle; the next 2 numbers identify the 7-1/2 minute quadrangle; the fifth number identifies the 2-1/2 minute quadrangle; and the last 2 numbers designate the well within the 2-1/2 minute quadrangle.

In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefix for the 39 counties that are all or partly in the Guadalupe, San Antonio, and Nueces River Basins are as follows:

County	Prefix	County	Prefix	County	Prefix
Atascosa	AL	Fayette	JT	Live Oak	SJ
Bandera	AS	Frio	KB	Maverick	TB
Bastrop	AT	Gillespie	KK	McMullen	SU
Bee	AW	Goliad	KP	Medina	TD
Bexar	AY	Gonzales	KR	Nueces	UB
Blanco	AZ	Guadalupe	KX	Real	WA
Caldwell	BU	Hays	LR	Refugio	WH
Calhoun	BW	Jim Wells	PW	San Patricio	WW
Comal	DX	Karnes	PZ	Uvalde	YP
DeWitt	HX	Kendall	RB	Victoria	YT
Dimmit	HZ	Kerr	RJ	Webb	YZ
Duval	JB	Kinney	RP	Wilson	ZL
Edwards	JJ	La Salle	RX	Zavala	ZX

In the report, only the degrees of latitude and longitude are shown on the maps; the 7-1/2 minute and 2-1/2 minute lines are not shown, as they would obscure other details. However, a well whose number is known can be located by identifying the 1-degree quandrangle from Figure 2 and using the degree lines on the individual well maps. Similarly, a well located on a map can be identified approximately by dividing a 1-degree quadrangle into 7-1/2 minute or 2-1/2 minute quadrangles.

Previous Investigations

A report by Deussen and Dole (1916) on "Ground water in La Salle and McMullen Counties, Texas," was the first of a number of county reports in the report area. Deussen (1924) and Trowbridge (1923, 1932) wrote comprehensive reports on the geology of the Coastal Plain, which together included more than one-half of the report area.

The Winter Garden district in Dimmit and Zavala Counties and adjacent areas was one of the first projects selected for study when a statewide investigation of the ground-water resources of Texas was begun by the U. S. Geological Survey in cooperation with the Texas Board of Water Engineers. Fieldwork began in 1929 and the first report on the Winter Garden district was published in 1931 by White and Meinzer. Other reports include those by Livingston and Lynch (1937), Livingston (1947b), Turner and Robinson (1934), White, Turner, and Lynch (1934), Moulder (1957), Turner and others (1960), and Mason (1960).

A comprehensive investigation of the geology and hydrology of 13 counties in and near the Edwards Plateau (Figure 1) was started in 1932 as a cooperative project between the U. S. Geological Survey and the Texas Board of Water Engineers. The project has since been enlarged by the cooperation of the San Antonio City Water Board, the Edwards Underground Water District, the San Antonio City Public Service Board, and the Bexar Metropolitan Water District. Preliminary results of the investigation were reported by Livingston and others (1936) and by Livingston (1947a); other reports include those by Lang (1953, 1954) and Livingston (1942). The hydrology of the San Antonio area was discussed by Sayre and Bennett (1942), Petitt and George (1956), and Garza (1962a). Detailed investigations on the geology and ground-water resources of nine counties include those for Uvalde and Medina (Sayre, 1936), Comal (George, 1952), Edwards (Long, 1962), Bexar (Arnow, 1959), Medina (Holt, 1959), Hays (DeCook, 1960), Kinney (Bennett and Sayre, 1962), Bandera (Reeves and Lee, 1962), Uvalde (Welder and Reeves, 1962), and Real (Long, 1958). Garza (1962b) reported on the chemical analyses of water from observation wells in the vicinity of San Antonio. The geology and ground-water resources of 11 counties in the Coastal Plain were described by Lonsdale (1935), Sayre (1937), Lonsdale and Day (1937), Rasmussen (1947), Sundstrom and Follett (1950), Anders (1957, 1960), Dale and others (1957), Anders and Baker (1961), Marvin and others (1962), and Mason (1963). Investigations of the ground-water resources of Gonzales, DeWitt, La Salle, and McMullen Counties are scheduled for completion in 1963. Many reports concerning small areas are in the open files of the U. S. Geological Survey and Texas Water Commission.

During the period 1936-57, a statewide inventory of water wells, by counties, was undertaken by the Texas Board of Water Engineers in cooperation with the U. S. Geological Survey. These reports, published in mimeographed form, include records of wells, drillers' logs, water analyses, and maps showing the locations of wells and springs.

Periodic measurements of water levels in selected observation wells in the principal aquifers of the State are made by the Texas Water Commission. These measurements help to evaluate the effects of ground-water development in relation to available supply. Records of such measurements in hundreds of wells in 15 counties in the report area are available for the period 1929-63. The records, by counties, are published periodically by the Texas Water Commission. Records of water levels in some observation wells also are published by the U. S. Geological Survey in the annual reports on water levels and artesian pressures in the United States. (See Selected References.)

A statewide inventory of the public-water supplies of Texas was made in the 1940's by the Texas Board of Water Engineers in cooperation with the U. S. Geological Survey. These reports, Sundstrom and others (1948, 1949) and Broadhurst and others (1950, 1951), include descriptions of the public water-supply systems, chemical analyses of ground water and surface water, logs of selected wells, and discussions of the water resources and standards of water quality. Almost all the area in the Guadalupe, San Antonio, and Nueces River Basins is included in the report on the public-water supplies of southern Texas by Broadhurst and others (1950).

Acknowledgments

The collection of basic data was greatly facilitated by the cooperation of well drillers and well owners. Appreciation is expressed also for the information furnished by several petroleum geologists, officials of the cities and industries, the Soil Conservation Service of the U. S. Department of Agriculture, and the county agricultural agents.

GEOGRAPHY

The Guadalupe, San Antonio, and Nueces River Basins are in two physiographic sections--the Edwards Plateau of the Great Plains province and the West Gulf Coastal Plain of the Coastal Plain province (Figure 1 and Fenneman, 1938, p. 100). The Balcones escarpment separates these two sections and extends southward from Austin, about 10 miles northeast of the report area, through San Marcos, New Braunfels, and San Antonio, thence westward across Medina, Uvalde, and Kinney Counties. The southeastward-facing escarpment is from 200 to 400 feet high between Austin and central Uvalde County; farther west, the escarpment is less pronounced. The Balcones escarpment is the remnant of a fault scarp caused by the vertical movement of the rocks in the Balcones fault zone.

The Edwards Plateau and the top of the Balcones escarpment are partly protected from erosion by a cap of very resistant limestone. In the northern part of the Nueces Basin, broad areas of the plateau are relatively undissected by stream erosion; however, in the Guadalupe and San Antonio Basins, broad valleys have been cut in the plateau and remnants of the resistant limestone form cliffs on the crests of the divides. Only a small amount of land along the streams is suitable for farming; consequently, almost all the Edwards Plateau in the report area is devoted to ranching. The altitude of the plateau ranges from about 600 feet along the Guadalupe River where it cuts through the Balcones escarpment at New Braunfels to about 2,400 feet on the divides in the northern part of the report area.

The West Gulf Coastal Plain extends from the Balcones escarpment southeast to the Gulf of Mexico (Figure 1). Low relief and the gentle gulfward slope of the land surface characterize that part of the section near the Gulf of Mexico; the surface is rolling or moderately hilly in that part of the section near the Balcones escarpment. Low ridges formed by beds of resistant sandstone roughly parallel the coast line. The ridges, or cuestas, are asymmetrical in cross section and have a steeper slope facing inland. The streams that drain the Coastal Plain have flood plains bounded by terraces which may be several miles wide. The altitude of the West Gulf Coastal Plain ranges from about 1,500 feet in central Kinney County to sea level at the mouths of the Nueces and Guadalupe Rivers.

CLIMATE

The climate of the Guadalupe, San Antonio, and Nueces River Basins ranges from semiarid in the western part of the Nueces Basin to dry subhumid in the eastern and southeastern parts of the Guadalupe Basin (Thornthwaite, 1952, p. 32). According to Thronthwaite's classification, which is based on a moisture index, the potential evapotranspiration is compared with the precipitation. When precipitation is the same as potential evapotranspiration and water is available as needed, water is neither deficient nor in excess, and the climate is neither dry nor moist. As water deficiency becomes larger with respect to potential evapotranspiration, the climate becomes more arid; conversely, as water surplus becomes larger, the climate becomes more humid.

Thornthwaite's map (1952, Fig. 30) indicates no surplus moisture in the Guadalupe, San Antonio, and Nueces Basins. The moisture deficiency decreases eastward, and, consequently, the climate changes from semiarid to dry subhumid.

Precipitation ranges from an annual mean of about 22 inches in the western part of the Nueces Basin to about 34 inches in the eastern part of the Guadalupe Basin (Figure 3). The average monthly precipitation at Winter Haven, San Antonio, Dilley, and Beeville, 35 miles south-southeast of Karnes City, are shown in Figure 4. The average monthly temperature and precipitation at Kerrville, Uvalde, Seguin, and Cuero are shown in Figure 5. In general, most of the precipitation is during the spring and summer. However, in the Nueces Basin, where the climate is semiarid, precipitation generally is insufficient for growing most crops without supplemental supplies of water.

Temperature and evaporation records at Winter Haven, San Antonio, Dilley, and Beeville show that the temperature and evaporation are highest during June, July, and August (Figure 6). The average annual evaporation ranges from more than 78 inches in the western part to about 60 inches in the eastern, which is about two or three times the average annual precipitation. The length of the growing season differs from year to year, but the average ranges from 221 days in Kerr County to 334 days in Nueces County.

GENERAL GROUND-WATER HYDROLOGY

The following discussion of some of the general principles of ground-water hydrology is presented as a review to aid in understanding the hydrologic discussions of the aquifers in the Guadalupe, San Antonio, and Nueces River Basins.

Source and Occurrence of Ground Water

The source and occurrence of ground water are integral parts of the hydrologic cycle, during which water follows paths of various length and complexity (Figure 7). The primary source of all ground water is precipitation. Water from precipitation, which is not evaporated at the surface, transpired by plants, or retained by capillary forces in the soil, migrates downward by gravity through the zone of aeration until it reaches the zone of saturation, where the rocks are saturated with water. The upper surface of the zone of saturation is the water table. Open spaces in the rocks--interstices or pore spaces between grains in clastic rocks, such as sand and gravel, and cracks, fissures, or solution cavities in carbonate rocks, such as limestone--contain the water in the zone of saturation.

Aquifers may be divided into two classes--water table, or unconfined aquifers, and artesian, or confined aquifers--depending on the mode of occurrence of the water. Unconfined water occurs in water-table aquifers wherever the upper surface of the zone of saturation is under atmospheric pressure only and is free to rise or fall with changes in the volume of water stored. A well penetrating a water-table aquifer becomes filled with water to the level of the water table. Confined water occurs in artesian aquifers which are separated from the zone of aeration by rocks of lower permeability; hence, the water is confined an under pressure. A well that penetrates an artesian aquifer becomes filled with water to a level above the point where the water was found. The level or surface to which the water will rise in artesian wells is called the piezometric surface. Although the terms water table and piezometric surface are synonymous in the outcrop area, the term piezometric surface as used in this report is applicable only in artesian areas. If the pressure is sufficient to cause the water to rise above the land surface, the well will flow.

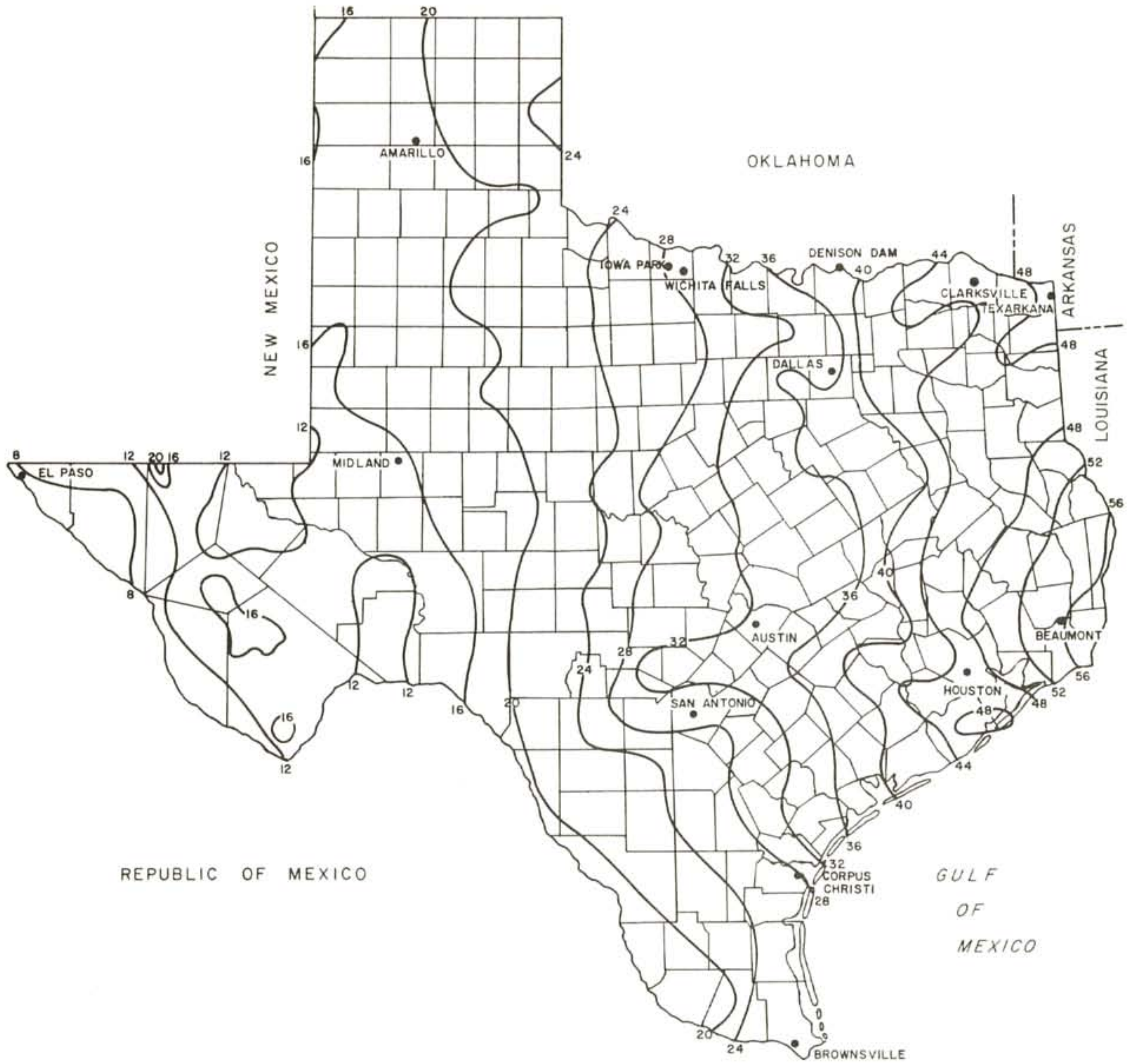

Figure 3

Map of Texas Showing Mean Annual Precipitation, in Inches, Based on the Period 1931-55

(After map prepared by U. S. Weather Bureau)

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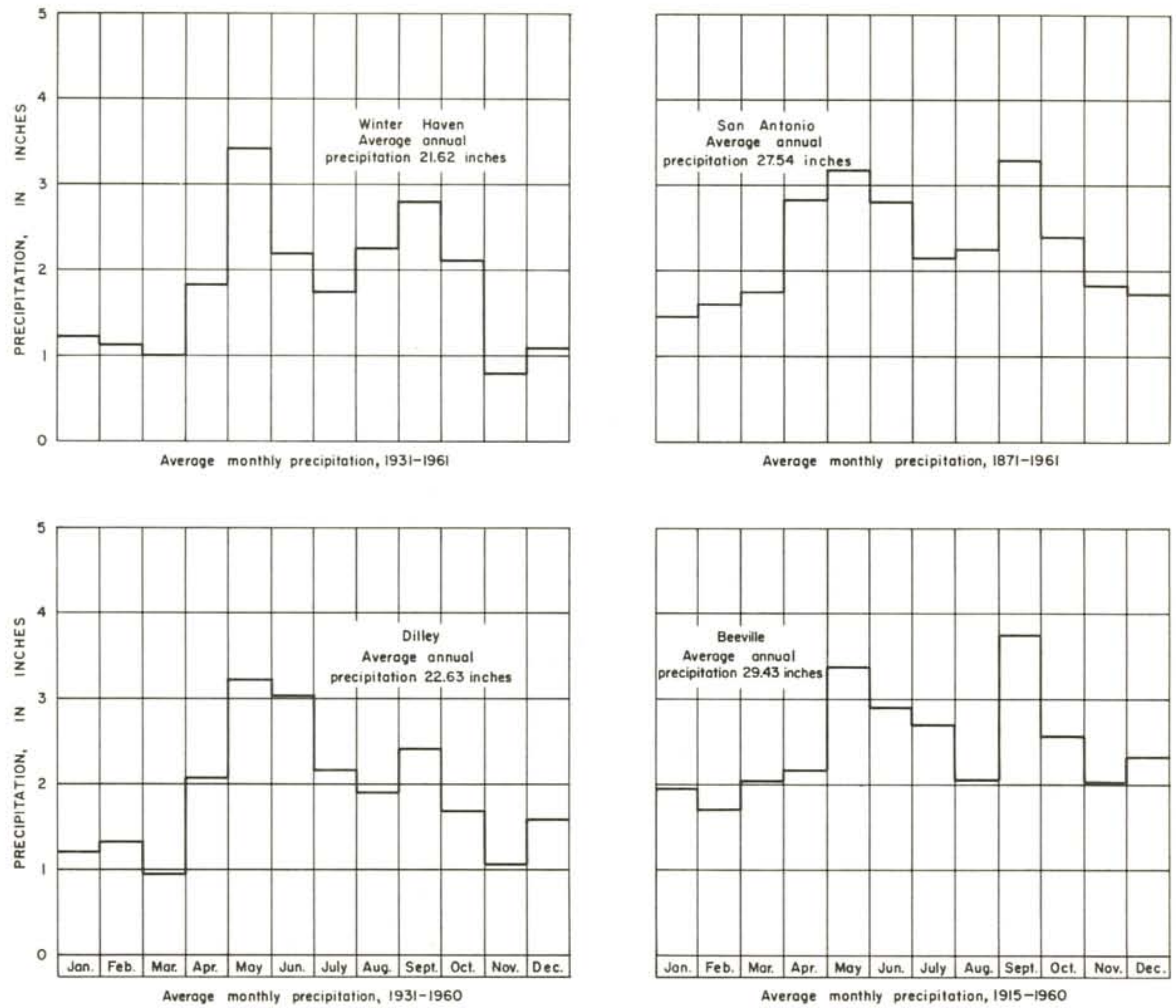

Figure 4

Average Monthly Precipitation at Winter Haven, San Antonio, Dilley, and Beeville

(Data from the U. S. Weather Bureau)

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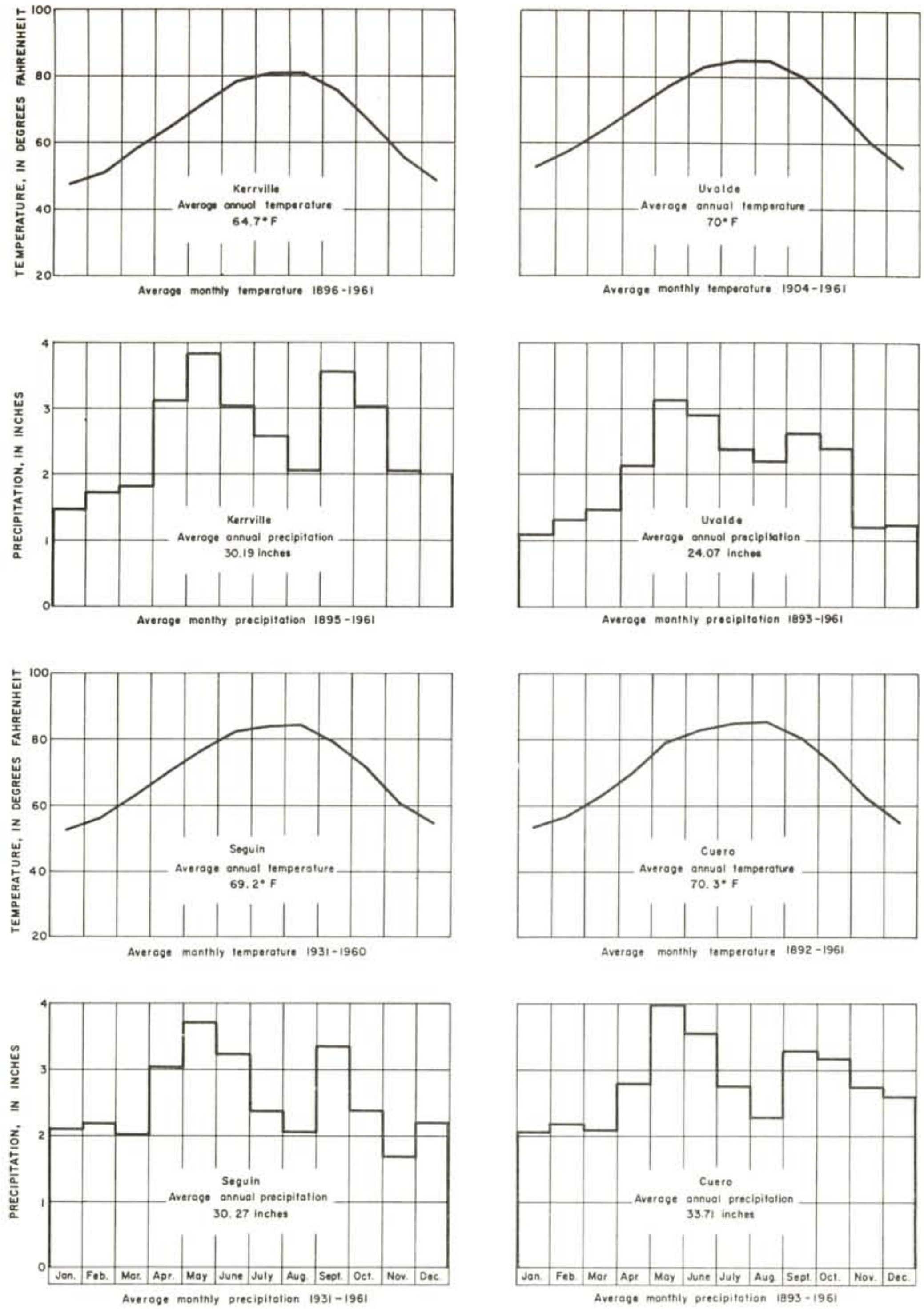

Figure 5

Average Monthly Temperature and Precipitation at Kerrville, Uvalde, Seguin, and Cuero

(Data from the U. S. Weather Bureau)

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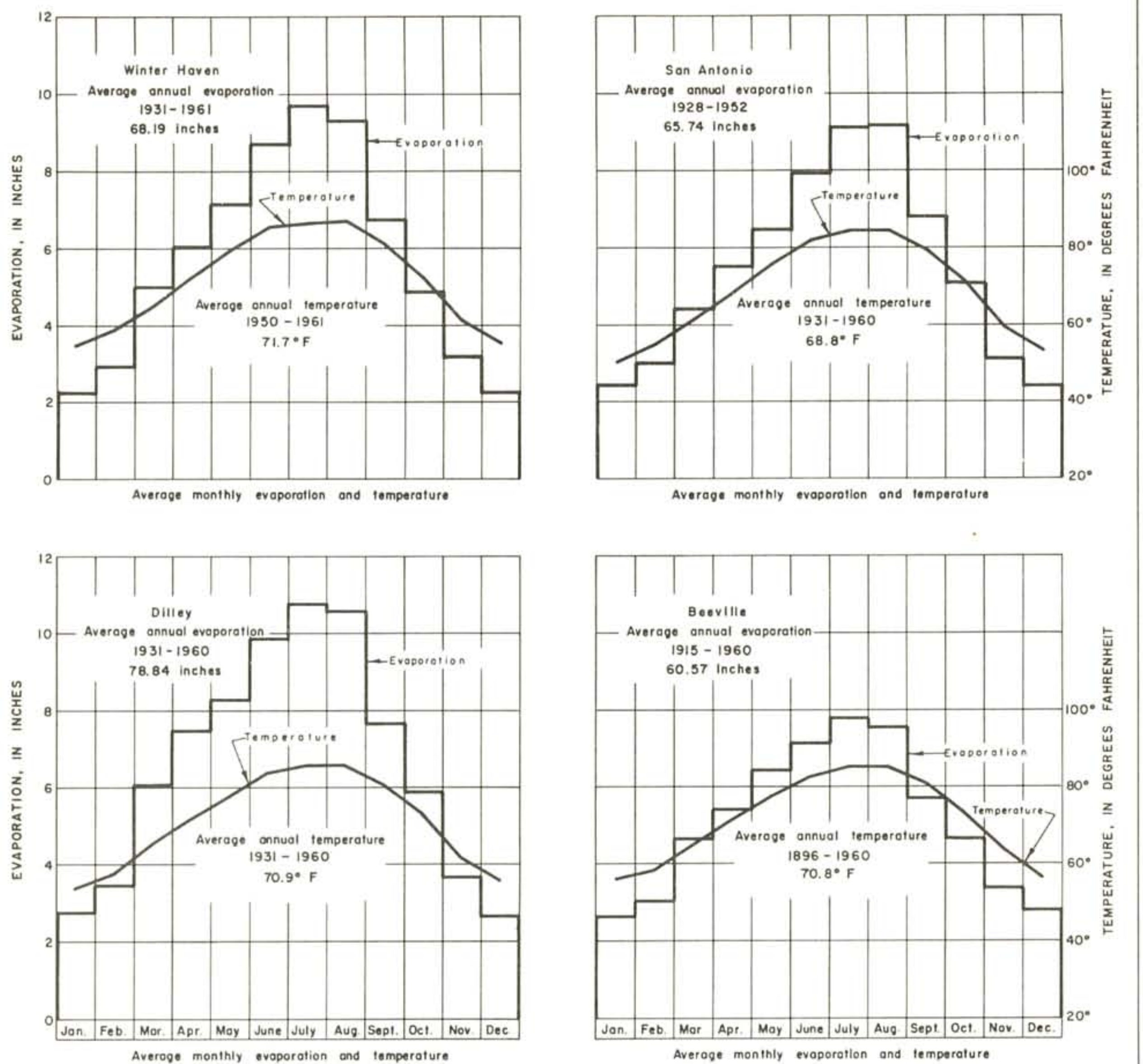

Figure 6

Average Monthly Evaporation and Temperature at Winter Haven, San Antonio, Dilley, and Beeville

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

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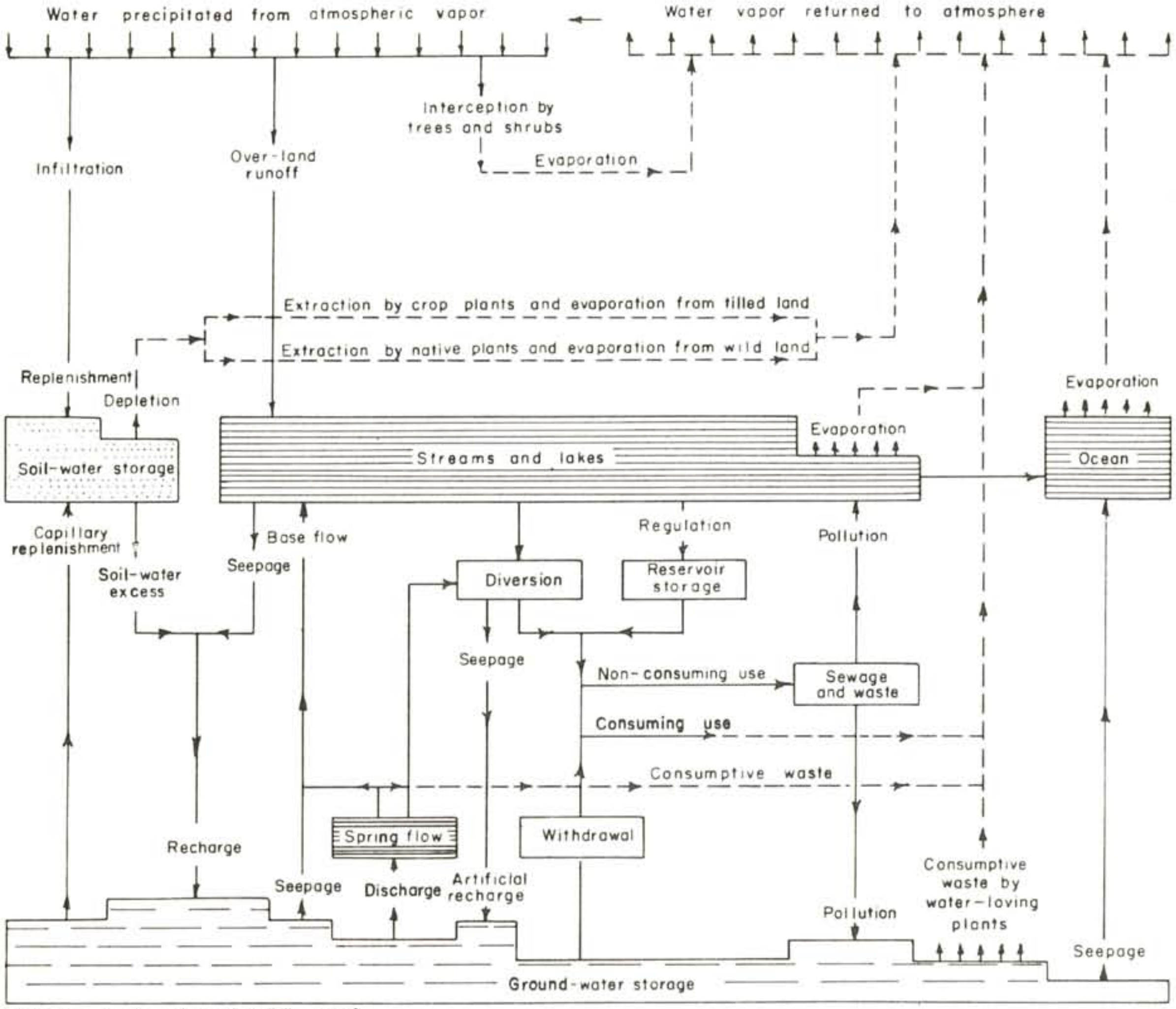

Modified from Piper (1953, p. 9)

Figure 7

The Hydrologic Cycle in the Guadalupe, San Antonio, and Nueces River Basins

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Recharge, Movement, and Discharge of Ground Water

Aquifers may be recharged either by natural or artificial processes. Natural recharge comes from rain, either where it falls or by runoff enroute to a water course, melting snow or ice, water in streams, lakes, or other natural bodies of water, subsurface transfer of water from one saturated rock unit to another, infiltration resulting from irrigation, and disposal of industrial wastes and sewage. Artificial recharge is accomplished by injection through wells and infiltration basins of various kinds.

The natural source of water for recharge is precipitation. In general, the greater the seasonal precipitation on the intake area of an aquifer the greater the recharge. Also, a given amount of rainfall in a short period usually produces less recharge than the same amount of rainfall over a longer period, although there are exceptions. A larger proportion of the precipitation infiltrating during the dormant or nongrowing season will reach the zone of saturation than during the season of active plant growth.

Gravity is the motivating force in the movement of water. After initial infiltration, the dominant direction of movement through the zone of aeration is vertical. After reaching the zone of saturation, the movement of the water generally has a large horizontal component in the direction of decreasing head or pressure. The movement is seldom uniform in direction or velocity. The water may be impeded by structural barriers, such as faults and folds, or by masses of impervious material--or the water may follow a devious path along courses of material having the least resistance to flow.

The rate of movement of ground water is a direct function of the size of the open spaces and interconnecting passages in rocks. The movement of ground water may range from velocities and volumes approaching zero to those of rapidly flowing streams. In most sand and gravel, the movement of ground water is very slow, ranging from tenths of a foot per day to many feet per year. Faster rates of movement usually are associated with cavernous limestone aquifers, where water flowing in subterranean channels may have velocities comparable to surface streams.

Water is discharged from aquifers both naturally and artificially. The most abvious method of natural discharge is by springs. Other means of natural discharge include seepage to streams, lakes, and marshes that intersect the water table, transpiration by vegetation, and evaporation through the soil where the water table is close to the land surface. Ground water also is discharged naturally beneath the land surface by transfer of water from one aquifer to another in response to differences in head. Because gravity is the motivating force in its movement, ground water is always discharged naturally from an aquifer at a lower altitude than the intake or recharge area of that aquifer. Withdrawal of water from pumping and flowing wells represents artificial discharge of ground water.

Chemical Quality of Ground Water

The mineral constituents of ground water are dissolved principally from the soil and rocks through which the water has passed; consequently, the differences in chemical character of ground water reflect in a general way the nature of the geologic formations in contact with the water. Deep water usually is free from contamination by organic matter, but the chemical content of ground water usually increases with depth. The temperature of ground water near the land surface generally approximates the mean annual air temperature of the region and increases with depth.

The suitability of a water supply depends on the chemical quality of the water and the limitations associated with the comtemplated use of the water. Various criteria for water-quality requirements have been developed including most categories of water quality, bacterial content, physical characteristics, and chemical constituents. Usually, water-quality problems of the first two categories can be alleviated economically, but the removal or neutralization of undesirable chemical constituents can be difficult and expensive. For many purposes the total dissolved-solids content constitutes a major limitation on the use of the water. A general classification of water based on dissolved-solids content is as follows (Winslow and Kister, 1956, p. 5):

Description	Dissolved-solids content, in 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

The United States Public Health Service has established and from time to time 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 public water supplies. According to the standards, chemical constituents should not be present in a 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 (ppm)
Chloride (Cl)	250
Fluoride (F)	*
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Total dissolved solids	500

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

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

Water having concentrations of chemical constituents in excess of the recommended limits may be objectionable for various reasons. In areas where the nitrate content of water is in excess of 45 ppm (parts per million), a potential danger exists. Concentrations of nitrate in excess of 45 ppm in water used for infant feeding have been related to the incidence of infant cyanosis (Maxcy, 1950, p. 271). High concentrations of nitrate may be an indication of pollution from organic matter, commonly sewage. Excessive concentrations of iron and manganese in water cause reddish-brown or dark-gray precipitates that stain clothes and plumbing fixtures. Water having a chloride content exceeding 250 ppm may have a salty taste, and sulfate in water in excess of 250 ppm may produce a laxative effect. Excessive concentrations of fluoride in water may cause teeth to become mottled; however, fluoride in concentrations of about 1 ppm may reduce the incidence of tooth decay (Dean, Arnold, and Elvove, 1942, p. 1155-1179).

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. The commonly accepted standards and classifications of water hardness are shown 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 quality of water for industry does not depend necessarily on potability. Water suitable for industrial use may or may not be acceptable for human consumption. Ground water used for industry may be classified into three principal use categories--cooling, process, and boiler.

Cooling water usually is selected for its temperature and source of supply, although its chemical quality also is significant. Any characteristic that may affect adversely heat-exchange surfaces is undesirable. Calcium, magnesium, aluminum, iron, and silica may cause scale. Corrosiveness is another objectionable feature. Calcium and magnesium chloride, sodium chloride in the presence of magnesium, acids, oxygen, and carbon dioxide are among substances that make water corrosive.

The quality of water for the production of steam must meet rigid requirements. Here the problems of corrosion and encrustation are intensified greatly. Some treatment of boiler water may be needed, and it may be better to evaluate the suitability of the water for treatment rather than for direct use as raw water. Silica in boiler water is undesirable because it forms a hard scale, the scale-forming tendency increasing with pressure in the boiler.

Process water is subject to a wide range of quality requirements. Usually rigidly controlled, these requirements commonly involve physical, chemical, and biological factors. In general, water used in manufacture of textiles must be low in dissolved-solids content and free of iron and manganese. The paper industry, expecially where high-grade paper is made, requires water in which all heavy metals are either absent or in small concentrations. Water free of iron, manganese, and organic substances normally is required by many beverage industries. Unlike cooling and boiler water, much of the process water is consumed or undergoes a change in quality in the manufacturing process and is not available generally for reuse.

The suitability of water for irrigation depends on the chemical quality of the water and other factors such as soil texture and composition, crop types, irrigation practices, and climate. Many classifications of irrigation water express the suitability of water in terms of one or more of these variables and offer criteria for evaluating the relative overall suitability of irrigation water rather than placing rigid limits on the concentrations of certain chemical constituents. The most important chemical characteristics pertinent to the evaluation of water for irrigation are the proportion of sodium to total cations, an index of the sodium hazard; total concentration of soluble salts, an index of the salinity hazard; residual sodium carbonate; and concentration of boron.

Sodium can be a significant factor in evaluating quality of irrigation water because of its potential effect on soil structure. A high percentage of sodium in water tends to break down soil structure by deflocculating the colloidal soil particles. Consequently, soils can become plastic, movement of water through the soil can be restricted, drainage problems can develop, and cultivation can be rendered difficult. A system of classification commonly used for judging the quality of water for irrigation was proposed in 1954 by the U. S. Salinity Laboratory Staff (1954, p. 69-82). The classification is based primarily 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). This classification of irrigation water is diagrammed in Figure 8.

An excessive concentration of boron renders a water unsuitable for irrigation. Scofield (1936, p. 286) indicated that boron concentrations as much as 1 ppm are permissible for irrigating most boron-sensitive crops and concentrations as much as 3 ppm are permissible for the more boron-tolerant crops, as shown in the following table:

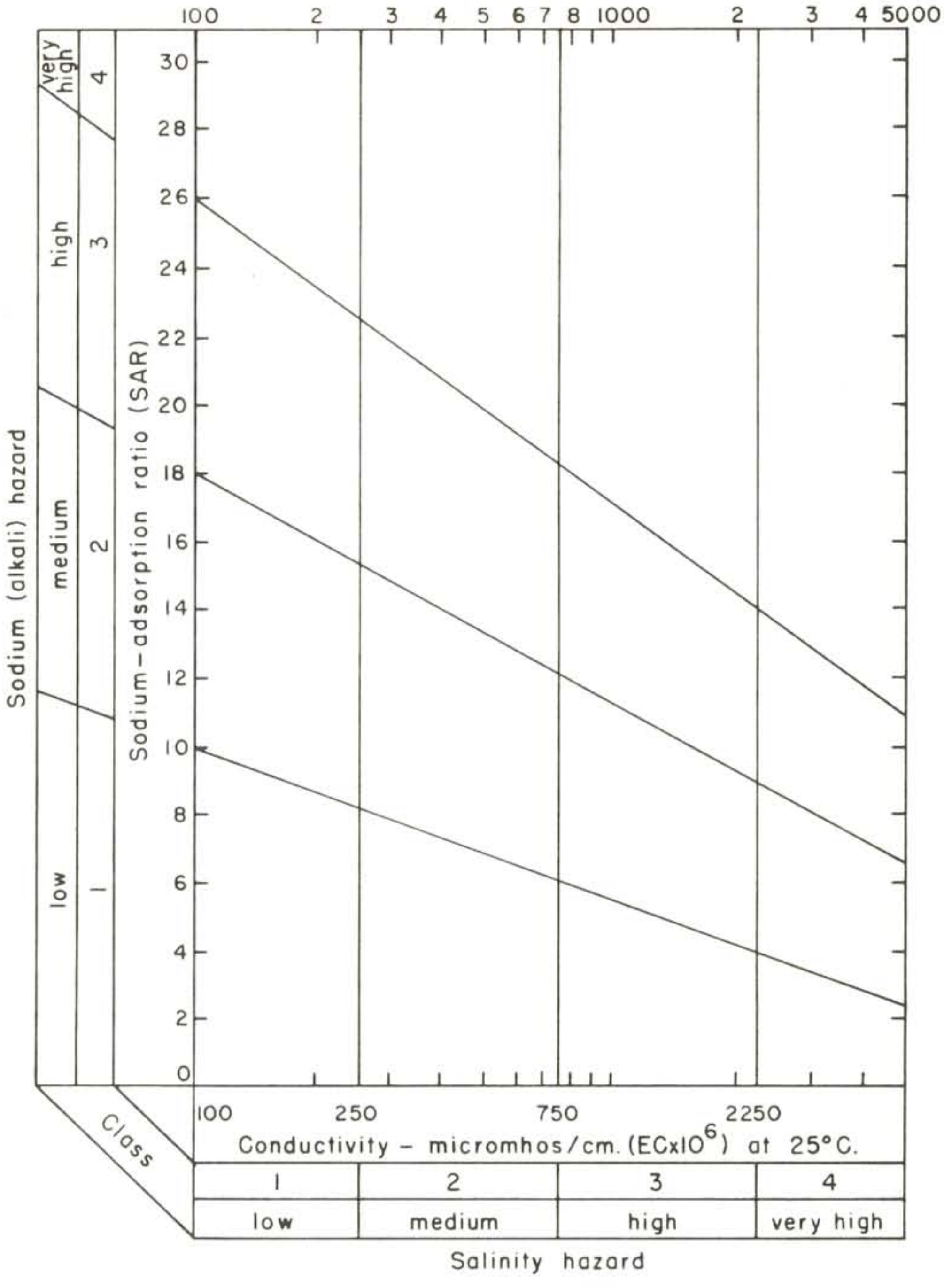

Figure 8

Diagram for the Classification of Irrigation Waters

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

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Permissible limits of boron for irrigation waters

Classes of water		Sensitive crops (ppm)	Semitolerant crops (ppm)	Tolerant crops (ppm)
Rating	Grade			
1	Excellent	<0.33	<0.67	<1.00
2	Good	0.33 to .67	0.67 to 1.33	1.00 to 2.00
3	Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	Unsuitable	> 1.25	> 2.50	>3.75

Quality limits for livestock are variable. The limit of tolerance depends principally on the kind of animal, and, according to Heller (1933, p. 22), the total amount of soluble salts in the drinking water, more so than the kind of salt, is the important factor. Heller also suggests that as a safe rule, 15,000 ppm dissolved-solids content should be considered the upper limit for most of the more common stock animals.

Changes in Water Levels

Water levels in wells respond continuously to natural and artificial factors acting on the aquifers. In general, the major factors that control changes in levels are the rates of recharge to and discharge from the aquifers. Changes of levels are caused also by variations in atmospheric pressure, variations in the load on aquifers commonly caused by changes in the level of streams, lakes, and other bodies of water overlying artesian aquifers, tidal effects, and other less common disturbances. The fluctuations usually are gradual, but in some places levels rise or fall from several inches to feet in a few minutes.

Fluctuations due to natural factors generally are cyclic. Daily fluctuations are caused chiefly by barometric fluctuations, tidal effects, or changes in rate of evapotranspiration. Annual fluctuations are the result generally of changes in the amount of precipitation and evapotranspiration throughout the year; hence, changes in the amount of water available for recharge.

Water-level fluctuations of considerable magnitude may result from withdrawal of water from wells. In water-table aquifers, fluctuations of levels due to pumping are less pronounced generally than in artesian aquifers, the decline of level being the result of a decrease in the storage of water. In artesian aquifers, levels fluctuate primarily from an increase or decrease in pressure; the change in the amount of water in storage may be small.

Hydraulic Characteristics of Aquifers

The extraction of water from a well establishes a hydraulic gradient toward the well, the gradient being either that of the water table or piezometric surface. In a pumping or flowing well, the elevation of the water table or piezometric surface is lower than it was before discharge was started, and the difference between the discharging level and the static level (water level before pumping started) is the drawdown. The water table or piezometric surface surrounding a discharging well assumes more or less the shape of an inverted cone called the cone of depression.

Formulas have been developed to show the relations among the discharge of a well, the shape and extent of the cone of depression, and the properties of the aquifer, such as permeability, specific yield, and porosity. Permeability is defined as the capacity for transmitting water under pressure, quantitatively expressed as the rate of discharge of water in gallons per day through a cross section of 1 square foot under a unit hydraulic gradient; specific yield is the quantity of water that a formation will yield under gravity if it is first saturated and then allowed to drain; and the porosity is the ratio, in percent, of the aggregate volume of interstices in a rock to its total volume. The formulas indicate that, within limits, discharge from a well varies directly with drawdown--that is, doubling the drawdown of a well will double or nearly double its discharge. The discharge per unit of drawdown, or specific capacity, is of value in estimating the probable yield of a well drilled in a given formation.

Aquifer tests employing these formulas also supply hydraulic information about the aquifer with which the coefficients of transmissibility and storage may be computed. The coefficient of transmissibility is the rate of flow of water in gallons per day through a vertical strip of the aquifer 1 foot wide extending through the vertical thickness of the aquifer at a hydraulic gradient of 1 foot per foot and at the prevailing temperature of the water. The transmission capacity of an aquifer is defined as the quantity of water that can be transmitted through a given width of an aquifer at a given hydraulic gradient.

The coefficient of storage is the volume of water that the aquifer releases from or takes into storage per unit surface area, per unit change in the component of the head normal to that surface. Under artesian conditions, the coefficient of storage is a measure of the ability of the formation to yield water from storage by compression of the formation and the expansion of the water as the piezometric surface is lowered. The coefficient of storage for an artesian aquifer is small compared to that of a water-table aquifer; consequently, after an artesian well starts discharging, a cone of depression is developed over a wide area in a short time. In a water-table aquifer, the coefficient of storage is much larger, as it reflects removal of water from storage by gravity drainage of the aquifer, and, under these conditions, it is nearly equal to the specific yield.

Figure 9 shows the theoretical relation between drawdown and the distance from the center of pumpage for different coefficients of transmissibility. The calculations of drawdown are based on a withdrawal of 1 million gallons per day over a 1-year period from aquifers having coefficients of transmissibility and storage as shown. For example, if the coefficients of transmissibility and storage are 5,000 gpd (gallons per day) per foot and 0.0001, respectively, the drawdown or decline in the water level would be 85 feet at a distance of 1 mile from a well or group of wells discharging 1,000,000 gpd for 1 year.

Figure 10 shows the relation of drawdown to time with pumpage from an artesian aquifer of infinite areal extent. It shows that the rate of drawdown decreases with an increase of time. The equilibrium curve shows the drawdown-time relation when a line source of recharge is 20 miles from the point of discharge.

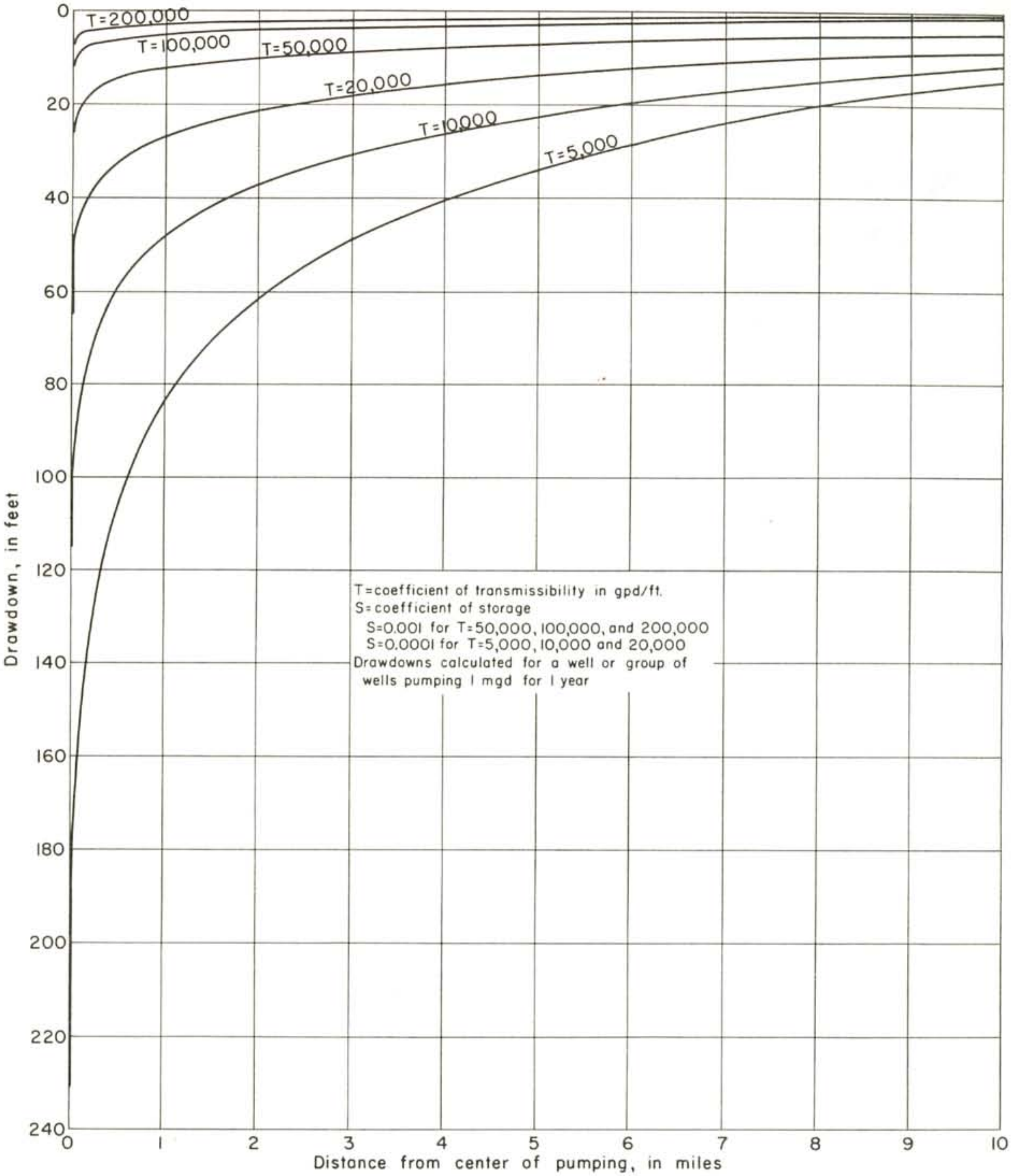

Figure 9

Graph Showing Relation of Drawdown to Transmissibility

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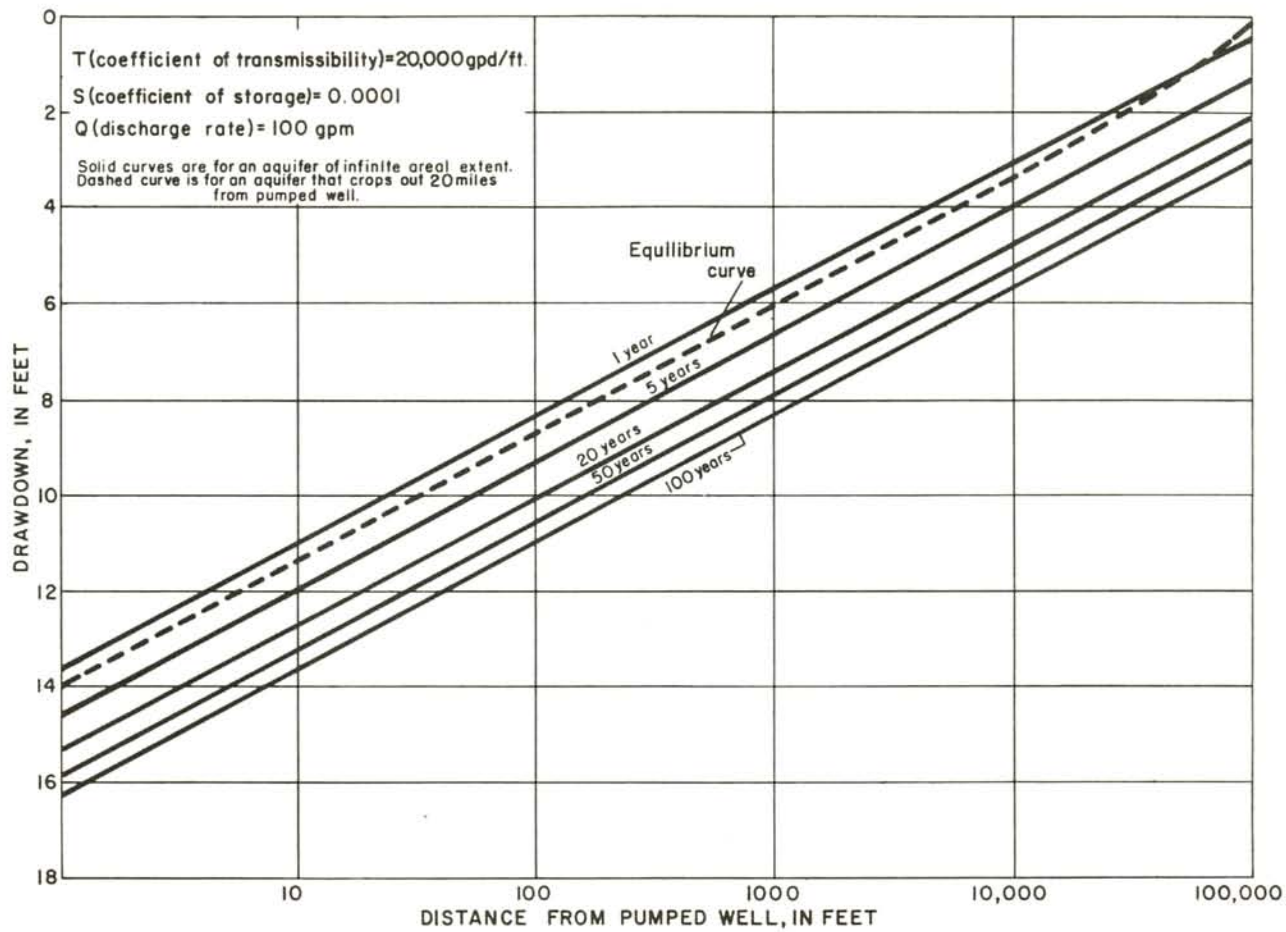

Figure 10

Graph Showing Relation of Drawdown to Time in an Artesian Aquifer

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Figure 11 shows the relation of drawdown to time with pumpage from a water-table aquifer of infinite areal extent. The drawdown is less than that in an artesian because of the larger coefficient of storage, other factors being equal. equal.

Wells drilled close together commonly create cones of depression that intersect, thereby excessively lowering the water table or piezometric surface. The overlapping of cones of depression or interference between wells may cause a serious decrease in yield of the wells, an increase in pumping costs, or both.

In discussing relative well yields in this report, small yields are less than 100 gpm (gallons per minute), moderate yields are from 100 to 1,000 gpm, and large yields are more than 1,000 gpm.

GENERAL GEOLOGY

Geologic History

The rocks described in this report are sediments that accumulated along the interior border of the extensive Gulf Coast geosyncline during the latter part of the Mesozoic Era and the Cenozoic Era. The following rock systems are represented, in ascending order: Cretaceous rocks of Mesozoic age and Tertiary and Quaternary rocks of Cenozoic age.

Cretaceous time began with a broad invasion of the sea from the south and southeast, across a landmass that had been reduced to low relief by erosion. The ancient landmass in the northern part of the report area is composed of Paleozoic strata bordered on the south and southeast by metamorphic rocks of unknown age (Flawn and others, 1961, Pl. 2). In the report area and in the area to the north, the Cretaceous formations from the Houston Formation to the Edwards Limestone are overlapped by younger formations, each of which in turn rests on pre-Cretaceous formations.

The Cretaceous sea continued its northward advance, and by Eagle Ford time, it had reached Colorado (Adkins in Sellards, Adkins, and Plummer, 1932, p. 260-261). Near the end of Cretaceous time, the sea retreated Gulfward. The Cretaceious Period marked the last great epicontinental marine invasion, and succeeding Tertiary seas were restricted to relatively narrow areas near the continental margin.

Tertiary history is characterized by the alternation between the encroachment of the Gulf of Mexico and deposition from the heavily loaded large streams. This oscillation of the sea prevailed throughout the early and middle part of the Tertiary Period, and many hundreds of feet of clastic sediments were deposited. In late Pliocene or early Pleistocene time, gravel, sand, and silt were deposited by streams over much of the Coastal Plain area. Erosion lowered much of the land surface, and as a result, remnants of ancient stream deposits were left as terraces capping some of the divide areas. Much of this terrace material is lag gravel composed of flint and other resistant rock fragments. Terraces of Pleistocene age underlain by gravel, sand, silt, and clay are common along the larger streams.

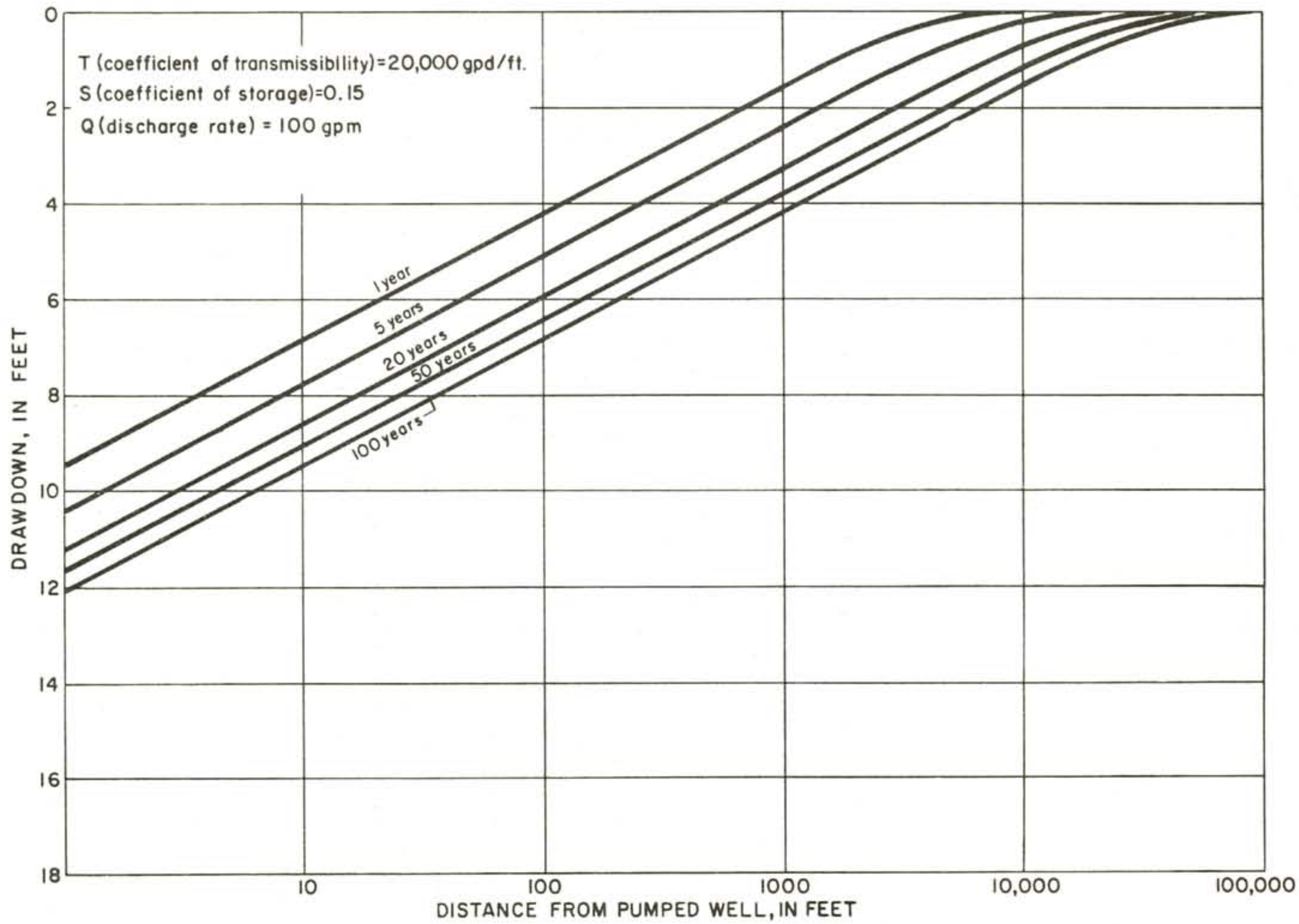

Figure 11

Graph Showing Relation of Drawdown to Time in a Water-Table Aquifer

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Geologic Structures

The structure of the rocks affects the occurrence and movement of ground water in the Guadalupe, San Antonio, and Nueces River Basins. Among the principal structural features in the report area are the Rio Grande embayment, the Balcones fault zone, and the Luling fault zone, all in the Gulf Coast geosyncline.

The configuration of the Gulf Coast geosyncline in the report area is indicated by the pattern of the outcrops of the Tertiary rocks (Plates 1 and 2). In the Guadalupe and San Antonio Basins, the outcrops of the formations trend southwestward, but in the western part of the Nueces River Basin, the formations make a broad, nearly right-angle turn southward. The amount of subsidence that has taken place in the geosyncline is indicated by the slope of the surface of the pre-Cretaceous rocks. According to Flawn and others (1961, Pl. 4), in the Nueces River Basin this surface slopes southward from an altitude of 1,000 feet above sea level in northern Real County to 2,500 feet below sea level in the central parts of Kinney, Uvalde, and Medina Counties, and to more than 12,000 feet below sea level in the central parts of Zavala and Frio Counties. In the Guadalupe and San Antonio River Basins, the pre-Cretaceous surface slopes southeastward from an altitude of 1,000 feet above sea level in northern Kendall County to 2,500 feet below sea level in northern Guadalupe County and the central part of Bexar County, and to more than 8,000 feet below sea level in the central part of Wilson County and southern Guadalupe County. The effect of this subsidence during the accumulation of the sediments is illustrated by the alternating beds of sand, silt, and clay of Tertiary and Quaternary age, which crop out in belts that roughly parallel the coast. The oldest formation crops out close to the northern and northwestern boundary of the Coastal Plain and progressively younger formations are exposed toward the coast (Plates 1 and 2). The formations thicken toward the coast and dip southeastward at an angle slightly greater than the slope of the land surface. The regional dip increases from the youngest to the oldest formations. The alternation of permeable and relatively impermeable strata within this structure is favorable to the occurrence of water under artesian pressure.

Rio Grande Embayment

The Rio Grande Embayment extends into Dimmit and Zavala Counties where it is composed of an anticline trending southeasterly across central Dimmit County flanked by southeastward-trending synclines in southwestern Zavala County and in southern and southwestern Dimmit County. These structures are clearly shown by the configuration of the top of the Carrizo Sand (Plate 8) and by the position of the outcrop of the Carrizo Sand, which in the vicinity of Carrizo Springs swings several miles east of its position to the north and south of Carrizo Springs. The dip of the rocks on the anticline and on the flanking synclines is low, generally not more than 80 feet per mile, and, consequently, the Carrizo Sand occurs at shallower depths over a large part of the Winter Garden district than in the rest of the report area. Eastward in the San Antonio and Guadalupe Basins (Plate 9), the dip is as much as 150 feet per mile.

Balcones Fault Zone

The Balcones fault zone consists of a series of more or less parallel faults in a belt about 15 miles wide that extends across the report area from the southern part of Hays County southwestward to Bexar County, and thence generally westward to Uvalde County (Plates 1 and 2). West of Uvalde County, the fault zone grades into a monocline that dips rather steeply southward. The faults are approximately parallel to the trend of the fault zone in Hays, Comal, and Bexar Counties; in Medina County and northeastern Uvalde County, the individual faults are also approximately parallel, but they occur at small angles to the trend of the fault zone (Plates 1 and 2). Most of the faults are of the normal or tension type with the downthrow to the south or east, depending on the strike. They range in length from a few hundred feet to about 50 miles. The displacement is greatest generally near the middle of the fault trace, and the maximum displacement of any single fault is about 700 feet (Petitt and George, 1956, p. 19). In Comal County, the combined displacement of all faults is about 1,500 feet. During faulting, fractures were developed in the limestone adjacent to the faults. These fractures are mostly parallel to the faults, and when enlarged by the solvent action of ground water, they become effective channels for the movement of ground water.

Luling Fault Zone

The Luling fault zone, 10 to 20 miles southeast of the Balcones fault zone, extends from northern Bastrop County, which adjoins Caldwell County on the east, to southeastern Medina County (Plates 1 and 2). It is a belt of more or less parallel faults, but not as wide as the Balcones fault zone. The faults of the Luling zone are normal faults also, but in contrast to those in the Balcones fault zone, the downthrown sides are on the northwest sides of the fault planes (Plate 1). The displacements of the faults range from a few feet in single faults to more than 1,500 feet for the combined displacement of several faults.

A graben separates the Balcones and Luling fault zones (Zink, 1957, Fig. 3). The structural significance of this graben is not obvious because of the strong tilting of the area to the southeast. In Caldwell County, the graben contains more than 1,000 feet of Upper Cretaceous shale and marl (Rasmussen, 1947, p. 10) and similar rocks occur in the graben elsewhere in the report area. Consequently, the rocks in the graben may be expected to yield only small amounts of ground water.

Geologic Units and Their Water-Bearing Properties

The geologic units that are of importance as sources of ground water in the report area range in age from Early Cretaceous to Pleistocene. In this report, the principal water-bearing units or aquifers are referred to as primary or secondary, depending on whether they yield large amounts of water in relatively large areas (primary aquifers), or whether they yield either large amounts of water in relatively small areas or small amounts of water in relatively large areas (secondary aquifers). The primary aquifers are the Edwards and associated limestones; the Balcones aquifer; the Carrizo Sand and Wilcox Group, undifferentiated, both of Eocene age; and the Gulf Coast aquifer from Miocene to Pleistocene in age. Secondary aquifers are the Hosston, Sligo, and Pearsall Formations, and the Glen Rose Limestone, all of Cretaceous age; the the Queen City Sand Member of the Mount Selman Formation and the Sparta Sand, both of Eocene age; the Leona Formation of Pleistocene age; and alluvial deposits of Recent age. The primary and secondary aquifers and their water-bearing properties are discussed in detail in the section on the major hydrologic subdivisions--the Edwards Plateau and the West Gulf Coastal Plain. Many other water-bearing formations yield small quantities of water in the report area, but because of their local extent, they are not discussed in detail.

The thickness of the various stratigraphic units and a brief discussion of their character and water-bearing properties are shown in Table 1.

Pre-Cretaceous Rocks

Pre-Cretaceous rocks do not crop out in the report areas, but underlie rocks of Cretaceous age at increasingly greater depths southward. These rocks, probably Paleozoic in age, consist of black, red, and green non-calcareous shale, sandstone, limestone, schist, and slate.

They are not known to yield water to wells in the report area.

Cretaceous System

The Cretaceous System of rocks in the Texas-Mexico region has been divided into the Coahuila, Comanche, and Gulf Series. Rocks of the Coahuila Series crop out in Mexico, and their probable equivalents are exposed at the surface in Arkansas, but do not crop out in Texas. The formations have been identified in oil tests in south-central and southwestern Texas, but are seldom recognized in water wells.

Coahuila Series

The oldest basinward strata of Cretaceous age, extending from Arkansas to Mexico, have been classified by Imlay (1945, p. 1416-1469) as the Hosston, Sligo, and Pearsall Formations, in ascending order. The Pearsall is the subsurface equivalent of the Travis Peak Formation of the Comanche Series. The Hosston and Sligo Formations are correlative with the Nuevo Leon and Durango Groups of the Coahuila Series of Mexico.

The Hosston Formation ranges in thickness from 0 to 900 feet and is composed of conglomerate, sandstone, red and green clay, shale, dolomite, and limestone. The overlying Sligo Formation ranges in thickness from 0 to 200 feet and is composed of limestone, in places dolomitic, sandy dolomite, shale, and sandstone. The Hosston and Sligo form a wedge from 0 to 1,100 feet thick between the underlying Paleozoic rocks and the overlying Pearsall Formation, the wedge thinning generally northward.

Small to moderate supplies of fresh water are obtained from the Hosston and Sligo Formations in Bandera County and from the Hosston Formation in northwestern Bexar County. Similar supplies might be expected in parts of Comal, Hays, Blanco, Kendall, and Kerr Counties.

Table 1.--Geologic units and their water-bearing properties, Guadalupe, San Antonio, and Nueces River Basins

Era	System	Series	Group	Geologic unit	Approximate thickness (ft.)	Lithologic character	Water-bearing properties
Cenozoic	Quaternary	Recent		Alluvium	0- 30	Clay, silt, sand, and gravel.	Yields small to moderate quantities of fresh water.
		Pleistocene		Leona Formation	0- 80	Silt, sand, and gravel.	Yields small to moderate quantities of fresh water; locally it yields sufficient quantities of water for irrigation.
				Beaumont Clay	50- 600	Clay and beds of sand.	Yields small to moderate quantities of fresh to slightly saline water in Victoria and Calhoun Counties.
				Lissie Formation	500- 600	Thick beds of sand containing lenses of gravel interbedded with clay and silt.	Yields small to large quantities of fresh water to wells in Goliad and Victoria Counties.
	Tertiary(?)	Pliocene(?)		Uvalde Gravel	0- 30	Gravel composed almost entirely of flint.	Caps some divide areas; not known to contain appreciable quantities of water because of its topographic position and thickness.
	Tertiary	Pliocene		Goliad Sand	100- 500	Sand and sandstone interbedded with clay and gravel. Caliche characteristic of formation in area of outcrop.	Yields small to moderate quantities of fresh to slightly saline water to wells in Goliad County and large supplies of fresh water to wells in Victoria County.
		Miocene(?)		Lagarto Clay	500-1,000+	Clay and sandy clay interbedded with sand and sandstone.	Yields small to moderate quantities of fresh to slightly saline water to wells in Karnes and Live Oak Counties.
		Miocene		Oakville Sandstone	200- 800	Sand and sandstone interbedded with silt and bentonitic clay.	Do.
		Miocene(?) and Oligocene(?)		Catahoula Sandstone or Tuff	5- 10	Sandstone, locally cemented to quartzite.	Occurs only in small area in eastern Gonzales County. Not known to yield water to wells in report area.
					500-1,000+	Tuff, tuffaceous clay, sandy clay, bentonitic clay, and lenticular sandstone.	Yields small to moderate quantities of fresh to slightly saline water in Karnes and Live Oak Counties.
		Oligocene(?)		Frio Clay	200- 300	Clay and silty clay with small amounts of sand and gypsum.	Not known to yield water to wells.
		Eocene	Jackson		900-1,500	Clay, sand, silt, bentonitic clay, volcanic ash, lignite, and tuffaceous sand.	Yields small to moderate quantities of fresh to moderately saline water in Karnes and Live Oak Counties.
			Claiborne	Yegua Formation	670-1,000+	Medium to fine sand, silt, and clay in San Antonio and Guadalupe River Basins. Chiefly clay, with some sandy clay, lignite, gypsum, limestone, and limestone concretions in Nueces River Basin.	Generally yields small quantities of slightly to moderately saline water. Locally yields moderate quantities of fresh water in the San Antonio and Guadalupe River Basins. Yields small quantities of moderately to very saline water in the Nueces River Basin.
				Cook Mountain Formation (San Antonio and Guadalupe River Basins)	400- 450	Chiefly fossiliferous clay and shale, a few lenses of sandstone and limestone, and some glauconite and gypsum.	Yields small quantities of slightly to moderately saline water.

(Continued on next page)

Comanche Series

The Comanche Series has been divided into the Trinity, Fredericksburg, and Washita Groups, in ascending order. The oldest rocks exposed in the report area are part of the Trinity Group--the Cow Creek Limestone Member of the Travis Peak Formation crops out in northern Comal County, and the overlying Hensall Sand Member of the same formation crops out along the Blanco River in western Hays County and along the Guadalupe River in eastern Kendall County (Plate 1).

Trinity Group

Travis Peak (Subsurface Pearsall) Formation

In the report area, the Trinity Group includes the Travis Peak Formation and the overlying Glen Rose Limestone. Imlay (1945, p. 1441) assigned the rocks above the Sligo Formation and below the Glen Rose Limestone to the Pearsall Formation in the subsurface section in south Texas, the type section being at a well in Frio County. He subdivided the Pearsall Formation into the Pine Island Shale, Cow Creek Limestone, and Hensell Shale Members, in ascending order. These members compose a lithic sequence similar to the members of the Travis Peak Formation (Hill, 1901, p. 141) where they crop out, and Imlay suggested that the name Travis Peak be restricted to the formation where it is exposed at the surface in Kendall, Hays, and Comal Counties (Plate 1).

Pine Island Shale Member.--In Bandera County, the Pine Island Shale Member of the Pearsall Formation consists of sandy fossiliferous dark-blue to gray shale containing thin interbedded layers of dolomitic limestone. The thickness of the member ranges from 45 feet in the northern part of the county to about 70 feet in the southern part. The Pine Island yields no water to wells, but it is an important stratigraphic marker on electric logs of wells.

Cow Creek Limestone Member.--The Cow Creek Limestone Member of the Travis Peak and Pearsall Formations consists chiefly of sandy fossiliferous limestone and dolomite in Bandera County, but it is essentially a massive detrital limestone in Hays County. The member maintains a fairly uniform thickness of 50 to 75 feet throughout its extent in the report area. The Cow Creek and the underlying Pine Island Shale produce an easily recognized resistivity pattern on electric logs of wells. The Cow Creek yields small quantities of fresh water to wells in a large part of the Edwards Plateau.

Hensell Sand Member.--The Hensell Sand Member of the Travis Peak Formation (the Hensell Shale Member of the Pearsall Formation) consists of poorly cemented conglomerate, sandstone, and ferruginous clay in the northern part of Bandera County, changing to sandstone, shale, limestone, and sandy dolomite in the southern part. The member is 150 feet thick in the northern part of Bandera County and only 20 feet thick in the southern part. Lozo and Stricklin (1956, Fig. 4) interpret the Hensell as a sandy facies of the lower member of the Glen Rose Limestone.

The Hensell Sand Member is an important aquifer in only the northern part of Bandera County (Reeves and Lee, 1962, p. 11). Wells having yields of from 200 to 500 gpm of fresh water have been developed in the northern part of the county. In the southern part of the county, the yields are small and the water has a much larger sulfate content. Consequently, most wells in this area are drilled to the underlying and more permeable beds of the Cow Creek Limestone Member. In Comal County, the Hensell generally yields sufficient water for domestic and livestock use.

Glen Rose Limestone

In Comal County, George (1952, p. 17-18) divided the Glen Rose Limestone into lower and upper members, the division arbitrarily being made at the top of the Salenia texana zone. A persistent thin limestone bed at the top of the zone is composed of a layer of shells of the fossil Corbula texana Whitney. Throughout south-central Texas, the bed is commonly referred to as the "Corbula." Immediately above the Corbula texana bed is a zone 20 to 30 feet thick composed of dolomite, anhydrite, marl, and limestone, usually described as the lower anhydrite beds of the upper member of the Glen Rose. About 200 feet higher is a similar zone--the upper anhydrite beds. The two anhydrite zones are the most productive rocks in the upper member of the Glen Rose, but the high sulfate content makes the water unfit for most uses. The outcrop of the Glen Rose includes more than one-half of the area of the Edwards Plateau in the Guadalupe and San Antonio Basins but less than one-tenth of the plateau in the Nueces Basin (Plates 1 and 2).

Lower Member.--The lower member of the Glen Rose Limestone consists chiefly of massive fossiliferous limestone in the basal part and thin beds of marl and limestone in the upper part.

The thickness of the lower member of the Glen Rose in the northern part of the report area increases downdip, mainly because the time-equivalent Hensell thins in the downdip direction. In the northern part of Hays County, the lower member is about 124 feet thick; at Wimberley it is about 250 feet, and farther southeast in the county, it probably exceeds 300 feet. In the northern part of Bandera County, the lower member is 190 feet thick and in the southern part, 380 feet; in the northern part of Edwards County, it is 50 feet thick and in the southern part, 350 feet.

In general, the lower member of the Glen Rose Limestone yields small to moderate supplies of fresh water to wells. In places in the report area, the lower member is capable of transmitting large volumes of water. In Comal and Kendall Counties, large springs issue from the cavernous limestone; however, the many wells that have penetrated the entire thickness of the lower member have not obtained large yields.

Upper Member.--The upper member of the Glen Rose Limestone consists of shale and nodular marl alternating with thin beds of impure limestone; it also contains two beds of anhydrite. The limestone is more resistant to erosion than the shale and marl, and the member produces a characteristic terrace or "stair-step" topography. The thickness of the upper member is about 400 feet in Hays, Bandera, and Edwards Counties.

In general, the upper member of the Glen Rose yields small quantities of water to wells. The anhydrite beds, which are readily identified in electric logs because of their high resistivity, yield small quantities of saline water.

Fredericksburg Group

The Fredericksburg Group has been divided into the Walnut Clay, Comanche Peak Limestone, Edwards Limestone, and Kiamichi Formation, in ascending order. The Fredericksburg Group and the Georgetown Limestone of the Washita Group are shown in the geologic maps as a single unit (Plates 1 and 2). The Fredericksburg Group of rocks has a maximum thickness of about 900 feet.

The Comanche Peak and Edwards Limestones of the Fredericksburg Group and the Georgetown Limestone of the Washita Group were considered as a single hydrologic unit and referred to as the Edwards and associated limestones by Petitt and George (1956, p. 16). The Edwards and associated limestones supply most of the water for municipal, industrial, irrigation, and domestic uses in the Balcones fault zone area.

Walnut Clay

The Walnut Clay consists of sandy clay, marl, and limestone ranging in thickness from 1 to 20 feet. The thinness and persistence of the formation warrant its use as a stratigraphic marker. The Walnut Clay yields small quantities of water to a few farm wells in Comal County (George, 1952, p. 21-22), but generally is non-productive.

Comanche Peak Limestone

The Comanche Peak Limestone consists generally of light-gray nodular marly limestone. Adkins (in Sellards, Adkins, and Plummer, 1932, p. 334-337) indicated that the Comanche Peak is not of the same age throughout its extent, but that it is a nodular facies of the Fredericksburg Group; it may be, in part, laterally continuous with the Walnut Clay below and the Edwards Limestone above. The Comanche Peak which, in contrast to the Edwards, contains no flint, ranges in thickness from 30 to 70 feet.

The Comanche Peak is not differentiated by well drillers from the overlying Edwards Limestone. Because the formations are similar lithologically, they probably have similar water-bearing characteristics.

Edwards Limestone

The Edwards Limestone, which forms the surface of a large part of the Edwards Plateau, consists principally of light-gray brittle thick-bedded to massive limestone, commonly dolomitic, with minor beds of argillaceous or siliceous limestone and calcareous shale. Bedded or nodular chert and flint characterize much of the formation, but do not occur in the basal or upper part of the formation. The dolomitic beds have a sugary texture and when crushed in drilling yield sand-sized particles. The "sandstone" and "sandy limestone" reported in the Edwards by many drillers actually are beds of unconsolidated fine-grained dolomite.

In the outcrop, the Edwards weathers and forms a surface having a reddish calcareous clay soil containing numerous chert and flint nodules and fragments. In many places, both on the outcrop and in the subsurface, the Edwards is extensively honeycombed and cavernous. In general, the thickness of the Edwards Limestone in the report area ranges from 350 to 600 feet.

George (1952, p. 37) stated, "Some idea of the solvent action of ground water on the limestones in Comal County may be obtained from the chemical character of the water that issues at Comal Springs. The dissolved-solids content in the water at the spring averages about 285 parts per million. The average flow of the springs over a period of about 20 years has been 320 cubic feet per second. On this basis an average of more than 200 tons of rock material is carried away daily in solution by the water that issues from these springs."

The Edwards Limestone yields moderate to large quantities of fresh water and is the most prolific unit of the three limestones included in the Edwards and associated limestones. The water occurs chiefly in solution openings.

Kiamichi Formation

The Kiamichi Formation consists principally of black shale, brown and black limestone, which may be petroliferous, and anhydrite.

In the subsurface, the Kiamichi Formation is identified by the dark sulfurous and petroliferous nature of the drill cuttings and by high resistivity on electric logs. The thickness of the formation ranges from 155 feet at the outcrop in northwest Uvalde County (Welder and Reeves, 1962, p. 17) to about 210 feet in wells in Uvalde and Kinney Counties (Bennett and Sayre, 1962, p. 30). East of Uvalde County, the formation is absent in the report area. The Kiamichi Formation is not known to yield fresh water to wells in the report area.

Washita Group

The Washita Group has been divided into the Georgetown Limestone, Grayson Shale (formerly the Del Rio Clay), and Buda Limestone, in ascending order. The Georgetown Limestone has been included in the rocks that comprise the Edwards and associated limestones. The rest of the Washita Group, all the Gulf Series, and the Midway Group of Tertiary age are shown in the geologic maps as a single unit (Plates 1 and 2).

Georgetown Limestone

The Georgetown Limestone lies disconformably upon the Edwards Limestone in the report area except in the western part where it overlies the Kiamichi Formation. In much of the report area, the contact between the Georgetown and Edwards Limestones shows little evidence of the disconformity other than the absence of the Kiamichi Formation. In some places, the upper part of the Edwards and the lower part of the Georgetown also are missing.

The Georgetown Limestone consists principally of hard massive limestone containing thin beds of marl in some places. The formation contains chert nodules at least in Uvalde and Kinney Counties. From Hays County to Medina

County, the thickness of the Georgetown Limestone ranges from 20 to 65 feet. In Uvalde County, the thickness ranges from 310 to 400 feet, and in Kinney County the thickness may be as much as 500 feet.

The Georgetown Limestone yields large quantities of fresh water in Bexar County, and it is the principal aquifer in Uvalde County. In Hays and Comal Counties, however, the Georgetown generally is not water bearing.

Midway Group, Gulf Series, Buda Limestone, and Grayson Shale

The geologic Formations from the Grayson Shale of Late Cretaceous age to the Wills Point Formation of Paleocene age, which include aquifers of only local importance, are shown in the geologic maps (Plates 1 and 2) and in the geologic sections (Plates 3 through 6) as a unit. Brief descriptions of the lithology and water-bearing properties of the Formations in this unit are given in Table 1. The unit crops out in a belt from 10 to 22 miles wide between the Balcones escarpment and the base of the Wilcox Group from Hays the Wilcox Group (Plates 1 and 2). The total thickness of the unit ranges from about 2,400 to 6,600 feet.

The Grayson Shale, Buda Limestone, Eagle Ford Shale, and Austin Chalk extend across the width of the report area. The Austin Chalk yields small to moderate amounts of fresh to slightly saline water to wells in the report area, and the Eagle Ford yields small quantities of water to wells west of Bexar County.

The correlation of Taylor marl and the Navarro Group in the San Antonio and Guadalupe River Basins with their equivalents in the Nueces River Basin is shown in Table 2.

The Taylor Marl, Anacacho Limestone, Upson Clay, San Miguel Formation, and Escondido Formation all yield small amounts of water to a few wells in the report area; however, the production is very localized and much of the water is saline. The Kincaid Formation and the Wills Point Formation, which extend across the width of the report area, are not known to yield water to wells.

Tertiary System

The primary aquifers in the Tertiary System are (1) the Carrizo Sand and Wilcox Group of Eocene age and (2) the Gulf Coast aquifer of Miocene to Pleistocene age, comprised of the Catahoula Tuff, Oakville Sandstone, Lagarto Clay, Goliad Sand, Lissie Formation, and Beaumont Clay. Secondary aquifers are the Sparta Sand, and the Queen City Sand Member of the Mount Selman Formation, both of Ecocene age.

Eocene Series

Wilcox Group

In southwestern Texas, the Wilcox Group is represented by only one formation, the Indio (Trowbridge, 1923, p. 90). From Bexar County northeastward,

Table 2.--Subdivisions of the Gulf Series

Nueces River Basin		San Antonio and Guadalupe River Basins
Navarro Group		Navarro Group
Escondido Formation		Kemp Clay
Olmos Formation		Corsicana Marl
San Miguel Formation	Anacacho Limestone	Taylor Marl
Upson Clay		
Austin Chalk		Austin Chalk
Eagle Ford Shale		Eagle Ford Shale

Plummer (in Sellards, Adkins, and Plummer, 1932, p. 571-606) divided the Wilcox Group into three formations: Seguin, Rockdale, and Sabinetown, in ascending order. However, for the purposes of this report, the Wilcox Group is undifferentiated.

Plummer (in Sellards, Adkins, and Plummer, 1932, p. 573) described the group as follows: "The strata of the Wilcox group comprise a heterogeneous series, several hundred feet thick, of sandy, lignitiferous littoral clays, cross-bedded river sands, compact, noncalcareous lacustrine or lagoonal clays, lignite lentils, and stratified deltaic silts. The upper layers have a larger proportion of sand, and some massive beds from 50 to 100 feet thick are made up entirely of medium-grained sand, largely of continental origin, but possibly reworked to some extent by the transgressing shoreline waters that inaugurated the Claiborne epoch."

The basal part of the Wilcox and the uppermost part are composed of sand and clay of shallow marine origin. The basal sand and clay contain gypsum and some lignite; thus, water from these beds contains a noticeable amount of sulfate. The sand and clay in the uppermost part of the Wilcox contain ferruginous concretions and some glauconite. Nonmarine sediments comprise the middle four-fifths of the group and include thick lenses of water-bearing sand, lenticular beds of lignite, some of commercial importance, and clays. The Wilcox thickens from 150 feet in the outcrop to more than 2,300 feet downdip. The Wilcox Group yields small to moderate quantities of fresh to very saline water.

Claiborne Group

In the Guadalupe and San Antonio River Basins, the Claiborne Group has been divided into the Carrizo Sand; Reklaw, Queen City Sand, and Weches Greensand Members of the Mount Selman Formation; Sparta Sand; Cook Mountain Formation; and Yegua Formation, in ascending order. In the Nueces Basin, the group has been divided into the Carrizo Sand; Mount Selman Formation, undifferentiated, except west of the Frio River where the Mount Selman has been divided into the Bigford Member and the overlying post-Bigford beds; the Sparta Sand and the Cook Mountain Formation, undifferentiated; and the Yegua Formation. The correlation of these units in and between basins is shown in Plates 5 and 6.

Carrizo Sand

The Carrizo Sand consists of coarse to fine sand, sandstone, silt, shale, and clay. In general, the sand is thickly bedded, loosely cemented, remarkably clean, and commonly crossbedded. Electric logs of a large number of wells indicate that in a large part of the area the Carrizo consists principally of beds of massive sand. Plates 3 through 6, which are based on interpretations of electric logs, show that the massive sand extends from the eastern edge of the Guadalupe Basin westward to Frio and LaSalle Counties, where it ranges from 600 to 800 feet in thickness; westward, the beds of massive sand become thinner, ranging from 200 to 300 feet in thickness.

The Carrizo Sand is about 200 feet thick in the Winter Garden district; it ranges in thickness from 600 feet near its outcrop in Wilson County to about 1,000 feet in wells near the Wilson-Karnes County line.

The Carrizo Sand is a primary aquifer in the report area. It yields moderate to large quantities of fresh to slightly saline water for irrigation, municipal, and industrial purposes.

Mount Selman Formation

Reklaw Member.--The Reklaw Member of the Mount Selman Formation consists mostly of clay with some glauconitic sand in the basal part. In some areas, the Reklaw is sandy at the outcrop. The thickness of the Reklaw ranges from about 200 feet in Wilson County to about 400 feet in LaSalle County. The Reklaw yields small quantities of fresh to moderately saline water to wells in and near the outcrop.

Queen City Sand Member.--The Queen City Sand Member consists of medium to fine sand, sandy clay, silty clay, clay, and shale, and ranges in thickness from about 500 feet in Gonzales County to about 1,000 feet in LaSalle County. The Queen City is a secondary aquifer in the report area and yields small to moderate quantities of fresh to salightly saline water. In Wilson and Gonzales Counties, the Queen City yields water to several irrigation and public-supply wells. However, moderate quantities of fresh water are obtained in places in and near the outcrop where the sands are relatively massive. Yields ranging from 200 to 600 gpm may be expected from wells in the outcrop area where the thickness of the Queen City exceeds 300 feet. Where the sands are thin and fine grained, however, only small amounts of slightly saline water can be obtained.

Weches Greensand Member.--The Weches Greensand Member of the Mount Selman Formation consists principally of fossiliferous glauconitic shale and sand. Because of the iron-bearing mineral, glauconite, the Weches weathers to a conspicuous reddish-brown ferruginous clayey soil. The thickness of the Weches ranges from about 100 to 200 feet. The Weches is not known to yield water to wells.

Bigford Member.--The Bigford Member of the Mount Selman Formation crops out in a belt trending northward through Dimmit County and western Zavala County, thence eastward through northern Zavala County into the north-central part of Frio County (Plate 2). The Bigford is equivalent to the Reklaw Member and the lower part of the Queen City Sand Member.

The Bigford Member consists chiefly of gypsiferous sandy clay, but contains many lenses of sandstone near the base. It also contains calcareous concretions, a few thin layers of limestone, many thin beds of lignite, and an abundance of plant remains in some thin beds of sand and shale. Iron-bearing minerals are common in the Bigford. The Bigford Member is predominantly shale and sandy shale in Zavala County and predominantly sand in Dimmit County; the thickness generally ranges from 400 feet near the outcrop to about 800 feet downdip in eastern Dimmit County (Turner and others, 1960, p. 47). In and near the outcrop in the northern part of Zavala County, the Bigford yields small quantities of fresh water. Elsewhere the water is moderately to very saline. According to Lonsdale (1935, p. 29), the Bigford Member does not yield much water to wells in Frio County, and the water generally is slightly saline.

Post-Bigford Beds.--The outcrop of the post-Bigford beds occupies a broad belt trending northward from northern Webb County to central Zavala County, thence eastward to central Frio County (Plate 2). The post-Bigford beds are composed chiefly of dark clays, a few thin beds of sandstone and limestone, and thin beds of coal. The clay beds contain large quantities of gypsum as lenses, stringers, and crystals. In Frio County, the post-Bigford beds are divisible into a lower clay member and an upper sandy member, but their character changes along the strike, and in Atascosa County, they consist largely of alternating sand and clay beds (Lonsdale, 1935, p. 30). The sandstones are generally lenticular and in many places are quartzitic. The maximum thickness of the post-Bigford beds in the Winter Garden district is about 700 feet. Along the outcrop in Atascosa and Frio Counties, the average thickness is also 700 feet; downdip it may be as much as 900 feet. According to Lonsdale and Day (1937, p. 35), the post-Bigford beds are 1,165 feet thick along the Rio Grande in Webb County, indicating that the beds thicken southward.

In the Winter Garden district, the sandstone lenses in the lower part of the post-Bigford beds yield small supplies of slightly to moderately saline water. In the western part of Frio County, the sandy beds in the upper part yield small to moderate quantities of fresh to slightly saline water suitable for domestic use and irrigation.

Mount Selman Formation, Undifferentiated

Where it crops out in Atascosa County and the eastern part of Frio County (Plate 2), the Mount Selman Formation has not been differentiated; however, downdip in the southern part of Atascosa County, the Mount Selman can be divided into its three members--the Reklaw, Queen City Sand, and Weches Greensand--on the basis of electric logs (Plate 6). The Mount Selman yields small to moderate supplies of fresh to slightly saline water.

Sparta Sand

The Sparta Sand crops out in a narrow northeastward-trending belt in the San Antonio and Guadalupe River Basins (Plate 1); it has been mapped with the Cook Mountain Formation in the Nueces Basin. The Sparta consists of medium to fine sand and clay. The upper two-thirds of the formation is mostly sand; the lower one-third is mostly clay. The Sparta Sand ranges from about 100 to 110 feet in thickness, and because of its uniform thickness and lithology, the formation is relatively easy to recognize on electric logs.

The Sparta Sand yields small to moderate amounts of fresh to slightly saline water in the outcrop area; it generally yields slightly to moderately saline water downdip. In Wilson County, the Sparta is not used as a source of irrigation water, but it seems likely that enough water to irrigate small tracts could be obtained from the formation (Anders, 1957, p. 17).

Cook Mountain Formation

In the San Antonio and Guadalupe Basins, the Cook Mountain Formation consists of fossiliferous clay and shale containing a few sandstone and limestone lenses and minor amounts of glauconite and gypsum. The formation is about 450 feet thick in Wilson County. In the San Antonio and Guadalupe Basins, the Cook Mountain Formation yields small amounts of slightly to moderately saline water to a few wells.

Cook Mountain Formation and Sparta Sand, Undifferentiated

In the Nueces Basin, the Cook Mountain Formation and the Sparta Sand have not been differentiated, and they are shown in the geologic map as a single unit (Plate 2).

In the Nueces Basin, the Cook Mountain Formation and the Sparta Sand, undifferentiated, consists of sandstone, gypsiferous clay, impure limestone, and lignite; much of the sandstone is glauconitic. The formation varies considerably in lithologic character along the strike. In eastern Atascosa County, the formation consists largely of alternating beds of gypsiferous clay and glauconitic sandstone. In the western part of Atascosa County and in Frio County, the lower part consists largely of glauconitic sandstone, in many places fossiliferous, and only a minor amount of clay; the upper part is chiefly clay. Lonsdale and Day (1937, p. 43-44) described a composite columnar section 630 feet thick from outcrops of the Cook Mountain near Laredo about 20 miles south of the report area, where sandstone constitutes more than 50 percent of the formation. Near Laredo, the formation consists of alternating beds of sandstone or sand and clays or sandy clay, but farther north in Webb County, clay is more prevalent in the upper third of the formation. Similar conditions exist across the Winter Garden district. The thickness of the Cook Mountain Formation and Sparta Sand, undifferentiated, ranges from 600 to 900 feet.

The lower sandy parts of the Cook Mountain Formation and Sparta Sand, undifferentiated, yield slightly to moderately saline water, some of which is suitable for domestic use and for irrigation where soils are sandy and are well drained. Near Dilley in southern Frio County, the formation yields sufficient water for irrigation. In the upper clayey parts of the formation, water suitable for domestic use is difficult to obtain.

Yegua Formation

In Wilson and Karnes Counties, the Yegua Formation consists of medium to fine sand, silt, clay, and small amounts of gypsum; whereas, in Atascosa and Frio Counties, the formation is composed mostly of clay, but also sandy clay, lignite, gypsum, limestone, and limestone concretions. The gypsum is rather uniformly distributed through the clay, and the thickness of the lignite ranges from thin seams to that of commercial value. Farther west in Webb County, the formation becomes less sandy and more gypsiferous. The thickness of the Yegua ranges from 670 feet in the outcrop in Webb County to more than 1,000 feet in Karnes County.

In the San Antonio and Guadalupe Basins, the Yegua generally yields small amounts of slightly to moderately saline water principally for livestock use, but also in some places for doemstic purposes. Locally, the Yegua yields moderate quantities of fresh water. In the Nueces Basin, most of the water in the Yegua is so highly mineralized that it is unfit even for livestock, although a few wells locally obtain moderately saline water suitable for livestock use. In the part of the basin where the Yegua is gypsiferous, the water probably is unsatisfactory for most purposes.

Jackson Group

The Jackson Group includes a lower part consisting of clay, bentonitic clay, sandy or silty clay, silt, thin sand beds, and a small amount of lignite and an upper part consisting mainly of beds of tuffaceous sand interbedded with bentonitic clay, volcanic ash, and a small amount of lignite. The Jackson ran ranges in thickness from about 900 feet in the outcrop in Karnes County to about 1,500 feet in Webb County.

In Karnes and Live Oak Counties, the Jackson yields small to moderate amounts of fresh to moderately saline water. According to Lonsdale (1935, p. 46), "The water from the Jackson formation [in Atascosa and Frio Counties] is variable in chemical quality. The sandstone from the lower part of the formation yields considerable quantities of water, some of which is suitable for use, but the higher beds generally yield water that is highly mineralized and is frequently unsuitable for use."

Oligocene(?) Series

Frio Clay

The Frio Clay crops out only in the Nueces Basin in a belt that extends southwestward from Live Oak County beyond the boundary of the basin (Plate 2); it is overlapped by the Catahoula Tuff in the San Antonio and Guadalupe Basins. The Frio is composed of bentonitic and slightly calcareous clay and silty clay, with small amounts of sand and gypsum. It ranges in thickness from about 200 to 300 feet. The Frio is not known to yield water to wells in the report area.

Oligocene(?) and Miocene(?) Series

According to Plummer (<u>in</u> Sellards and others, 1932, p. 713), the Catahoula outcrop may be divided conveniently into two areas for purposes of description--the east Texas outcrop and the southwest Texas outcrop. The east Texas outcrop, which comprises the Catahoula Sandstone and interbedded ash deposits, extends only a short distance into the eastern part of the Guadalupe River Basin; the southwest Texas outcrop, which comprises the Catahoula Tuff, extends from Gonzales County southwestward across the Nueces River Basin (Plates 1 and 2).

Catahoula Tuff

The Catahoula Tuff crops out in a southwestward-trending belt that ranges in width from less than 1 mile in the eastern part of Gonzales County to as much as 14 miles in Duval County (Plates 1 and 2). It consists chiefly of tuff, tuffaceous clay, sandy clay, bentonitic clay, and lenticular sandstone. The Catahoula Tuff ranges in thickness from 500 feet at its contact with the overlying Oakville Sandstone in Live Oak County to more than 1,000 feet in the subsurface in Webb County.

The Catahoula Tuff yields small to moderate quantities of fresh to slightly saline water in Karnes and Live Oak Counties. Most of the municipal supply for Karnes City and part of the supply for Kenedy is obtained from wells that tap sands in the Catahoula Tuff. Five irrigation wells in Karnes County obtain part or all of their water from the Catahoula. In Live Oak County, most of the water pumped from the Catahoula is satisfactory for livestock; locally, the water is satisfactory for domestic use. In Webb County, small amounts of moderately saline water are obtained from wells in the outcrop of the Catahoula Tuff.

Catahoula Sandstone

The Catahoula Sandstone crops out in an area of a few square miles in eastern Gonzales County in the Guadalupe Basin (Plate 1). In this area, the sandstone locally is quartzitic and has a thickness ranging from 5 to 10 feet (Renick, 1936, p. 62-63; pl. III, columnar sections 11 and 12). The Catahoula Sandstone is not a source of water in the report area.

Miocene Series

Oakville Sandstone

The Oakville Sandstone unconformably overlies and partly overlaps the Catahoula Tuff. The Oakville consists of cross-bedded, medium- to fine-grained sand and sandstone interbedded with sandy clay, some of which is silty and bentonitic. The thickness of the Oakville ranges from 200 feet near its outcrop in Live Oak County to 800 feet in Karnes County.

The Oakville Sandstone yields small to moderate quantities of fresh to slightly saline water to wells in Karnes and Live Oak Counties. In Karnes

County, where it is the principal aquifer, the Oakville yields moderate quantities of fresh to slightly saline water to some irrigation wells and to the municipal wells at Runge and Kenedy (Anders, 1960, p. 27). In Live Oak County, properly constructed wells in the Oakville yield moderate to large quantities of fresh to slightly saline water where 100 feet or more of the formation is saturated (Anders and Baker, 1961, p. 18). Locally, water from the Oakville may contain excessive amounts of fluoride.

Miocene(?) Series

Lagarto Clay

The Lagarto Clay consists of clay, sandy or silty clay, calcareous clay with calcareous nodules, and beds of sand or sandstone. The sand in the Lagarto is finer grained and more thinly bedded than the sand in either the underlying Oakville or the overlying Goliad, and generally, the clay beds in the Lagarto are thicker and more persistent than those in the Oakville or the Goliad. Locally, thick beds of sand similar to those in the Oakville and Goliad make identification of the Lagarto difficult on electric logs. In general, beds of sand are most common near the outcrop and are replaced progressively by beds of clay downdip. The thickness of the Lagarto ranges from about 500 feet in Karnes County (Anders, 1960, p. 27) to more than 1,000 feet in Live Oak County (Anders and Baker, 1961, p. 19).

The Lagarto yields small to moderate quantities of fresh to slightly saline water to many wells for domestic, livestock, irrigation, and public supply in Karnes County; it yields small quantities of slightly saline water to many wells in Live Oak County and moderate quantities of fresh to slightly saline water to a few irrigation wells.

Pliocene Series

Goliad Sand

The Goliad Sand overlies the Lagarto Clay uncomformably and the outcrop forms a prominent cuesta. The Goliad Sand consists of sand and sandstone interbedded with clay and gravel. Where it crops out in the report area, the Goliad is cemented with caliche, and the white color of the caliche is characteristic of the formation in the outcrop. The thickness of the Goliad ranges from 100 feet in Karnes County to 500 feet in Goliad County.

The Goliad Sand supplies small to moderate quantities of fresh to slightly saline water to wells in Goliad County and large quantities of fresh water for municipal, industrial, and agricultural use in Victoria County.

Tertiary(?) System

Pliocene(?) Series

Uvalde Gravel

The Uvalde Gravel, the oldest and highest terrace deposit, is found in remnants capping hills and interstream divides. Because the deposits are thin and difficult to distinguish in the field, they are not shown on the geologic map (Plates 1 and 2). Plummer (in Sellards, Adkins, and Plummer, 1932, p. 777-779) described the Uvalde as consisting of gravel composed almost entirely of rounded flint cobbles with pieces of limestone, quartz, and flint pebbles in a matrix of chalky marl and caliche and having a maximum thickness of 30 feet. The Uvalde Gravel does not contain appreciable quantities of water becuase of its topographic position and thickness.

Quaternary System

Pleistocene Series

Lissie Formation

The Lissie Formation, which crops out in a belt of irregular width in the southern end of the report area (Plates 1 and 2), consists of thick beds of sand containing lenses of gravel interbedded with clay and silt. In the outcrop, the formation is cemented with caliche and in some places caliche is encountered downdip in shallow wells. The thickness of the Lissie ranges from 500 feet in Goliad County to 600 feet in Victoria County.

The Lissie yields small supplies of fresh water for domestic and livestock use in Goliad County; it yields large supplies of fresh water for municipal, industrial, and agricultural use in Victoria County.

Beaumont Clay

The Beaumont Clay consists of clay and beds of sand. The thickness of the Beaumont ranges from 50 feet in Goliad County to 600 feet in Victoria County. The Beaumont yields small to moderate quantities of fresh to slightly saline water in Victoria and Calhoun Counties.

Pleistocene and Recent Series

Leona Formation and Alluvium

The Leona Formation of Pleistocene age, consisting of silt, sand, and gravel, includes the stream terraces between the Recent flood plains and the high-level Uvalde Gravel. The thickness of the Leona ranges from 0 to about

80 feet. The Leona yields small to moderate amounts of fresh water; locally, it yields sufficient quantities of water for irrigation.

The Recent alluvium, consisting of clay, silt, sand, and gravel, includes the flood plain and channel deposits of the present streams. The thickness of the Recent alluvium ranges from 0 to about 30 feet. The Recent alluvium retards to some extent the runoff of storm water by absorbing water during the higher stream stages and releasing it slowly as springflow as the stream flow decreases. The Recent alluvium yields small to moderate quantities of fresh water.

The Leona Formation and the Recent alluvium are considered in this report as one aquifer because they have similar hydrologic characteristics. Consequently, they are shown as a unit on the geologic maps (Plates 1 and 2).

GROUND WATER IN THE EDWARDS PLATEAU

The Edwards Plateau hydrologic subdivision, about one-fourth of the report area, contains approximately 7,300 square miles and includes all or parts of 13 counties. It extends from the northern boundary of the report area southward and southeastward to the Balcones escarpment. Because most of the land is devoted to ranching, it is the least populated section. The principal towns and populations, according to the 1960 census, include Bandera, 1,036; Blanco, 789; Boerne, 2,169; Comfort, 1,650; Kerrville, 8,901; and Leakey, 587. Ground water is the chief source of water for the public supplies in the area.

The climate is classified as semiarid (Thornthwaite, 1952, p. 32). The average annual precipitation ranges from about 20 inches in the west to 25 inches in the east. The mean annual temperature ranges from 64°F to 69°F.

The chief uses of ground water in the Edwards Plateau are for public supply, domestic, and livestock needs. Only a small amount of ground water is used for irrigation.

Primary Aquifer

Edwards and Associated Limestones

The only primary aquifer in the Edwards Plateau is in the Edwards and associated limestones; the geographic distribution of the aquifer is shown in Plates 1 and 2.

Physical Description

The Edwards and associated limestones, which include the Comanche Peak, and Georgetown Limestones, are exposed throughout a large part of the Guadalupe, San Antonio, and Nueces River Basins, except on the high divides where they are capped by younger formations and in the stream valleys where erosion has exposed the underlying Glen Rose Limestone. The unit consists of hard, massive, cherty, marly, and dolomitic limestone and dolomite. The thickness of the Edwards and associated limestones in the Edwards Plateau ranges from 400 to 550 feet. In many places, both on the outcrop and in the subsurface, the unit is extensively honeycombed and cavernous, and the water is contained in and transmitted through the porous fossiliferous beds, dolomitic beds, and fracture and solution channels.

Although the Edwards and associated limestones do not yield large quantities of water to wells in the Edwards Plateau part of the Guadalupe, San Antonio, and Nueces Basins, they contain a primary aquifer because of the large supply of water obtained from the unit in other basins of the Edwards Plateau.

Recharge, Movement, and Discharge of Ground Water

The Edwards and associated limestones are recharged primarily by precipitation on the outcrop. The water moves rapidly downward from the surface to the water table, thence south and southeastward to discharge areas along stream valleys or southward into the Balcones aquifer. The water is discharged chiefly through seeps and springs at the contact between the Edwards and associated limestones and the underlying Glen Rose Limestone. The water occurs under water-table conditions except locally where artesian conditions have been reported by drillers.

Chemical Quality of Ground Water

The chemical analyses of water from six wells in the Edwards and associated limestones are shown in Table 3. The locations of the wells are shown by means of bars over the well symbols on the well maps (Plates 1 and 2). The analyses shown are only a few of the total number on record, but they may be considered representative of the quality of ground water in the Edwards and associated limestones in the Edwards Plateau. The analyses show that the water is characteristically hard, averaging about 220 ppm, and low in dissolved-solids content, ranging from about 200 to 300 ppm. The water is suitable for most industrial uses and for irrigation and public supply.

Utilization and Present Development

The Edwards and associated limestones in the Edwards Plateau supply water only for domestic and livestock uses. The wells, which range in depth from 200 to 300 feet, generally yield less than 10 gpm (gallons per minute), and most are pumped by windmills. The wells are designed to produce only enough water for domestic or livestock use, but larger yields probably could be obtained in many places, if necessary. In 1961, an estimated 2,000 acre-feet of ground water was pumped for domestic and livestock uses.

Changes in Water Levels

Records of fluctuations of water levels in wells are scarce in the Edwards Plateau. The only records covering a period of several years are for wells in Edwards County (Long, 1962, p. 114-115), and Real County (Long, 1958, p. 25) where the water levels showed no significant changes during the period of record.

Table 3.--Chemical analyses of water from selected wells in the Edwards Plateau, Guadalupe, San Antonio, and Nueces River Basins

[Analyses given are in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio (SAR)]

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) a/	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	PH
Hosston Formation																						
AS-69-23-801	1,137	Jan. 17, 1957	13	--	--	39	20	137	15	364	70	85	3.0	0.0	--	0.8	561	180	60	4.4	949	7.7
69-24-202	842	May 2, 1962	13	0.25	0.00	38	22	107	14	364	42	58	2.0	.0	0.00	.50	476	186	53	3.4	808	7.2
Hosston and Sligo Formations, undifferentiated																						
AS-69-16-901	780	May 20, 1954	13	--	--	38	25	*106		378	46	50	--	0.0	--	--	464	198	54	3.3	824	7.7
69-23-601	1,085	Jan. --, 1957	13	--	--	32	21	*134		360	51	73	2.8	.0	--	--	504	166	64	4.5	858	7.6
Cow Creek Limestone Member of the Pearsall Formation																						
AS-69-20-201	872	Feb. 12, 1957	11	--	--	121	83	*91		331	482	41	3.6	0.2	--	--	996	644	23	1.6	1,400	7.6
Hensell Sand Member of the Travis Peak Formation (Hensell Shale Member of the Pearsall Formation)																						
RJ-56-63-604	605	Nov. 16, 1945	14	2.1	--	62	43	9.0	6.3	370	26	19	0.8	0.2	--	--	380	332	6	0.2	645	7.9
69-06-801	450	July --, 1954	14	--	--	86	62	*39		342	222	30	--	.0	--	--	654	470	15	.8	998	8.0
RB-68-01-302	300	Oct. 18, 1961	12	1.7	--	92	56	99	14	358	164	156	1.9	.0	--	--	828	460	31	2.0	1,300	7.0
Lower member of Glen Rose Limestone																						
AS-69-16-701	400	Jan. 17, 1957	12	--	--	74	55	*51		372	156	33	2.6	0.2	--	--	569	410	21	1.1	898	7.5
69-23-201	143	Feb. 7, 1957	12	--	--	98	38	*25		363	131	13	--	2.5	--	--	504	401	12	.5	749	8.0
69-24-501	165	Aug. 24, 1955	15	0.01	--	97	69	*12		397	198	14	--	1.0	--	--	601	526	5	.2	947	7.4
Upper member of Glen Rose Limestone																						
AS-68-25-401	275	Feb. 7, 1957	13	--	--	492	92	*20		243	1,370	15	1.8	0.1	--	--	2,120	1,610	3	0.2	2,330	7.2
69-14-101	445	May 6, 1954	9.2	--	--	516	421	*124		274	2,910	25	--	.0	--	--	4.140	3,020	8	1.0	4,220	7.7
69-16-601	135	Jan. 16, 1957	11	--	--	149	121	*46		375	577	36	4.4	.0	--	--	1,130	870	10	.7	1,520	7.4
Edwards and associated limestones																						
WA-69-02-401	400	Mar. 26, 1956	13	--	--	51	16	7.4	0.6	224	7.4	12	0.2	1.5	--	--	219	193	8	0.2	381	7.8
69-03-501	433	do	13	--	--	56	21	8.7	.4	265	6.3	15	.4	.9	--	--	252	226	8	.3	446	7.9
AS-69-12-101	301	Feb. 12, 1957	13	--	--	72	22	*10		326	3.4	12	--	5.6	--	--	298	270	8	.3	513	7.3
69-13-501	232	Feb. 8, 1957	12	--	--	71	21	6.0	--	311	4.0	12	--	5.5	--	--	284	264	5	.2	497	7.3
JJ-70-05-301	231	Mar. 11, 1954	12	--	--	60	13	8.1	.8	225	6.1	15	.3	8.7	--	.21	238	203	8	.2	419	7.6
70-07-401	500	June 8, 1954	14	--	--	54	13	*11		218	5.8	15	.6	4.5	--	.03	226	188	11	.3	406	7.9
Alluvium																						
RB-68-11-405	40	Nov. 2, 1945	12	0.04	--	104	18	8.3	2.6	300	69	20	0.4	10	--	--	415	334	5	0.2	607	6.8
WA-69-18-301	37	Apr. 3, 1956	13	.00	--	90	17	7.1	1.0	336	14	14	.1	4.5	0.01	0.04	326	294	5	.2	567	7.5

a/ Includes the equivalent of any carbonate (CO_3) present.
* Sodium and potassium calculated as sodium (Na).

Availability and Potential Development

The quantity of fresh water in storage in the Edwards and associated limestones in the Edwards Plateau is not known but probably is large. The amount of water available for perennial development also is not known but Long (1962, p. 27) estimated from base-flow records of the South Llano and Nueces Rivers that about 150,000 acre-feet of water is annually recharged to the aquifer in Edwards County. This volume was more than 150 times the withdrawals in the county. Similar quantities are probably available in areas of similar size elsewhere on the plateau.

Problems

The base flow of the streams leaving the Edwards Plateau is sustained by the natural ground-water discharge. Thus, large developments of ground water from the Edwards and associated limestones would result in a reduction in base flow of the streams draining the plateau.

Secondary Aquifers

The Hosston Formation, Sligo Formation, Travis Peak Formation (Pearsall Formation in subsurface), the Glen Rose Limestone, all of Cretaceous age, and the Recent alluvium are classed as secondary aquifers in the Edwards Plateau; they furnish water to all the public supply and irrigation wells. About 3,000 acre-feet was pumped for domestic and livestock uses in 1961 from the secondary aquifers.

Hosston and Sligo Formations

The Hosston Formation ranges in thickness from 0 to 900 feet and is composed of conglomerate, sandstone, red and green clay, shale, dolomite, and limestone. The overlying Sligo Formation ranges in thickness from 0 to 200 feet and is composed of limestone, in places dolomitic, sandy dolomite, shale, and sandstone. The Hosston and Sligo form a wedge, 0 to 1,100 feet thick, between the underlying Paleozoic rocks and the overlying Pearsall Formation, the wedge thinning generally northward.

The Hosston and Sligo are overlapped by younger rocks and do not crop out in Texas. Consequently, recharge in the report area is from other rocks, presumably younger. The water is under artesian pressure and movement probably is downdip toward the south or southeast. Some natural discharge occurs probably by seepage into overlying formations, and only small quantities of water are discharged by wells.

Small to moderate supplies of fresh water are obtained from the Hosston and Sligo. Chemical analyses of water from two wells in the Hosston Formation and two wells in the Hosston and Sligo Formations, undifferentiated (Table 3) show that the water contains less than 1,000 ppm dissolved solids and ranges from hard to very hard.

The principal pumpage from the Hosston and Sligo Formations during 1961 was about 110 acre-feet (0.1 mgd) for the public supply of the city of Bandera.

Inadequacy of data precludes a determination of the quantity of water available from the Hosston and Sligo Formations. Reeves and Lee (1962, p. 10) reported two public supply and two irrigation wells tapping the Hosston and Sligo in Bandera County. Similar supplies might be expected in parts of Comal, Hays, Blanco, Kendall, and Kerr Counties.

Travis Peak Formation
(Pearsall Formation in Subsurface)

The members of the Travis Peak or Pearsall Formation are the Pine Island Shale of the Pearsall, Cow Creek Limestone of both Travis Peak and Pearsall, and Hensell Sand of Travis Peak of Hensell Shale of Pearsall Formation. The Pine Island Shale Member ranges in thickness from 45 to 70 feet and is not known to yield water to wells. The Cow Creek Limestone Member ranges in thickness from 50 to 75 feet and is composed of massive detrital limestone and dolomite. The Hensell Sand Member ranges in thickness from 20 to 150 feet and is composed of sandstone, conglomerate, shale, limestone, and dolomite. The Travis Peak Formation crops out along streams in northern Comal County, eastern Kendall County, and western Hays County.

The Travis Peak Formation is recharged in part by direct infiltration of precipitation on the outcrop but also by seepage from streams that cross the outcrop. The water is under artesian pressure and the general direction of movement probably is down the dip of the formation toward the south or southeast. Some natural discharge occurs probably by seepage into the overlying formations, and a small quantity is discharged from wells.

Chemical analyses of water from one well in the Cow Creek Limestone Member and three wells in the Hensell Sand Member (Table 3) show that the water contains less than 1,000 ppm dissolved solids and is very hard.

The Cow Creek yields small quantities of fresh water for domestic and livestock uses in a large area, but the Hensell is the most heavily developed secondary aquifer in the Edwards Plateau.

The Hensell Sand Member supplies most of the water used by the cities of Kerrville and Comfort and the irrigation wells in Kerr County and part of the supply for the city of Boerne. The estimated pumpage from the Hensell in 1961 was 2,300 acre-feet (2.1 mgd) for public supply and 200 acre-feet for irrigation, a total of 2,500 acre-feet.

The inadequacy of the data precludes a determination of the quantity of water available from the Travis Peak Formation, but it probably is many times the amount of ground water pumped in 1961.

Glen Rose Limestone

The Glen Rose Limestone is divided into two members. The lower member ranges in thickness from 50 to 380 feet in the Edwards Plateau and is composed of massive limestones in the basal part and thin beds of marl and limestone in the upper part. The upper member is approximately 400 feet thick and is composed of shale and marl alternating with thin layers of impure limestone; it also contains two thin beds of anhydrite. The outcrop of the Glen Rose Limestone includes more than 50 percent of the area of the Edwards Plateau in the Guadalupe and San Antonio Basins, but less than 10 percent in the Nueces Basin (Plates 1 and 2).

The Glen Rose Limestone is recharged in part by direct infiltration of precipitation on the outcrop but also by seepage from streams that cross the outcrop. The water is generally under artesian pressure and the general direction of movement probably is down the dip of the formation toward the south or southeast. Natural discharge is by springs, although some discharge occurs probably by seepage into the overlying formations. A small quantity is discharged from wells.

The lower member of the Glen Rose yields small to moderate supplies of fresh water. Chemical analyses of water from three wells in the lower member (Table 3) show that the water contains less than 1,000 ppm dissolved solids and is very hard. The upper member generally yields small quantities of water, mostly saline. Chemical analyses of water from three wells in the upper member (Table 3) show the characteristic high sulfate content of water from the section containing the anhydrite beds.

The estimated pumpage in 1961 from major wells in the Glen Rose Limestone was 580 acre-feet, all for irrigation use. The potential development of ground water from the Glen Rose Limestone is unknown, but probably is small. Petitt and George (1956, p. 17) wrote that in some places the lower member of the Glen Rose is capable of transmitting large quantities of water; however, the many wells that penetrated the entire thickness of the member generally have not obtained large yields. The high sulfate content of the water in the upper member is a potentially serious problem because the outcrop includes about one-fourth of the area of the Edwards Plateau in the Guadalupe and San Antonio Basins. Particular care is necessary when drilling wells through the Glen Rose to insure that the anhydrite beds, which are the source of the sulfate, are cased off or cemented to prevent the contamination of the water of better quality in the deeper aquifers.

Recent Alluvium

The Recent alluvium ranges in thickness from 0 to more than 30 feet and consists of clay, silt, sand, and gravel. It forms the flood plains and low terrace deposits along the streams.

The water in the alluvium is under water-table conditions and the movement generally is toward the streams. Natural discharge is mainly by springs, but some water seeps into underlying permeable rocks. A small quantity is discharged from wells.

The alluvium yields small quantities of fresh water. Chemical analyses of water from two wells in the alluvium (Table 3) show that the water contains less than 1,000 ppm dissolved solids and is very hard.

The alluvium supplies small quantities of water to a number of domestic and livestock wells. The estimated pumpage from major wells in the alluvium in 1961 was 59 acre-feet for public supply.

The potential development of the ground-water resources in the alluvium is limited by the small areal extent and storage capacity of the aquifer.

GROUND WATER IN THE WEST GULF COASTAL PLAIN

The West Gulf Coastal Plain in the Guadalupe, San Antonio, and Nueces River Basins extends from the Gulf of Mexico northwestward to the Balcones escarpment (Figure 1). Characterized by low relief and a gentle gulfward slope, the West Gulf Coastal Plain comprises about 20,100 square miles or 73 percent of the report area.

The West Gulf Coastal Plain is the most populous section in the report area. The principal cities and population according to the 1960 Census include San Antonio, 606,871; Victoria, 33,047; New Braunfels, 15,631; Seguin, 14,299; San Marcos, 12,713; and Uvalde, 10,293. Ground water is the source of water for the public supplies in the area except Seguin, Gonzales, and Three Rivers, which are supplied from surface water.

The chief uses of ground water in the West Gulf Coastal Plain are for public supply and irrigation. A large part of the irrigation is in the Winter Garden district, although irrigation is practiced also in the area west of San Antonio.

The climate ranges from semiarid in the western part of the Nueces River Basin to dry subhumid in the Guadalupe River Basin (Thornthwaite, 1952, p. 32). The mean annual precipitation ranges from 24.07 inches at Uvalde (Figure 5) to 35.66 inches at Victoria (Marvin and others, 1962, p. 8). The mean annual temperature ranges from 67.8°F at San Marcos to 71.7°F at Winter Haven (Figure 6). The average annual evaporation ranges from 60.57 inches at Beeville, near the report area, to 78.84 inches at Dilley (Figure 6).

Primary Aquifers

The primary aquifers in the West Gulf Coastal Plain are the Balcones aquifer, the Carrizo Sand and Wilcox Group, undifferentiated, and the Gulf Coast aquifer.

Balcones Aquifer

Physical Description

The Balcones aquifer of this report refers to that part of the Edwards and associated limestones in which the water is fresh and is under artesian pressure. The aquifer extends from the Balcones escarpment southward and southeastward to the downdip limit of fresh water (Plate 7) and includes an area of about 2,100 square miles. The Balcones aquifer is composed of hard massive limestone, dolomitic limestone, and marly limestone, and has a thickness ranging from 450 to 900 feet.

Occurrence of Ground Water

Ground water occurs under artesian conditions in the Balcones aquifer. The water occurs in a network of channels that have been enlarged by the solvent action of the water on the limestones. Interconnected solutional cavities of all shapes and size, some as large as caves, form more or less linear channels, which generally follow fractures that are associated with and parallel to faults. Other channels were developed in porous limestone beds that contain large numbers of fossils.

Recharge of Ground Water

A large part of the recharge to the Balcones aquifer is seepage from streams that cross the outcrop of the aquifer in the Balcones fault zone. The flow of the spring-fed streams from the Edwards Plateau furnishes more or less continuous recharge to the Balcones aquifer, but the quantity is small; most of the recharge occurs during periods of flood runoff. A small amount of recharge results from the infiltration of precipitation on the outcrop of the aquifer in the Balcones fault zone.

The estimated annual recharge from streamflow from 1934 to 1959 is shown in Table 4 and Figure 12 (Garza, 1962a, Table 3). In 1946, the estimated recharge from streamflow was 556,100 acre-feet; in 1947, which was the beginning of a period of drought, it was 422,600 acre-feet; and in 1956, the last year of the drought, it was only 43,700 acre-feet. During the period 1957-59, when precipitation was above normal, recharge totaled 3,544,400 acre-feet, ranging from 690,000 acre-feet in 1959 to 1,711,000 acre-feet in 1958. During the 26-year period, 1934-59, the annual recharge averaged about 502,000 acre-feet.

Movement of Ground Water

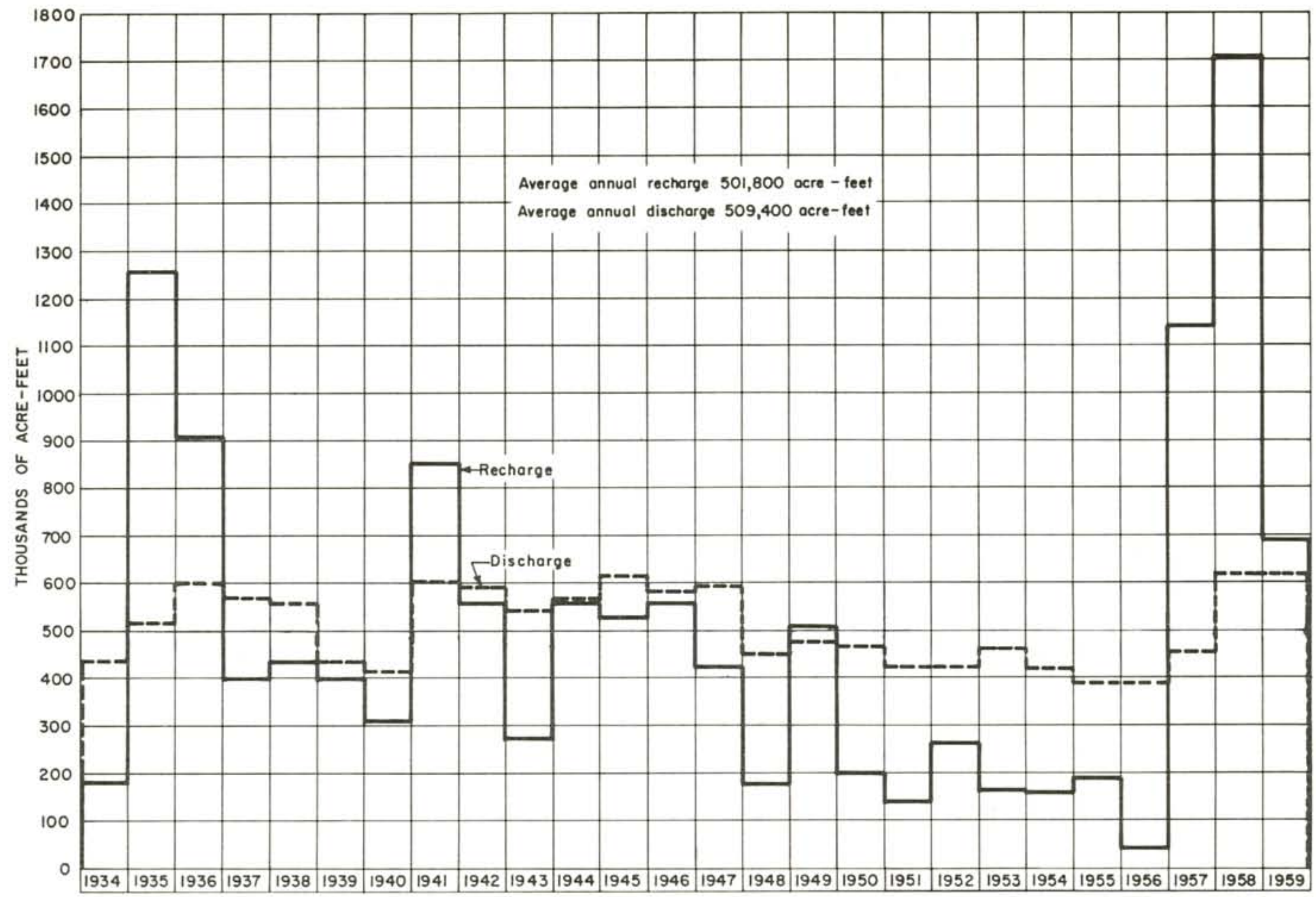
The approximate altitude of water levels in wells in the Balcones aquifer in March 1958 is shown in Plate 7. According to Garza (1962a, p. 24), "In the area of outcrop of the Edwards and associated limestones, water-table conditions prevail and the hydraulic gradients are steep, the water moving generally southward and southeastward toward the artesian part of the aquifer. In the artesian zone [Balcones aquifer], however, the hydraulic gradients are relatively low and the ground water moves eastward and northeastward, roughly parallel with the main system of faults. This relatively low hydraulic gradient indicates that movement is through large openings, whereas the steep gradients indicate movement through smaller openings in which losses in hydrostatic head are large."

Discharge of Ground Water

Ground water is discharged from the Balcones aquifer through springs and wells. Prior to 1954, most of the discharge was from springs; however, in 1954, the discharge from wells exceeded the discharge from springs, and by 1956, the last year of the long drought, approximately 80 percent of the total discharge was from wells (Figure 13). In 1957, when precipitation was above normal, the discharge from wells approximately equalled the flow from springs, but in 1958 and 1959, when precipitation continued above normal, the discharge from wells was only about 35 percent of the total discharge.

Table 4.--Estimated recharge to and discharge from the Balcones aquifer, 1934-59, in thousands of acre-feet

Year	Recharge	Discharge	Year	Recharge	Discharge	Year	Recharge	Discharge
1934	179.6	437.9	1943	273.1	539.3	1952	275.5	424.9
1935	1,258.0	518.6	1944	560.9	567.4	1953	167.6	468.3
1936	909.6	598.2	1945	527.8	614.8	1954	160.9	424.3
1937	400.7	571.2	1946	556.1	583.9	1955	192.0	388.8
1938	432.7	557.8	1947	422.6	593.5	1956	43.7	392.0
1939	399.0	432.8	1948	178.3	450.6	1957	1,143	456.5
1940	308.8	416.6	1949	508.1	479.8	1958	1,711	617.7
1941	850.7	601.2	1950	200.2	466.7	1959	690.4	621.2
1942	557.8	594.7	1951	139.9	425.6			
						Total	13,050	13,244
						Average	501.9	509.4



(Adapted from Garza, 1962a, Tables 3 and 4)

Figure 12

Estimated Annual Recharge to and Discharge from the Balcones Aquifer

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(After Garza, 1962a, Fig. 9)

Figure 14

Discharge from Comal Springs, Water Level in Well AY-68-37-301, Precipitation at Boerne, and Comparison of Accumulated Recharge and Accumulated Discharge in the Balcones Aquifer

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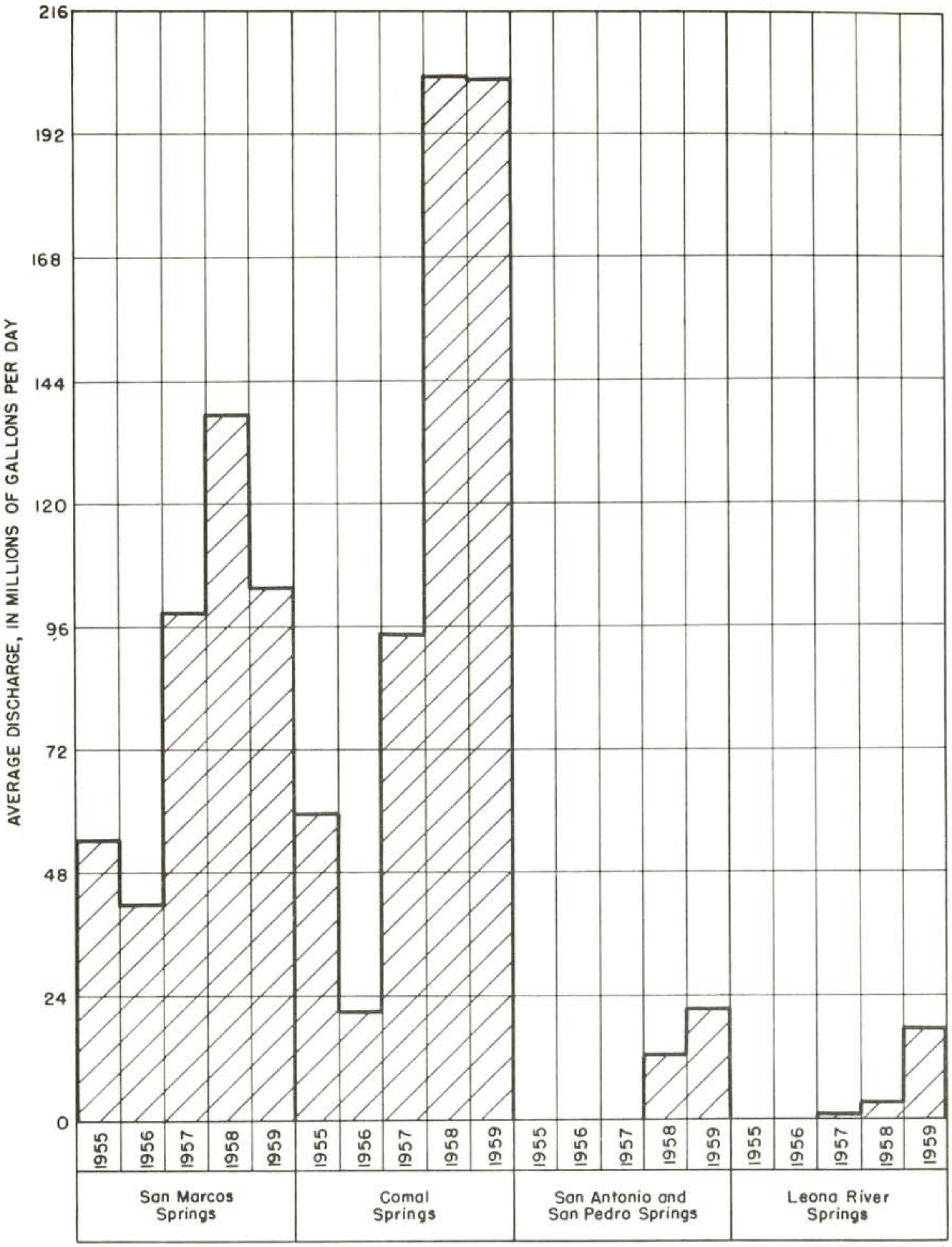

(After Garza, 1962a, Fig. 5)

Figure 15

Discharge from Major Springs in the Balcones Aquifer

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Table 5.--Discharge of ground water by major wells and springs in the Balcones aquifer, 1961

Major subdivision	Spring flow		Well discharge						Total*	
			Public supply		Industrial		Irrigation			
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.
GU- 4	218	244,160	3.6	4,032	0.6	672	0.1	112	220.0	250,000
GU- 6	0	0	.1	112	0	0	.1	112	.2	220
GU- 7	124.0	138,320	1.8	2,016	0	0	.1	112	130.0	140,000
Subtotal	340	380,000	5.5	6,200	.6	670	.3	340	350	390,000
SA- 1	0	0	.3	336	0	0	11.9	13,328	12.0	14,000
SA- 3	37.4	41,888	100.5	112,560	23.4	26,208	14.0	15,680	180.0	200,000
SA- 4	0	0	2.3	2,576	0	0	.2	224	2.5	2,800
Subtotal	37	42,000	100	120,000	23	26,000	26	29,000	195	220,000
NU- 3	0	0	0	0	0	0	8.0	8,960	8.0	9,000
NU- 4	0	0	0	0	0	0	.1	112	.1	110
NU-15	0	0	.2	224	0	0	4.6	5,152	4.8	5,400
NU-17	0	0	.5	560	0	0	1.3	1,456	1.8	2,000
NU-19	27.6	30,912	2.8	3,136	1.4	1,568	12.8	13,776	44.0	49,000
NU-21	0	0	0	0	0	0	1.2	1,316	1.2	1,300
NU-25	0	0	.1	112	0	0	1.0	1,120	1.1	1,200
Subtotal	28	31,000	3.6	4,000	1.4	1,600	29	32,000	61	68,000
Total*	410	460,000	110.0	130,000	25.0	28,000	55	61,000	600.0	680,000

* Figures are approximate because some of the pumpage is estimated. Figures are shown to the nearest 0.1 mgd and to the nearest acre-foot. Totals are rounded to two significant figures.

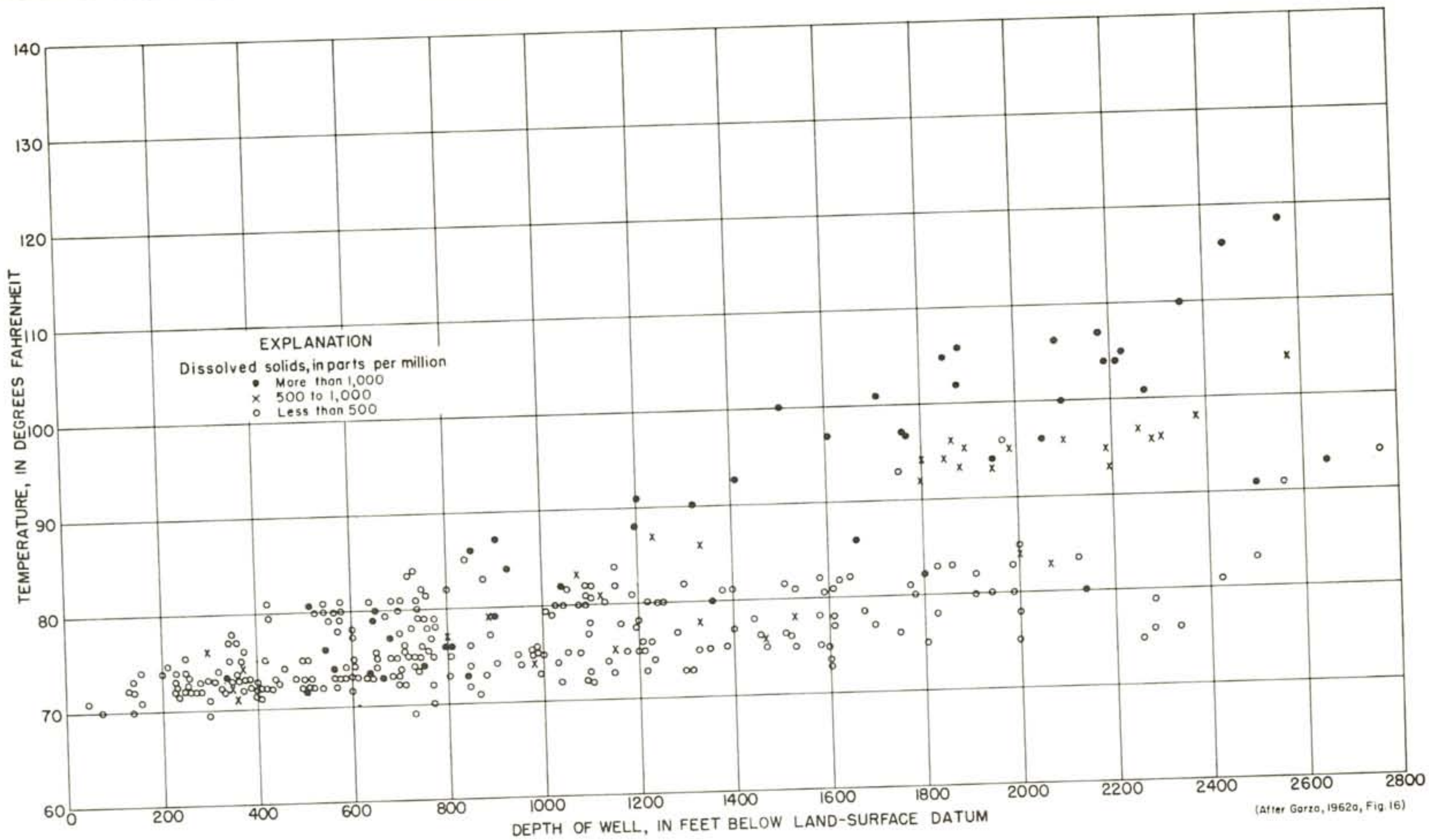

Figure 16

Temperature, Depth, and Quality of Water in the Balcones Aquifer

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Table 6.--Chemical analyses of water from selected wells in the Balcones aquifer, Guadalupe, San Antonio, and Nueces River Basins

[Analyses given are in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio (SAR)]

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) a/	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25° C)	pH
Edwards and associated limestones																						
RP-70-46-401	435	Mar. 13, 1962	15	--	--	34	20	*170		412	20	118	4.0	1.0	--	--	585	168	69	5.7	1,020	7.1
70-46-901	514	Aug. 28, 1959	13	--	--	460	69	*61		258	1,260	29	--	.2	--	--	2,020	1,430	9	.7	2,200	6.7
70-48-701	300	Aug. 8, 1961	25	--	--	114	8.3	*34		364	20	49	.6	2.2	--	--	463	318	19	.8	736	6.6
YP-69-41-701	593	do	17	--	--	129	3.5	*21		394	13	20	.2	22	--	--	450	336	12	.5	705	6.7
69-50-601	562	Dec. 21, 1959	--	--	--	--	--	--		264	553	110	--	--	--	--	--	756	--	--	1,610	7.1
69-52-401	1,410	May 3, 1961	18	--	--	220	75	414	22	352	876	425	--	.5	--	0.47	2,200	858	50	6.1	3,190	6.9
69-53-701	2,575	Sept. 22, 1960	--	--	--	--	--	--		232	119	33	--	--	--	--	--	312	--	--	684	7.5
TD-68-42-701	2,765	Aug. 26, 1959	14	--	--	51	19	8.4	.9	209	37	14	.4	1.2	--	.10	249	205	8	.3	421	6.9
69-47-301	1,510	June 17, 1959	11	0.04	0.00	66	15	6.4	.9	246	16	11	.2	4.8	0.03	.09	252	226	6	.2	438	7.5
69-54-501	2,000	Sept. 18, 1959	14	.98	--	61	15	*12		236	17	19	.3	.8	--	--	255	214	11	.4	444	7.5
AL-68-50-201	2,360	July 22, 1957	22	--	--	96	34	13	2.0	226	183	22	3.2	.0	--	--	550	380	7	.3	757	7.4
68-51-101	2,656	Oct. 10, 1961	15	--	--	420	169	*299		139	1,370	600	2.8	.0	--	--	2,940	1,740	27	3.1	3,870	6.7
AY-68-30-501	576	Dec. 6, 1956	12	.37	--	68	19	19	1.8	242	47	34	.3	1.5	---	--	323	248	14	.5	551	7.7
68-37-701	1,582	May 1, 1956	--	--	--	--	--	--		240	30	16	--	--	--	--	274	230	--	--	482	7.6
68-38-301	854	Mar. 9, 1956	19	--	--	624	226	*1,080		257	2,010	1,800	--	4.4	--	--	5,890	2,490	49	9.5	8,190	6.8
AY-68-43-601	1,909	Jan. 2, 1958	--	--	--	--	--	--		245	--	18	--	--	--	--	--	216	--	--	473	7.8
68-45-301	2,179	Oct. 3, 1956	--	--	--	--	--	--		291	1,950	990	--	--	--	--	4,510	2,560	--	--	5,780	7.2
68-51-201	2,226	Oct. 12, 1955	22	--	--	556	194	*473		276	1,750	770	--	2.0	--	1.3	3,870	2,180	30	4.1	4,820	7.4
KX-68-30-302	370	Aug. 7, 1958	11	--	--	61	36	31	2.7	243	89	57	1.6	.0	--	.32	422	300	18	.8	717	7.4
68-31-103	545	Sept. 9, 1959	14	--	--	178	222	751	41	950	220	1,470	4.6	.0	--	6.2	3,370	1,360	54	8.9	5,600	6.6
DX-68-23-701	300	Dec. 3, 1936	--	--	--	33	28	*16		195	32	28	--	--	--	--	233	198	--	--	--	--
68-23-901	450	Oct. 26, 1936	--	--	--	166	110	*380		348	500	630	--	--	--	--	1,957	868	--	--	--	--
LR-67-01-301	336	Sept. 3, 1953	11	2.1	--	48	33	*15		267	47	14	--	.5	--	--	306	256	11	.4	542	7.7
67-02-101	600	Aug. 26, 1952	15	--	--	139	94	*426		260	513	642	2.8	.2	--	--	1,960	734	56	6.8	3,300	7.6
67-09-401	200	Oct. 1, 1937	--	--	--	149	68	*145		354	277	275	--	--	--	--	1,090	652	--	--	--	--

a/ Includes the equivalent of any carbonate (CO_3) present.
* Sodium and potassium calculated as sodium (Na).

In 1961, most of the spring flow was from Comal and San Marcos Springs in the Guadalupe River Basin; the greater part of the pumpage for public supply and industrial use was in San Antonio, and almost all the pumpage for irrigation was in the San Antonio and Nueces River Basins.

Changes in Water Levels

Water levels in about 150 observation wells that tap the Balcones aquifer are measured periodically. In most of these wells, the water levels fluctuate seasonally in response to changes in ground-water withdrawals; the annual fluctuations reflect the shifting imbalance between recharge to and discharge from the aquifer. In general, water levels fluctuate more rapidly during periods of recharge than during periods of discharge, the magnitude of the fluctuation depending on the proximity of the well to the centers of pumping or recharge.

The changes in water levels in representative wells that draw from the Balcones aquifer are shown in Figures 17 and 18. From 1947 to 1956, the trend of the water levels was downward, reflecting the drought throughout the area and the accompanying increase in ground-water withdrawals. Water levels rose somewhat during 1952 and 1953 after heavy rains in parts of the area; however, the recharge was insufficient to stop the general downward trend. In most of the wells, water levels declined to record lows in 1956, although in eastern Kinney County and Uvalde County, water levels were lowest in 1957. They rose rapidly as a result of the above-normal rainfall during 1957-59, nearly reaching the levels of 1947. Figure 14 shows a close correlation of water-level fluctuations in well AY-68-37-301, in central Bexar County, discharge of Comal Springs, and precipitation at Boerne. The fluctuations in the flow of Comal Springs reflect chiefly the changes in pumping rates in the area of heavy pumping in Bexar County.

Availability and Potential Development

The Balcones aquifer has a large volume of ground water in storage in the interconnected solution channels, fractures, and porous limestone strata. Petitt and George (1956, p. 64) stated:

> "Knowledge of the storage characteristics and capacity of the ground-water reservoir are helpful in planning water-supply development for the future.
>
> "According to Livingston, Sayre, and White (1936, p. 102), the area in Bexar County in which the Edwards and associated limestones [Balcones aquifer] contain water suitable for most purposes covers about 500 square miles. If the aquifer has an average thickness of 500 feet and a specific yield of only 2 percent, the total storage amounts to about 3,000,000 acre-feet. Bexar County, however, constitutes only about one-fifth of the...area.... This would suggest that the total storage...under the foregoing assumptions would be about 15,000,000 acre-feet."

Garza (1962a, p. 37) correlated the changes of water levels in selected wells with changes in the amount of water in storage in each of four segments of the aquifer. For the period 1947-56, the declines of 55 to 100 feet in the

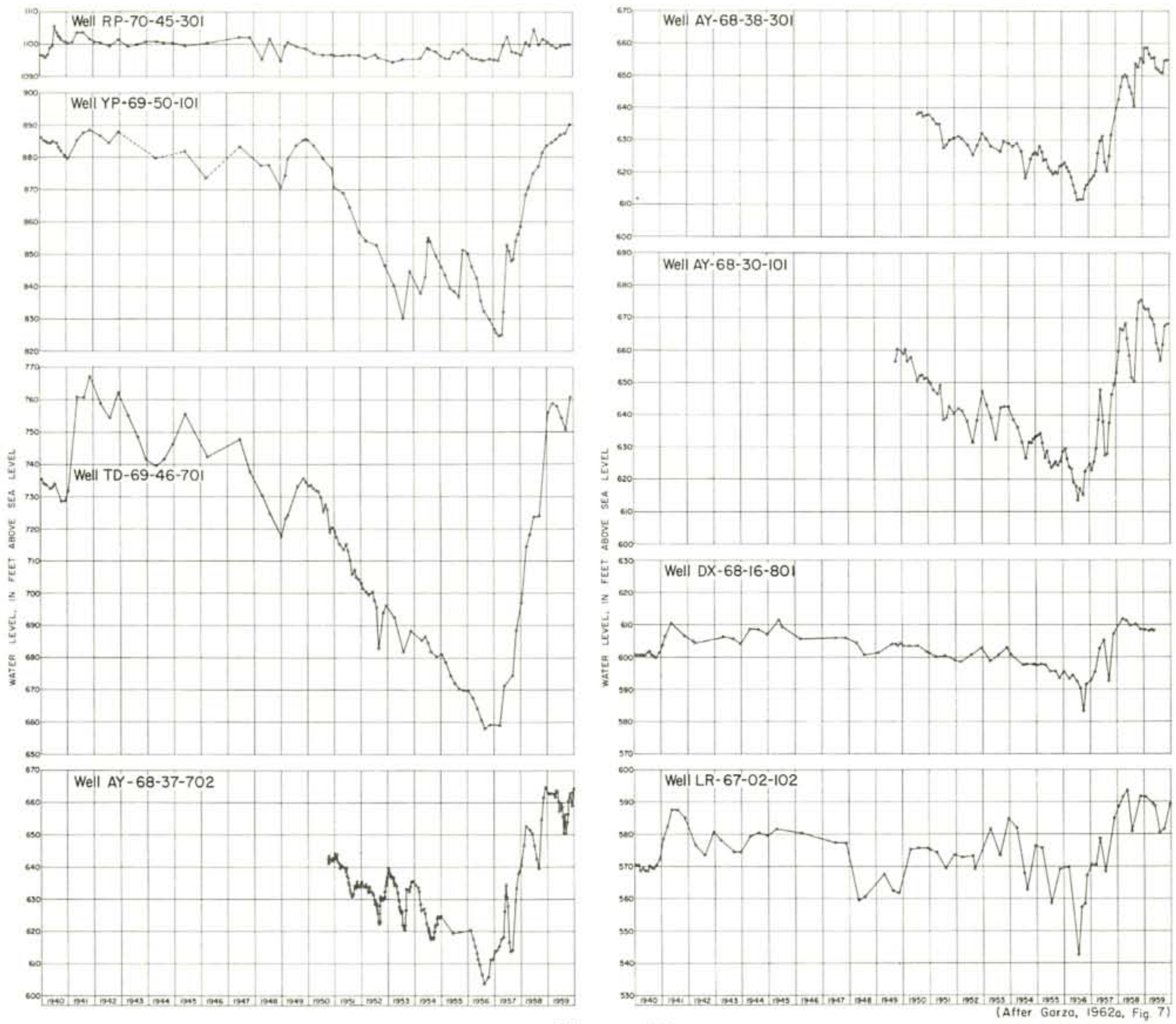

Figure 17

Hydrographs of Representative Wells in the Balcones Aquifer

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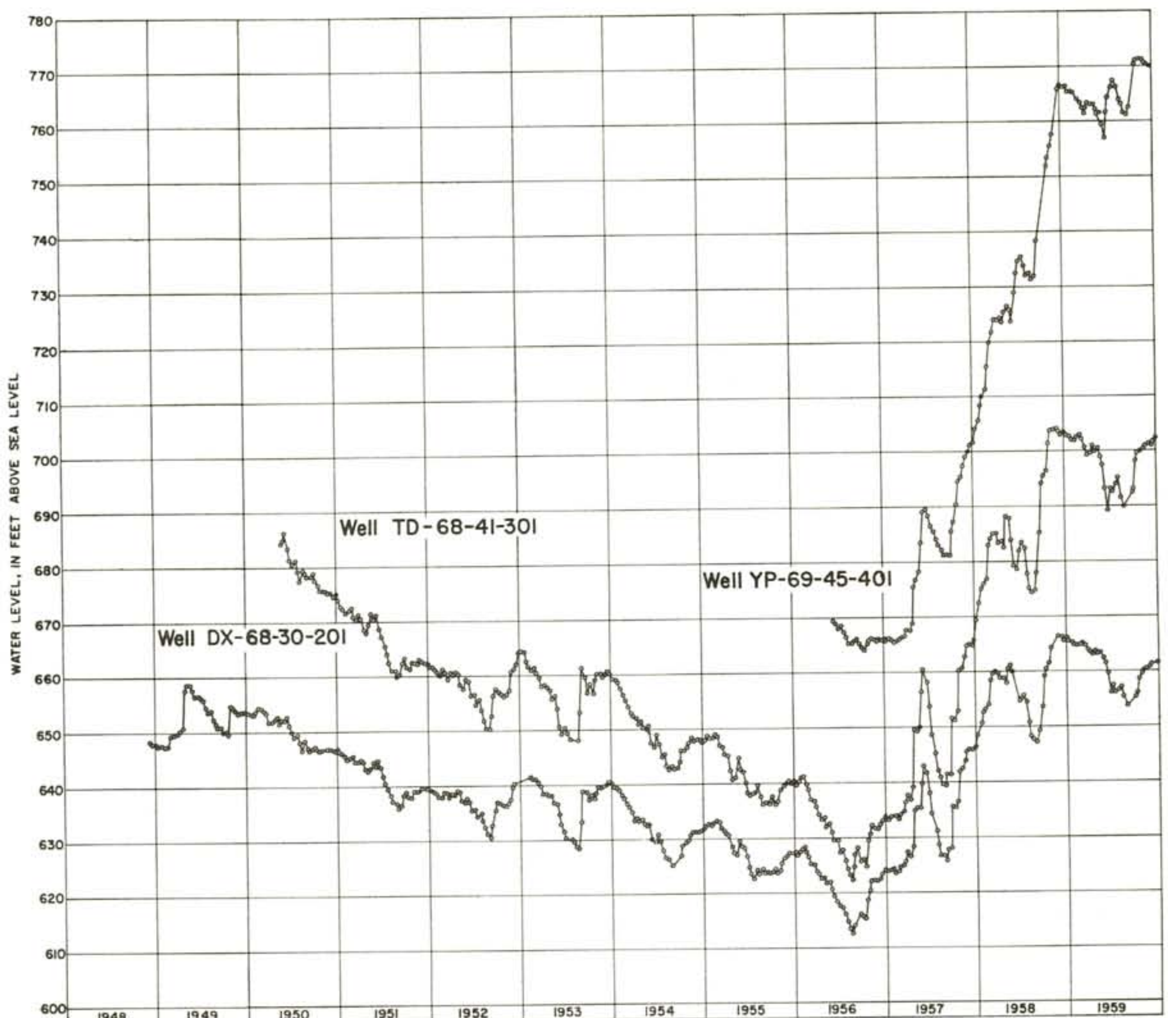

(After Garza, 1962a, Fig 8)

Figure 18

Hydrographs of Representative Wells in the Balcones Aquifer

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selected wells represented a decrease in storage of 2,045,000 acre-feet. For the period 1957-58, the rises of 50 to 100 feet in the selected wells represented a storage increase of 1,865,000 acre-feet. The decrease in storage during the 10-year period was almost completely replaced by the increase in the 2-year period.

Studies of recharge to and discharge from the Balcones aquifer (Figure 12) indicate that the long-term average yield of the aquifer might be about 500,000 acre-feet per year. This, however, does not take into consideration the unknown but large quantity of water in storage. Thus, the rate of withdrawal might be considerably greater than 500,000 acre-feet per year for short periods, and the aquifer could be recharged almost completely in a very short period of above-normal rainfall.

Problems

The principal problem regarding the Balcones aquifer is that the aquifer is heavily pumped, and it is conceivable that in the near future, the rate of withdrawal might reach the long-term rate of recharge. Such agencies as the city of San Antonio and the Edwards Underground Water District are vitally concerned with the problem and are attempting to solve it by seeking additional sources of water for the area or by determining means to increase effectively the rate of recharge to the aquifer.

The increase in the mineral content of the water as the artesian pressure decreases along the southern and southeastern boundary of the aquifer is a potentially serious problem. Additional development of water from the Balcones aquifer may result in declines in water levels greater than those during the drought that ended in 1956, and as a consequence, the line separating the fresh and the slightly to moderately saline water may shift toward the heavily pumped parts of the aquifer.

Carrizo Sand and Wilcox Group, Undifferentiated

Physical Description

The Carrizo Sand and the sands in the Wilcox Group are interconnected hydrologically; therefore, they are treated in this report as a single primary aquifer. The Carrizo Sand is composed of coarse to fine sand, sandstone, silt, and clay. The Wilcox is generally finer grained, consisting of clay, silt, medium- to fine-grained sandstone, sandy shale, and thin beds of lignite.

The thickness of the Carrizo ranges from about 200 feet in the western part of the Nueces Basin to about 1,000 feet in the eastern part and from 600 to 1,000 feet in the San Antonio and Guadalupe Basins. The thickness of the Wilcox ranges from less than 600 feet in the western part of the Nueces Basin to more than 2,000 feet in the eastern part; it ranges from 150 to 2,300 feet in the San Antonio and Guadalupe Basins.

The Carrizo Sand and Wilcox Group, undifferentiated, crops out in a belt ranging from 5 to 15 miles wide that trends northward from western Dimmit County to northwestern Zavala County, thence eastward to northern Atascosa

County. The belt is about 14 miles wide where it trends northeastward across southern Bexar, northern Wilson, southern Guadalupe, northwestern Gonzales, and eastern Caldwell Counties (Plates 1 and 2).

The dip of the Carrizo Sand and Wilcox Group, undifferentiated, based on the dip of the top of the Carrizo Sand (Plates 8 and 9), is southeastward except in the central part of Dimmit County where structural irregularities affect the direction of dip. In the western part of the Nueces Basin, the dip of the Carrizo averages 80 feet per mile; in the eastern part of the Nueces Basin and in the Guadalupe Basin, the dip is about 150 feet per mile. The dip in the San Antonio Basin averages about 130 feet per mile from the outcrop to 1,200 feet below sea level and increases to nearly 160 feet per mile between an elevation of 1,200 and 6,400 feet below sea level (Plate 9).

Recharge, Movement, and Discharge of Ground Water

Ground water in the outcrop of the Carrizo Sand and Wilcox Group, undifferentiated, occurs under water-table conditions. Downdip from the outcrop, the Carrizo is overlain by the Mount Selman Formation, and the water is under artesian conditions, where it is confined by the relatively impermeable overlying strata.

The principal source of recharge to the Carrizo Sand and Wilcox Group, undifferentiated, is precipitation on the outcrop. In many places, the outcrop is loose porous sand which offers ideal conditions for the infiltration of precipitation. Only a small percentage of the annual precipitation, however, is added to the ground water in storage. Seepage from streams that cross the outcrop contributes small quantities of recharge.

Estimates of annual recharge to the Carrizo Sand in the Winter Garden district (Dimmit and Zavala Counties and the adjacent part of Maverick County) range from 22,000 acre-feet during 1937-38 (Turner and others, 1960, p. 65) to 27,000 acre-feet during 1929-30 (White and Meinzer, 1931, p. 11). Mason (1960, p. 44) estimated the average annual recharge to the Carrizo Sand in Dimmit County during 1929-57 as 9,300 acre-feet, or about 26,600 acre-feet for the Winter Garden district. It is likely that recharge to the Carrizo in other parts of the Guadalupe, San Antonio, and Nueces Basins is of a similar magnitude. No quantitative data are available on recharge to the Wilcox Group.

In general, the water in the Carrizo Sand and Wilcox Group, undifferentiated, in the San Antonio and Guadalupe Basins moves southeastward parallel to the dip of the aquifer (Plate 9). The general direction of movement in the Nueces Basin is shown by the contour map of the piezometric surface for the Winter of 1960-61 (Plate 10). The movement is at right angles to the contours, generally southerly and southeasterly and parallel to the dip of the aquifer (Plate 8) in the eastern part of the Nueces Basin, except in the heavily pumped areas in northern Atascosa and northeastern Frio Counties. In the western part of the Nueces Basin in northwestern Frio, northern and western Zavala, and western Dimmit Counties, the movement of the water is also in the general direction of the dip of the Carrizo (Plate 8), except in the heavily pumped areas in northwestern Frio and northern Zavala Counties. The piezometric contours are closed around the heavily pumped area extending from Crystal City to central Dimmit County, indicating that the water is moving toward the area from all directions.

Ground water is discharged from the Carrizo Sand and Wilcox Group, undifferentiated, naturally by evapotranspiration, spring flow where the Guadalupe and San Antonio Rivers and Cibolo Creek cross the outcrop, interformational leakage, and artificially through wells, most of the discharge being through pumped wells. The several springs southwest of the city of Carrizo Springs had ceased to flow by 1929 owing to the decline of artesian head.

Chemical Quality of Ground Water

The chemical analyses of water from 23 wells in the Carrizo Sand and Wilcox Group, undifferentiated, in the Nueces Basin are given in Table 7; analyses of water from 20 wells in the San Antonio and Guadalupe Basins are given in Table 8.

The Carrizo Sand yields moderate to large quantities of fresh to slightly saline water. The water in and near the outcrop generally is low in dissolved-solids content, but is hard; the water obtained downdip contains more dissolved solids, but is softer. The Carrizo Sand contains fresh to slightly saline water to a depth of about 5,400 feet below sea level in the Nueces Basin; to about 4,800 feet in the San Antonio Basin; and to about 3,400 feet in the Guadalupe Basin.

The Wilcox Group yields water that is generally more mineralized than that from the Carrizo.

The water in the Carrizo Sand and Wilcox Group generally is suitable for public supply and for most industrial uses. The water in the deeper part of the aquifer is hot, measured temperatures ranging as high as about 140°F and this water, of course, would not be suitable for cooling. Much of the deep water also is unsuitable for continuous irrigation because of high SAR (sodium adsorption ratio). This water probably could be used, however, on well-drained soils on a supplementary basis.

Utilization and Present Development

Nueces River Basin

In 1961, about 180,000 acre-feet (160 mgd) of water was pumped from the Carrizo Sand and Wilcox Group, undifferentiated, in the Nueces River Basin, of which 95 percent or slightly more than 170,000 acre-feet (150 mgd) was used for irrigation (Table 9). Public-supply systems accounted for 5,700 acre-feet (5.1 mgd), and industries pumped an estimated 1,300 acre-feet (1.2 mgd).

Most of the irrigation is in Dimmit, Zavala, Frio, and Atascosa Counties. Table 9 shows that a substantial part of the pumpage is from wells in the Winter Garden district in Dimmit and Zavala Counties, which includes all or parts of subdivisions 4, 6, 19, and 20. The public water supplies for Asherton, Big Wells, Carrizo Springs, Cotulla, Crystal City, Devine, Dilly, Jourdanton, Pearsall, Poteet, and Tilden are obtained from wells in the Carrizo Sand. The canning industry in the Winter Garden district is the largest user of water pumped for industrial purposes.

Table 7.--Chemical analyses of water from selected wells in the West Gulf Coastal Plain, Nueces River Basin

[Analyses given are in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio (SAR)]

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Cal-cium (Ca)	Magne-sium (Mg)	Sodium (Na)	Potas-sium (K)	Bicar-bonate (HCO_3) a/	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Boron (B)	Dis-solved solids	Hardness as $CaCO_3$	Per-cent so-dium	Sodium adsorp-tion ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
									Wilcox Group											
HZ-76-40-901	475	May 20, 1930	33	0.10	116	25	291	9.5	502	385	169	--	0.12	--	1,280	392	62	6.4	--	--
77-25-701	247	July 18, 1949	34	--	184	41	*115		310	302	220	--	.0	--	1,050	628	29	2.0	1,680	7.7
TD-68-49-401	200	Oct. 5, 1951	25	--	82	25	*43		333	40	61	--	.2	--	440	308	23	1.1	833	7.9
69-55-601	44	Feb. 28, 1951	62	--	1,560	278	*2,080		127	1,630	5,500	--	--	--	11,200	5,040	47	13	16,400	6.8
YP-69-60-601	150	Apr. 7, 1930	18	2.0	113	31	81	8.6	387	110	115	--	.2	--	680	410	30	1.7	--	--
ZX-69-57-501	100	May 20, 1930	--	3.1	140	47	*203		483	313	185	--	.6	--	1,130	543	45	3.8	--	--
69-58-601	120	Apr. 9, 1930	12	15	401	265	431	25	666	1,540	642	--	1.1	--	3,740	2,090	32	4.1	--	--
									Carrizo Sand											
AL-68-59-401	380	Feb. 22, 1928	18	1.1	31	6.2	28	5.1	52	50	51	--	0.10	--	227	103	36	1.2	--	--
78-06-901	3,200	July 17, 1956	22	--	19	7.9	128	7.8	349	46	25	--	.0	0.20	432	80	76	6.2	677	7.6
78-22-201	4,100	July 16, 1956	30	--	2.8	.3	270	3.4	569	59	46	1.0	.0	.35	711	8	98	42	1,070	8.1
HZ-77-26-401	504	Jan. 4, 1949	18	--	40	15	*70		276	41	32	--	.2	1.0	353	162	48	2.4	590	--
77-37-501	1,710	Apr. 4, 1930	23	.54	11	5.8	153	4.6	282	72	60	--	.73	--	474	51	87	9.3	--	--
KB-77-15-301	1,350	June 17, 1932	22	4.0	99	18	22	6.2	331	59	25	--	.05	--	414	321	13	.5	--	--
78-09-801	1,700	May 26, 1932	17	.17	66	14	25	7.8	270	38	15	--	.0	--	308	222	19	.7	--	--
RX-77-39-401	2,345	July 10, 1956	20	--	1.8	.6	251	2.0	341	100	121	.6	.0	.49	665	7	98	41	1,080	8.4
77-40-304	2,851	do	23	--	2.8	.5	336	2.9	618	98	92	1.4	.0	.46	861	9	98	49	1,350	8.3
SJ-78-23-501	4,842	Aug. 8, 1956	39	.13	2.8	.3	422	4.5	918	11	110	1.3	.0	.39	1,040	8	98	65	1,680	8.2
SU-78-36-201	4,250	July 12, 1956	32	--	1.6	.2	296	3.0	604	49	71	1.0	.0	.44	751	5	99	58	1,190	8.3
78-36-902	4,700	Mar. 16, 1959	37	--	2.1	.4	*379		776	68	87	--	.0	--	956	6	99	65	1,520	8.3
TD-68-49-901	141	June 2, 1952	42	--	42	8.6	*67		110	34	112	.4	1.5	.21	382	140	51	2.5	643	7.0
69-64-301	176	Oct. 4, 1951	36	--	67	8.1	*43		193	33	69	--	5.0	--	362	200	32	1.3	598	7.5
ZX-77-02-101	240	Dec. 27, 1948	16	--	105	24	*15		356	41	40	--	1.8	--	418	360	8	.3	751	--
77-11-701	1,163	do	16	--	98	25	*24		320	83	36	--	.0	--	448	348	13	.6	754	--
									Bigford Member of the Mount Selman Formation											
HZ-77-26-501	435	May 6, 1930	12	1.1	385	218	3,390	50	278	4,070	3,420	--	2.1	--	11,800	1,860	80	34	--	--
77-29-401	140	Dec. 7, 1949	16	--	418	294	*1,310		234	3,100	1,190	--	.0	--	6,440	2,250	56	12	7,880	7.7

See footnotes at end of table.

Table 7.--Chemical analyses of water from selected wells in the West Gulf Coastal Plain, Nueces River Basin--Continued

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) a/	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
ZX-77-01-701	230	Feb. 8, 1928	29	2.0	48	16	66	5.1	338	38	16	--	0.05	--	376	186	45	2.1	--	--
77-10-901	270	June 28, 1919	38	.25	145	65	*2,030		139	805	2,900	--	4.8	--	--	629	87	35	--	--
Queen City Sand Member of the Mount Selman Formation																				
SU-78-26-501	2,105	Dec. 27, 1962	21	--	3.0	0.7	*344		656	98	82	0.9	0.5	--	889	10	99	47	1,400	7.8
78-28-601	2,765	Mar. 17, 1959	22	--	2.1	.1	*813		1,480	128	298	3.1	.1	--	1,990	6	100	151	3,130	8.6
Mount Selman Formation, undifferentiated																				
AL-68-61-401	120	June 19, 1932	--	1.1	130	31	*110		286	120	235	--	0.0	--	767	452	35	2.3	--	--
78-13-701	956	do	21	.10	4.8	2.3	643	14	769	152	460	--	2.5	--	1,718	21	97	61	--	--
KB-77-16-102	242	June 18, 1932	14	.55	127	57	438	20	301	676	408	--	2.6	--	1,890	551	62	8.1	--	--
78-09-302	860	May 26, 1932	20	3.4	90	40	199	21	374	172	258	--	.0	--	987	389	51	4.4	--	--
RX-78-34-202	1,700	May 11, 1945	37	.63	3.1	.7	933	13	1,530	192	422	4.4	1.0	--	2,360	10	99	128	366	8.0
SU-78-20-801	2,300	Nov. 26, 1962	20	.06	2.5	.3	*380		744	104	80	.9	.0	--	972	7	99	62	1,510	8.0
Sparta Sand																				
RX-77-46-802	600	May 25, 1959	15	0.90	96	34	635	7.4	264	788	510	--	2.5	1.6	2,220	380	78	14	3,400	7.4
77-62-402	500	Nov. 20, 1962	20	1.0	88	47	286	8.8	270	496	212	0.4	.2	--	1,290	413	59	6.1	1,950	7.6
Cook Mountain Formation																				
RX-77-39-602	75	Oct. 4, 1950	21	1.8	106	45	430	--	299	589	385	--	0.0	2.0	1,720	450	68	8.8	2,700	7.7
77-47-601	250	July --, 1952	11	--	35	11	*2,060		456	1,830	1,650	1.4	.5	--	5,820	132	97	78	8,760	8.5
Cook Mountain Formation and Sparta Sand, undifferentiated																				
AL-78-18-301	450	June 19, 1932	--	--	9	--	*639		324	547	412	--	2.7	--	1,700	28	98	53	--	--
HZ-77-12-701	48	Dec. 7, 1949	39	--	82	17	*23		271	41	41	--	1.2	--	406	274	15	.5	661	7.4
KB-77-23-502	305	June 17, 1932	27	0.31	102	36	221	9.6	341	254	248	--	.4	--	1,070	403	54	4.8	--	--
77-23-805	307	Jan. 20, 1928	22	2.4	166	65	305	18	292	650	325	--	.4	--	1,700	682	48	5.1	--	--
YZ-85-07-601	1,630	Nov. 23, 1934	--	--	4.6	1.3	*598		344	410	432	0.1	.2	--	1,620	17	99	63	--	--
85-23-201	1,440	do	--	.75	20	3.9	*1,330		383	956	1,150	.0	.5	--	3,670	66	98	71	--	--
Yegua Formation																				
RX-78-34-101	400	Feb. 9, 1963	13	1.0	26	6.3	*1,750		332	1,120	1,740	--	3.5	--	4,820	91	98	80	7,740	7.5
Jackson Group																				
SJ-78-24-101	630	Apr. 4, 1957	32	--	72	9.8	*1,480		134	6.6	2,350	--	--	--	4,020	220	94	43	7,000	7.8
78-31-201	430	Feb. --, 1951	39	--	36	3.2	*1,280		497	925	1,070	--	1.0	--	3,600	103	96	55	5,640	8.0

See footnotes at end of table.

Table 7.--Chemical analyses of water from selected wells in the West Gulf Coastal Plain, Nueces River Basin--Continued

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Cal-cium (Ca)	Magne-sium (Mg)	Sodium (Na)	Potas-sium (K)	Bicar-bonate (HCO_3) a/	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Boron (B)	Dis-solved solids	Hardness as $CaCO_3$	Per-cent so-dium	Sodium adsorp-tion ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
SU-78-44-402	108	July 15, 1959	36	--	177	7.6	*279		338	454	234	--	0.0	--	1,350	473	56	5.6	2,010	7.0
78-44-501	64	do	44	--	94	6.4	*416		432	546	142	0.5	50	--	1,510	261	78	11	2,120	7.4
Catahoula Tuff																				
JB-84-04-704	124	June 12, 1931	--	--	104	--	821	--	181	204	1,210	--	26	--	2,410	306	85	20	--	--
84-11-801	105	June 9, 1931	--	--	100	--	779	--	263	336	1,080	--	112	--	2,580	488	78	15	--	--
SJ-78-24-201	180	Apr. 4, 1957	96	--	69	9.0	808	38	421	201	1,050	0.3	1.0	3.3	2,480	210	87	24	4,170	7.6
78-46-501	300	Oct. 10, 1957	77	--	57	7.7	586	--	552	246	500	--	16	4.3	1,760	174	88	19	2,930	7.9
SU-78-52-903	120	July 15, 1959	84	--	20	5.6	*348		532	114	187	3.3	3.8	--	1,030	73	91	18	1,600	7.4
78-60-601	485	July 16, 1959	83	--	392	111	*1,280		222	1,300	1,900	--	.2	--	5,180	1,430	66	15	7,520	7.0
Oakville Sandstone																				
SJ-78-32-801	69	Apr. 5, 1957	77	--	165	24	313	14	367	68	530	0.9	129	1.0	1,500	510	56	6.0	2,550	7.2
78-54-901	555	Apr. 24, 1957	19	--	15	4.2	*170		352	.0	96	--	.0	.77	482	55	87	9.9	822	7.9
Lagarto Clay																				
SJ-78-40-601	149	Apr. 5, 1957	46	--	148	32	313	9.2	237	94	640	0.5	0.2	0.55	1,400	500	57	6.1	2,540	7.4
79-41-401	269	Apr. 19, 1957	39	--	158	37	268	9.2	246	58	632	--	2.5	.41	1,330	546	51	5.0	2,410	7.1
SU-78-53-906	90	June 21, 1959	75	--	395	129	*781		252	226	1,900	--	64	--	3,730	1,520	53	8.7	6,180	6.7
78-62-102	73	June 23, 1959	48	--	96	16	*85		366	36	105	.4	4.5	--	576	306	38	2.1	953	6.6
Goliad Sand, Lissie Formation, and Beaumont Clay, undifferentiated																				
SJ-79-41-802	400	Apr. 18, 1957	30	--	30	9.1	260	5.1	314	36	285	0.5	0.2	0.61	811	112	83	11	1,430	7.6
79-49-102	75	Apr. 16, 1940	--	0.73	148	40	*150		276	86	385	.7	--	--	1,050	534	38	2.8	--	--
79-49-501	600	Sept.20, 1951	26	--	13	10	*313		318	88	285	--	.5	--	892	74	90	16	1,650	8.4
79-49-502	425	do	51	--	20	15	*153		175	28	190	--	5.8	--	549	112	75	6.3	966	8.2
79-49-801	450	Nov. 7, 1957	24	--	33	11	186	6.5	366	49	129	2.0	4.5	1.1	626	128	75	7.2	1,060	7.7
79-57-501	350	July 16, 1948	26	--	51	23	*258		422	87	240	--	10	--	903	222	72	7.5	1,550	--
Leona Formation																				
TD-69-46-601	41	May 16, 1930	--	--	60	17	*2.6		233	13	13	--	3.0	--	223	220	2	0.1	--	--
69-48-101	60	June 26, 1951	31	--	172	21	*248		356	44	288	--	387	--	1,370	516	51	4.7	2,180	7.4
ZX-77-02-601	60	Dec. 27, 1948	13	--	97	21	*9.7		372	19	12	--	9.2	--	368	328	6	.2	631	--
77-04-401	45	Feb. 9, 1928	25	0.06	125	18	30	2.9	364	90	33	--	7.3	--	520	386	15	.7	--	--
Leona Formation and alluvium																				
YP-69-49-301	--	Apr. 10, 1930	16	0.02	89	11	7.6	1.6	299	17	12	--	10	--	305	268	6	0.2	--	--

See footnotes at end of table.

Table 7.--Chemical analyses of water from selected wells in the West Gulf Coastal Plain, Nueces River Basin--Continued

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) a/	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
YP-69-57-301	40	July 17, 1957	21	--	68	15	9.5	2.8	244	28	16	--	0.0	--	290	231	8	0.3	486	7.3
									Alluvium											
SU-78-51-302	24	Nov. 28, 1962	34	0.09	110	11	*95		326	62	138	0.3	0.0	--	649	320	39	2.3	1,030	7.4
YZ-78-58-701	18	Dec. 2, 1934	--	.36	--	--	*55		216	29	56	.7	.10	--	312	168	42	1.8	--	--

a/ Includes the equivalent of any carbonate (CO_3) present.
* Sodium and potassium calculated as sodium (Na).

Table 8.--Chemical analyses of water from selected wells in the West Gulf Coastal Plain in the Guadalupe and San Antonio River Basins

[Analyses given are in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio (SAR)]

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) a/	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
Wilcox Group																						
AY-68-52-101	70	July 24, 1946	--	--	--	--	--	--		354	24	90	--	0.2	--	--	--	262	--	--	--	--
68-45-601	223	Sept. 8, 1953	--	37	--	--	--	--		318	--	585	--	--	--	--	--	1,730	--	--	3,390	7.3
BU-67-12-101	240	Aug. 11, 1952	38	1.88	--	98	12	61	1.2	367	28	71	0.2	.0	--	0.13	494	294	--	--	878	7.7
67-19-601	320	Feb. --, 1943	6.0	.02	--	2.7	1.7	*424		534	178	163	.2	.0	--	--	1,080	14	98	49	--	8.4
KR-67-19-901	230	Apr. 26, 1962	74	3.3	--	159	50	*75		326	206	200	.4	1.0	--	--	988	602	21	1.3	1,420	7.4
67-28-203	1,601	Apr. 25, 1962	17	.06	0.01	1.0	.5	695	2.6	972	52	470	1.6	2.2	0.13	1.6	1,770	4	99	151	2,940	8.1
KX-67-18-801	156	Apr. 13, 1962	36	1.1	--	87	14	60	4.3	333	48	64	.2	.0	--	.42	478	274	32	1.6	772	6.9
68-40-701	71	May 4, 1962	35	1.1	--	455	114	*243		382	828	635	.8	73	--	--	2,570	1,600	25	2.6	3,710	6.5
ZL-68-54-501	720	Oct. 29, 1954	17	.21	--	14	6.0	273	4.8	322	207	130	.5	.0	--	.66	820	56	90	16	1,350	8.4
68-39-901	100	Aug. 18, 1936	--	--	--	--	--	--		281	329	820	--	--	--	--	1,990	--	--	--	--	--
68-48-101	361	June 20, 1955	23	.01	.00	108	38	94	7.0	331	218	91	.1	1.0	.04	.17	778	426	32	1.9	1,170	7.4
Carrizo Sand																						
AY-68-54-201	155	July 25, 1946	--	--	--	--	--	--		232	260	106	--	4.0	--	--	--	285	--	--	--	--
BU-67-20-601	70	Apr. 4, 1947	--	--	--	23	10	*70		20	55	116	--	16	--	--	324	98	61	--	--	3.1
67-20-801	92	May 3, 1946	--	--	--	--	--	--		29	14	57	--	.0	--	--	--	30	--	--	--	--
KR-67-21-701	328	June 1, 1959	20	--	--	76	33	53	9.6	258	113	88	0.2	.5	--	--	520	325	25	1.3	883	7.1
67-44-201	2,190	Mar. 30, 1962	20	0.07	0.02	1.2	.0	113	1.3	257	14	18	.4	.0	0.09	.26	298	3	98	28	477	8.0
KX-67-33-902	153	Feb. 20, 1936	--	--	--	10	5	*58		24	22	92	--	--	--	--	199	46	--	--	--	--
67-34-101	150	Mar. 9, 1936	--	--	--	8	8	*25		73	<10	32	--	--	--	--	109	51	--	--	--	--
ZL-68-54-901	983	June 22, 1955	15	--	--	48	7.3	31	6.8	172	35	37	.1	.2	--	.07	261	150	30	1.1	463	7.5
68-64-401	2,010	Nov. 22, 1955	21	.10	.01	4.2	1.4	205	3.6	461	38	37	.5	.0	.09	.30	538	16	96	22	857	7.7
Reklaw Member of the Mount Selman Formation																						
KX-67-34-501	41	Apr. 9, 1936	--	--	--	26	22	*63		--	420	30	--	--	--	--	565	154	--	--	--	--
67-34-801	56	Mar. 12, 1936	--	--	--	334	201	*437		98	1,550	650	--	--	--	--	3,230	1,660	--	--	--	--
ZL-67-41-201	68	July 16, 1955	24	--	--	14	5.0	*21		22	4.0	40	0.0	27	--	--	146	56	45	1.2	255	6.1
68-54-801	110	Oct. 28, 1954	26	16	--	438	128	*309		453	1,030	600	.8	1.5	--	--	2,760	1,620	29	3.3	3,830	7.3

See footnotes at end of table.

Table 8.--Chemical analyses of water from selected wells in the West Gulf Coastal Plain in the Guadalupe and San Antonio River Basin--Continued

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) [a]	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
Queen City Sand Member of the Mount Selman Formation																						
BU-67-13-601	56	Apr. 18, 1946	--	--	--	--	--	--		72	90	96	--	76	--	--	--	96	--	--	--	--
67-13-901	16	Apr. 26, 1946	--	--	--	--	--	--		238	35	102	--	110	--	--	--	240	--	--	--	--
KR-67-34-801	54	Jan. 15, 1963	43	--	--	58	6.8	*52		220	39	44	0.4	0.5	--	--	358	172	39	1.7	553	6.9
67-43-406	500	Apr. 28, 1962	12	0.06	--	3.5	1.4	*289		212	210	178	.2	.0	--	--	808	14	98	3.4	1,350	7.8
ZL-67-49-101	315	Oct. 22, 1954	27	.32	0.04	56	22	108	10	220	163	87	.0	1.8	0.13	0.29	583	230	49	3.1	934	7.6
67-50-201	800	Sept. 3, 1936	--	--	--	67	26	*500		268	719	280	--	--	--	--	1,720	276	--	--	--	--
68-54-902	152	Nov. 3, 1954	28	.30	--	94	41	*120		314	217	125	.7	.8	--	--	812	402	39	2.6	1,250	7.9
Sparta Sand																						
KR-67-22-201	470	Jan. 25, 1963	13	--	--	78	30	*74		222	187	72	0.2	0.0	--	--	564	318	34	1.8	899	6.9
67-51-201	744	Mar. 12, 1963	13	--	--	19	16	*3,490		1,540	1.0	4,560	--	--	--	--	8,860	114	99	142	14,200	7.5
ZL-68-63-601	347	June 2, 1936	--	--	--	--	30	*1,820		1,220	28	2,170	--	--	--	--	4,660	124	--	--	--	--
68-64-101	436	Mar. 30, 1949	15	--	--	22	34	*734		400	1,010	290	--	2.2	--	--	2,290	195	89	23	3,310	--
Cook Mountain Formation																						
KR-67-36-502	283	Mar. 30, 1962	27	17	--	188	110	388	13	168	600	730	0.0	1.5	--	1.3	2,140	922	47	5.5	3,380	6.5
67-43-807	132	Mar. 13, 1963	34	--	--	335	89	*386		266	884	640	--	.0	--	--	2,500	1,200	41	4.9	3,620	6.7
ZL-67-49-901	145	June 25, 1936	--	--	--	--	--	--		12	1,570	635	--	--	--	--	3,230	--	--	--	--	--
68-63-602	205	June 2, 1936	--	--	--	--	--	--		415	610	2,570	--	--	--	--	5,230	--	--	--	--	--
68-64-301	39	May 19, 1936	--	--	--	106	40	*188		409	264	162	--	--	--	--	961	431	--	--	--	--
Yegua Formation																						
KR-67-29-801	30	Apr. 21, 1959	70	--	--	382	182	804	31	211	1,920	900	0.3	95	--	--	4,490	1,700	50	8.5	5,850	7.0
67-37-301	430	June 4, 1959	8.8	--	--	60	18	23	2.3	231	28	38	.3	3.5	--	--	296	224	18	.7	533	7.6
PZ-67-57-501	200	July 25, 1957	38	--	--	187	36	635	25	420	1,020	420	0	3.0	--	2.2	2,570	614	68	11	3,620	7.7
78-08-302	610	Nov. 21, 1955	46	0.27	0.02	18	1.5	1,130	11	285	1,040	830	.4	2.3	0.11	1.7	3,220	51	97	69	4,920	7.7
ZL-67-57-201	140	July 14, 1955	22	.02	.20	145	40	69	17	259	169	218	.2	.2	.07	.50	808	526	22	1.3	1,400	7.7
67-57-401	400	July 18, 1955	4.2	.00	.10	40	56	417	13	257	632	270	.2	.5	.07	.78	1,560	330	72	10	2,610	8.1
78-07-602	650	July 11, 1955	36	--	--	276	27	*741		261	1,260	625	--	3.0	--	--	3,100	800	67	11	4,360	8.1

See footnotes at end of table.

Table 8.--Chemical analyses of water from selected wells in the West Gulf Coastal Plain in the Guadalupe and San Antonio River Basins--Continued

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) a/	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
Jackson Group																						
KR-67-37-803	90	Oct. 26, 1962	31	--	--	64	9.2	*112		334	87	53	0.9	0.5	--	--	522	198	55	3.5	840	7.2
67-52-401	170	Mar. 12, 1963	72	--	--	282	18	*403		300	512	620	--	.0	--	--	2,060	778	53	6.3	3,170	6.7
PZ-78-07-603	305	Nov. 29, 1955	16	--	--	145	15	*1,010		204	914	1,060	--	1.2	--	--	3,260	424	84	21	5,170	7.7
79-01-401	87	July 31, 1957	92	--	--	275	35	334	39	304	222	780	--	3.2	--	--	1,930	830	45	5.0	3,210	7.7
ZL-78-07-601	235	June 8, 1936	--	--	--	--	--	--		232	1,230	550	--	--	--	--	2,800	--	--	--	--	--
78-08-201	118	Sept. 22, 1936	--	--	--	--	--	--		67	936	930	--	--	--	--	2,830	--	--	--	--	--
78-08-401	147	Nov. 28, 1955	40	--	--	157	5.8	*679		399	677	610	--	.4	--	--	2,370	416	78	14	3,670	7.7
Catahoula Tuff																						
HX-67-46-704	140	Nov. 1, 1962	42	0.01	--	76	4.0	*35		271	26	23	0.5	0.0	--	--	358	206	27	1.1	534	6.7
67-53-202	190	Dec. 19, 1962	86	--	--	42	5.0	*492		652	12	458	.3	.2	--	--	1,420	126	89	19	2,370	7.2
KR-67-38-603	60	Jan. 17, 1963	48	--	--	92	6.0	*75		366	42	40	1.3	17	--	--	517	254	39	2.0	781	6.8
67-52-601	132	Oct. 10, 1962	77	--	--	136	7.2	*149		338	173	166	8.3	.0	--	--	874	368	47	3.4	1,320	6.7
PZ-67-59-401	430	July 13, 1956	94	--	--	125	6.2	*168		319	109	232	--	1.5	--	--	932	338	52	4.0	1,440	7.3
79-01-901	872	Nov. 22, 1955	77	.03	0.00	6.4	.0	476	18	322	101	492	1.6	.1	0.02	2.7	1,320	16	96	52	2,230	8.0
79-09-301	400	Nov. 23, 1955	61	--	.01	152	16	681	34	371	309	940	.7	6.2	.01	1.8	2,380	445	75	14	3,920	7.3
Oakville Sandstone																						
HX-67-46-603	84	Nov. 28, 1962	27	--	--	111	4.9	*67		330	32	66	0.4	55	--	--	531	297	33	1.7	855	6.5
79-03-301	180	Dec. 19, 1962	21	--	--	225	36	*147		262	67	525	.9	1.5	--	--	1,150	710	31	2.4	2,140	6.9
KR-67-31-501	64	Jan. 16, 1963	59	--	--	102	3.6	*16		262	19	22	.4	47	--	--	436	270	11	.4	577	7.1
67-46-301	230	Jan. 17, 1963	44	--	--	54	7.4	*178		334	43	165	.3	.2	--	--	656	165	70	6.0	1,120	7.1
PZ-79-03-701	156	Oct. --, 1955	35	0.15	0.00	141	34	142	8.5	270	36	388	.5	5.6	0.03	0.30	924	492	38	2.8	1,670	7.6
79-10-401	422	Oct. 26, 1955	59	.11	.00	128	14	660	35	366	277	900	.6	13	.05	1.9	2,270	378	77	15	3,690	7.7
Lagarto Clay																						
HX-67-54-806	188	Nov. 28, 1962	18	--	--	28	8.7	*191		356	52	123	0.7	0.0	--	--	580	106	80	8.1	1,020	7.0
79-12-501	164	Jan. 8, 1963	48	--	--	165	32	*146		310	64	380	.7	2.0	--	--	990	543	37	2.7	1,740	6.9
79-19-502	60	Feb. 16, 1955	76	--	--	270	64	*135		389	155	529	1.1	.8	--	--	1,420	936	24	1.9	2,430	7.6
79-21-601	557	Mar. 15, 1955	34	0.04	0.00	100	28	113	3.6	338	37	212	.8	2.2	0.04	0.25	697	364	40	2.6	1,230	7.7

See footnotes at end of table.

Table 8.--Chemical analyses of water from selected wells in the West Gulf Coastal Plain in the Guadalupe and San Antonio River Basins--Continued

Well	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) a/	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
PZ-79-11-801	292	Apr. 18, 1956	36	--	--	68	16	204	8.3	339	37	262	--	3.5	--	0.45	802	235	64	5.8	1,420	7.6
79-11-802	63	Mar. 11, 1937	--	--	--	--	--	--		293	77	810	--	--	--	--	1,620	--	--	--	--	--
Goliad Sand																						
HX-79-07-203	168	Oct. 23, 1962	36	--	--	8.3	9.5	*52		322	17	54	0.4	1.0	--	--	411	246	32	1.4	681	7.4
79-07-206	64	Jan. 15, 1963	29	--	--	127	8.7	*49		302	27	122	.3	14	--	--	526	353	23	1.1	866	7.2
79-14-102	86	Oct. 6, 1954	57	--	--	273	33	*150		372	65	498	--	84	--	--	1,340	816	29	2.3	2,380	6.9
79-15-701	55	Feb. 23, 1955	65	--	--	169	38	*204		486	211	285	.8	.2	--	--	1,210	578	43	3.7	2,160	7.7
79-22-501	178	Feb. 22, 1955	58	--	--	98	20	*84		347	27	139	--	1.0	--	--	614	326	36	2.0	1,010	7.4
Lissie Formation																						
HX-79-22-901	123	Oct. 20, 1954	44	--	--	116	26	*117		348	75	202	--	3.0	--	--	781	396	39	2.6	1,320	7.3
79-23-401	86	Feb. 17, 1955	51	0.01	0.00	92	19	205	1.3	419	87	235	0.8	2.2	0.01	0.23	900	308	59	5.1	1,510	8.2
Goliad Sand and Lissie Formation, undifferentiated																						
WH-79-31-901	946	Feb. 13, 1962	11	0.00	--	45	31	196	0.9	391	83	182	0.4	0.8	--	--	768	240	64	5.5	1,300	7.6
79-32-801	560	do	18	--	--	36	27	*234		382	82	220	.3	.0	--	--	818	201	72	7.2	1,410	7.2
Lissie Formation and Beaumont Clay, undifferentiated																						
WH-79-32-803	110	Feb. 13, 1962	--	--	--	--	--	--		306	9.4	35	--	--	--	--	--	252	--	--	590	7.8
Leona Formation and alluvium																						
BU-67-03-703	25	Jan. 24, 1946	--	--	--	--	--	--		326	46	22	--	26	--	--	--	322	--	--	--	--
67-10-801	34	Feb. 13, 1962	12	0.00	0.00	78	16	11	0.7	275	26	22	0.3	3.8	0.08	0.10	322	260	8	0.3	538	6.7
68-24-101	65	Dec. 3, 1943	--	--	--	112	10	40		302	8	52	--	96	--	--	467	320	21	1.0	--	--
68-24-401	27	do	--	--	--	--	--	--		272	20	15	--	82	--	--	--	--	--	--	--	--
HX-67-62-215	39	Jan. 3, 1963	28	--	--	184	14	*163		304	46	368	.2	68	--	--	1,020	516	41	3.1	1,800	7.0
67-62-216	30	Jan. 9, 1963	46	--	--	328	51	*439		328	188	1,070	--	12	--	--	2,300	1,030	48	5.9	3,930	6.9
KR-67-27-803	30	Feb. 5, 1963	19	--	--	93	19	*20		306	41	26	.4	28	--	--	398	310	12	.5	735	6.9
67-38-803	30	Dec. 18, 1962	41	--	--	118	5.3	*22		330	24	40	.4	15	--	--	476	316	13	.5	684	6.8
KX-67-17-702	27	Nov. 20, 1957	22	--	--	130	6.1	*38		364	21	52	--	48	--	--	495	299	19	.9	817	7.9
68-32-304	25	Mar. 26, 1962	17	.00	.00	74	39	36	1.7	398	43	24	.4	29	.04	.12	460	345	18	.8	771	7.1
67-02-501	Spring	Feb. 8, 1946	14	.03	--	114	5.9	*15		286	24	21	.6	57	--	--	392	309	6	.4	637	7.3
67-09-301	45	Jan. 19, 1954	11	.06	--	77	20	*13		299	27	18	--	9.9	--	--	330	274	9	.3	581	8.5

a/ Includes the equivalent of any carbonate (CO_3) present.
* Sodium and potassium calculated as sodium (Na).

Table 9.--Pumpage from major wells tapping the Carrizo Sand and Wilcox Group, undifferentiated, 1961

Major subdivision	Public supply		Industrial		Irrigation		Total	
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.
GU- 4	0	0	0	0	0	0	0	0
GU- 7	.8	840	0	0	0	0	.8	840
GU- 9	.4	450	0	0	0	0	.4	450
Subtotal	1.2	1,300	0	0	0	0	1.2	1,300
SA- 3	0	0	0	0	0.3	336	.3	340
SA- 4	.1	112	0	0	0	0	.1	110
SA- 5	.6	672	0	0	1.2	1,367	1.8	2,000
Subtotal	.7	780	0	0	1.5	1,700	2.2	2,500
NU- 4	0	0	0	0	7.5	8,400	7.5	8,400
NU- 6	1.6	1,792	.5	560	34.9	39,088	37.0	41,000
NU- 9	.5	560	0	0	3.1	3,472	3.6	4,000
NU-17	0	0	0	0	2.9	3,248	2.9	3,200
NU-19	.1	112	0	0	16.2	18,144	16.0	18,000
NU-20	1.0	1,120	.2	224	25.8	28,896	27.0	30,000
NU-21	.4	448	.2	224	18.4	20,608	19.0	21,000
NU-23	0	0	.1	112	2.6	2,912	2.7	3,000
NU-25	1.5	1,680	.2	224	42.9	48,048	45.0	50,000
NU-27	0	0	0	0	.1	112	.1	110
Subtotal	5.1	5,700	1.2	1,300	150	170,000	160.0	180,000
Total	7.0	7,800	1.2	1,300	150.0	170,000	160.0	180,000

Figures are approximate because some of the pumpage is estimated. Figures are shown to nearest 0.1 mgd and to the nearest acre-foot. Totals are rounded to two significant figures.

San Antonio River Basin

In 1961, about 2,500 acre-feet (2.2 mgd) was pumped from major wells in the Carrizo Sand and Wilcox Group, undifferentiated, in the San Antonio River Basin (Table 9). Of the 2,500 acre-feet, 780 acre-feet (0.7 mgd) was for public supply and 1,700 acre-feet (1.5 mgd) for irrigation. The public supplies for Floresville, Poth, and Lavernia are obtained from the Carrizo and Wilcox.

Guadalupe River Basin

In 1961, pumpage from the Carrizo and Wilcox in the Guadalupe Basin was 1,300 acre-feet (1.2 mgd), nearly all of which was for public supply. The public water supply of Luling and part of the supply of Lockhart are obtained from wells in the Wilcox, whereas the public supply of Nixon is from the Carrizo. The withdrawal of ground water for irrigation is not shown in Table 9 because only very small quantities are used in the Guadalupe River Basin.

Changes in Water Levels

Water levels or artesian pressure in the Carrizo Sand and Wilcox Group, undifferentiated, fluctuate chiefly in response to changes in storage. The effects of recharge are distributed rather uniformly in the outcrop and are transmitted downdip, fluctuations caused by recharge being less discernible at progressively greater distances from the outcrop. The greatest changes in artesian pressure result from changes in pumping rates. During or after periods of heavy rainfall, many irrigators shut down their pumps, and the resultant recovery of the water levels often is mistakenly related to recharge.

Hydrographs showing fluctuations of water levels in wells in the Carrizo Sand in the Nueces River Basin (Figure 19) show a general decline. Several of the hydrographs show the effects of heavy pumping during the period 1951-56, when precipitation was below normal. In some wells, the water levels rose sharply following the heavy precipitation in 1957, 1958, and in the latter part of 1960 and early part of 1961. The hydrographs show that during the period 1944-61, the maximum net decline, about 144 feet, occurred in well ZX-77-18-601 in Zavala County. Actually, the water level declined as much as 236 feet during the period 1944-56; the water levels rose sharply in 1956-57 and again in 1960-61.

The relatively small pumpage compared to the large potential has resulted in little change in the water levels in wells in the Carrizo Sand and Wilcox Group, undifferentiated, in the San Antonio and Guadalupe River Basins. This is clearly shown in the hydrograph of well ZL-68-55-101 in Wilson County (Figure 19). During the period 1951-61, the water level declined only 3 feet.

Availability and Potential Development

The potential development of water from the Carrizo Sand and Wilcox Group depends on the ability of the aquifer to transmit water, the quantity of water in storage, and the rate of recharge. The coefficient of transmissibility of the Carrizo Sand, determined from tests of 35 wells in the Guadalupe, San Antonio, and Nueces River Basins, averaged about 50,000 gpd per foot, ranging

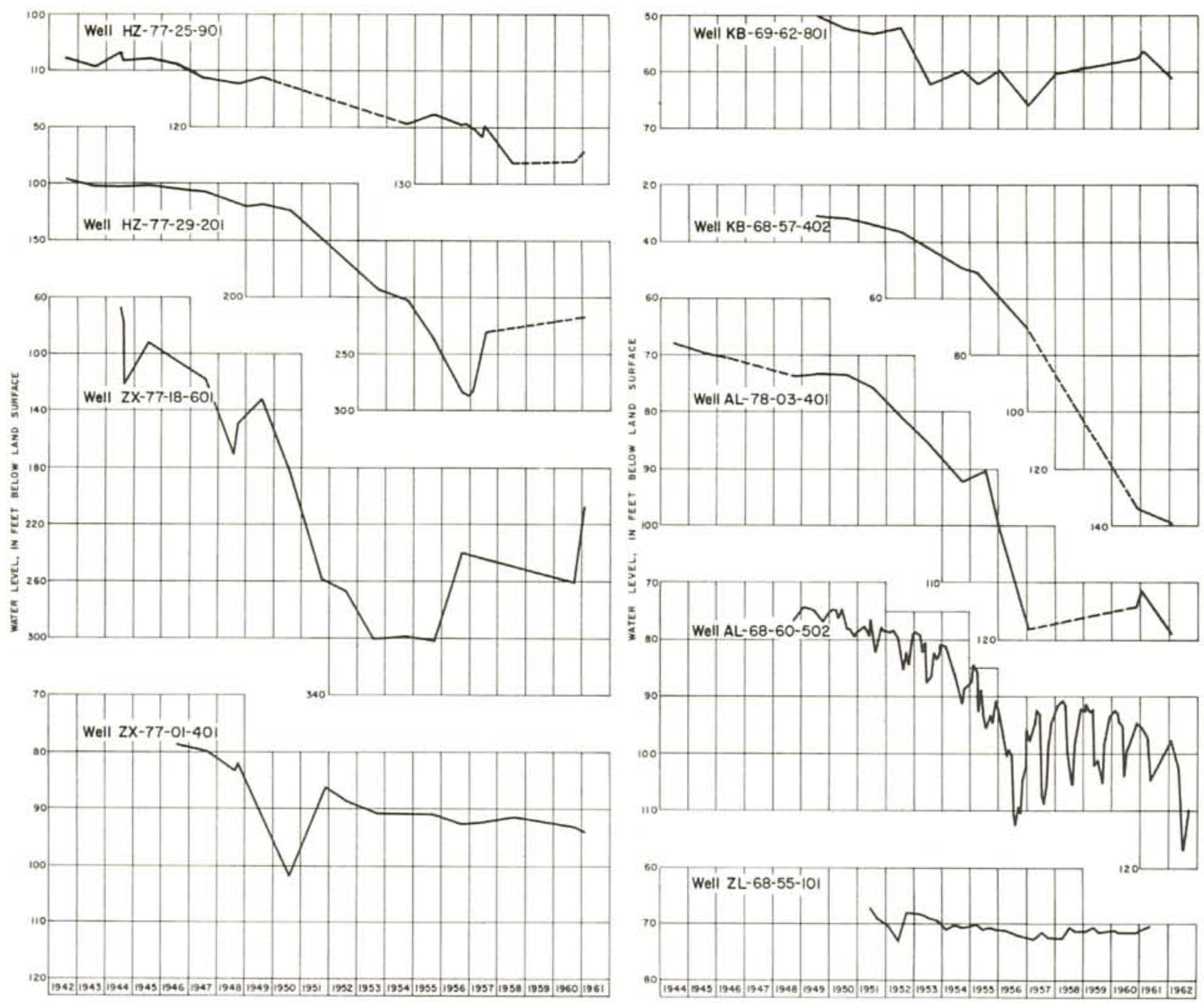

Figure 19

Hydrographs of Wells in the Carrizo Sand in Dimmit, Zavala, Frio, Atascosa, and Wilson Counties

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

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from 8,200 to as much as 175,000 gpd per foot. The coefficient of storage in 9 tests ranged from 0.0001 to 0.0008, and averaged 0.0003.

The specific capacities of wells in the Carrizo Sand and Wilcox Group, undifferentiated, ranged widely. The specific capacities of 15 wells ranged from 3.0 to 48.2, averaging 14.2 gpm per foot of drawdown.

The greatest thickness of the sands containing fresh to slightly saline water in the Carrizo Sand and Wilcox Group, undifferentaited, in the Nueces River Basin ranges from more than 1,000 feet in Atascosa County to more than 1,400 feet in Frio County (Plate 11). The approximate thickness of the sands in the Guadalupe and San Antonio River Basins is greatest in southern Gonzales County, where it is more than 1,400 feet (Plate 12).

Comparative estimates of the availability of ground water in the Carrizo Sand and Wilcox Group, undifferentiated, in the Guadalupe, San Antonio, and Nueces River Basins are given in Table 10. The estimates were computed using the following assumptions:

1. Water levels will be lowered to a maximum depth of 400 feet along a line of discharge midway between the center of the outcrop and the downdip limit of fresh to slightly saline water.

2. No water moves downward into the aquifer except in the outcrop where all recharge is assumed to occur along a line parallel to the strike of the outcrop and in the middle of the outcrop.

3. For computation of available water from storage:

a. The altitude of the water levels is the same at all points along the centerline of the outcrop; the altitude of the water level is the same at all points along the downdip limit of fresh to slightly saline water; and the altitude of the water level is the same at all points along the line of discharge.

b. The coefficient of storage in the water-table part of the aquifer is 0.10 and in the artesian part is 0.001.

c. The average width of the section is the effective width of the storage area.

4. For computation of the average transmission capacity of the aquifer (defined as the quantity of water that can be transmitted through a given width of an aquifer at a given hydraulic gradient):

a. No further decline in water level in the outcrop will occur.

b. The hydraulic gradient is the slope of a straight line from the water level in the outcrop to the level of drawdown at the line of discharge.

c. The assumed average coefficient of transmissibility of the sands in each basin is as shown in Table 10.

Table 10.--Comparative estimates of the availability of ground water in the Carrizo Sand and Wilcox Group, undifferentiated, in the Guadalupe, San Antonio, and Nueces River Basins

River basin	Estimated fresh water available from storage by lowering water level to 400 feet along line of discharge (million acre-feet)		Assumed coefficient of transmissibility	Transmission capacity at average gradient	Transmission capacity at maximum gradient	Rate of withdrawal		Time, in years, to lower water levels along a line of discharge to 400 feet below land surface			Recharge[a]	
	Per linear mile of aquifer	Total	(gpd/ft.)	(acre-ft./yr.)	(acre-ft./yr.)	(mgd)	(acre-ft./yr.)	With no recharge	With recharge equal to transmission capacity at average gradient	With recharge equal to transmission capacity at maximum gradient	At average gradient (in./yr.)	At maximum gradient (in./yr.)
Guadalupe	0.05	3.1	50,000	29,100	52,300	1.2[b]	1,300	2,384	[c]	[c]	0.83	1.44
						100	112,000	28	37	52		
						300	336,000	9.2	10	11		
San Antonio	.07	2.0	29,000	17,700	33,500	2.2[b]	2,500	769	[c]	[c]	.60	1.12
						50	56,000	36	52	93		
						100	112,000	18	21	25		
Nueces	.02	3.2	32,000	44,800	62,650	160[b]	180,000	18	24	27	.96	1.44
						300	336,000	10	11	12		
						500	560,000	6	6.2	6.4		

[a] Recharge equal to transmission capacity.
[b] Estimated 1961 rate of withdrawal.
[c] Average transmission capacity is greater than withdrawal.

d. Where recharge is considered, it is sufficient to supply the water that can be transmitted to the line of discharge at the assumed gradients.

e. The average width of the area is the effective width of the aquifer through which water is transmitted.

f. The average hydraulic gradient is the average of the present hydraulic gradient and the maximum hydraulic gradient that can be attained with a water level of 400 feet at the line of discharge.

5. For computation of time it will take to dewater to 400 feet at the line of discharge:

a. Storage is as computed.

b. Rate of discharge is as shown, assuming full recharge and assuming no recharge.

c. The average transmission capacity is the arithmetic average of the present rate based on the present hydraulic gradient and the maximum rate based on the maximum hydraulic gradient to be attained.

d. Other rates of withdrawal are as shown, assuming full recharge and assuming no recharge.

For purposes of computation, different rates of withdrawals include (1) the present rate of withdrawal and (2) rates arbitrarily chosen based on reasonable estimates of potential development. These rates of withdrawal, the amount of water in transient storage, and the average transmission capacity were used to determine the time required to dewater to 400 feet at the line of discharge. Only the amount of water in transient storage was used in computing the time required under the condition of no recharge. Results of the calculations are presented in Table 10 with the warning that the figures can be changed by a factor of several times by a small change in any one of several of the above assumptions. Limited basic data analyzed on a regional basis under assumed development conditions provide a preliminary estimate of water potentially available. Thus, these preliminary estimates, which are especially suited for comparative purposes, will need to be revised and kept current as development takes place and more data become available.

Nueces River Basin

An estimated 3,200,000 acre-feet of fresh water would be available from storage in the Carrizo Sand and Wilcox Group, undifferentiated, in the Nueces River Basin by lowering the water levels to 400 feet along a line of discharge (Table 10). The table shows that it would take about 6 years of pumping 500 mgd (about three times the 1961 rate of pumping) to lower the water levels along the line of discharge to 400 feet. After the water levels were lowered to 400 feet, the aquifer would transmit 62,650 acre-feet per year (about 60 mgd) without further lowering, assuming adequate recharge. Actually, the flow of water through the aquifer could be increased by installing wells closer to the outcrop, thereby increasing the hydraulic gradient. The amount of recharge on the outcrop necessary to replace the water moving downdip at the maximum transmission capacity (62,650 acre-feet per year) would be about 1.44 inches per year, or less than 5 percent of the annual rainfall.

San Antonio River Basin

About 2,000,000 acre-feet of fresh water would be available from storage in the Carrizo Sand and Wilcox Group, undifferentiated, in the San Antonio River Basin by lowering water levels to 400 feet along a line of discharge (Table 10). If the 1961 discharge rate (2.2 mgd or 2,500 acre-feet) were continuously maintained in wells evenly spaced along the assumed line of discharge and if recharge were adequate, the water levels would not be lowered to 400 feet. However, if the pumpage rate were increased to 50 mgd (56,000 acre-feet per year), the water levels could be lowered to 400 feet in about 36 years, assuming no recharge and that all water will be taken from storage. After the water levels are lowered to 400 feet, the aquifer will transmit 33,500 acre-feet per year (30 mgd) without additional drawdown, assuming adequate recharge. The amount of recharge on the outcrop necessary to replace the water moving downdip at the maximum transmission capacity (33,500 acre-feet per year) would be about 1.12 inches per year, or nearly 4 percent of the annual rainfall.

Guadalupe River Basin

About 3,100,000 acre-feet of fresh water would be available from storage in the Carrizo Sand and Wilcox Group, undifferentiated, in the Guadalupe River Basin by lowering the water levels to 400 feet along a line of discharge (Table 10). Based on the assumption of no recharge and that all the water will be taken from storage, the aquifer in the Guadalupe River Basin could furnish 336,000 acre-feet of water per year (300 mgd) for 9.2 years before the water levels would be lowered to 400 feet. At the end of that period, the aquifer could transmit 52,300 acre-feet per year (46 mgd) assuming 1.44 inches of recharge annually.

Problems

The decline of water levels in the most serious problem associated with the development of water from the Carrizo Sand and Wilcox Group, undifferentiated, in the Nueces River Basin. Continuing declines in some areas have resulted in reduced yields and increased pumping costs. Wider spacing of wells would result in a more uniform decline in water levels over the entire area.

The contamination of wells in the Carrizo Sand by saline water from the Bigford Member of the Mount Selman Formation has caused concern in localized areas. In the Winter Garden district, the Carrizo Sand is separated from the sands in the overlying Bigford Member by a relatively impermeable clay. Where the seal of clay is broken by an improperly constructed well, the moderately to very saline water from the Bigford may become mixed with the fresh water from the Carrizo Sand, especially during pumping when the artesian pressure in the Carrizo Sand is lower than that in the Bigford. Livingston and Lynch (1937, p. 1-20) described the corrosion of well casings by the mineralized water from the Bigford and the resulting contamination of the water in the Carrizo near and in the well.

Plans for the large-scale development of the ground-water resources in the Carrizo and Wilcox in the San Antonio and Guadalupe River Basins should include the proper well spacing to prevent excessive drawdowns. Also, the wells should be constructed to prevent the possible contamination of the fresh water in the Carrizo by the slightly saline water from the overlying Reklaw Member of the Mount Selman Formation.

Gulf Coast Aquifer

Physical Description

The Gulf Coast aquifer includes the following stratigraphic units: the Catahoula Tuff, Oakville Sandstone, Lagarto Clay, Goliad Sand, Lissie Formation, and Beaumont Clay. These stratigraphic units are interconnected hydrologically, and collectively they are classified as a primary aquifer--the Gulf Coast aquifer. The aquifer consists of sand, sandstone, silt, clay, and gravel. The aquifer crops out coastward of a line extending across southeastern McMullen, northern Live Oak, central Karnes, and southeastern Gonzales Counties (Plates 1 and 2). The Gulf Coast aquifer has a maximum thickness of about 1,800 feet in the Nueces River Basin and about 1,900 feet in the San Antonio and Guadalupe River Basins. The aquifer dips coastward, the oldest stratigraphic unit having the greatest dip (Plates 3, 4, and 5). The dip of the oldest unit, the Catahoula, is about 100 feet per mile in the Nueces Basin and about 120 feet per mile in the San Antonio and Guadalupe Basins. The dip of the Oakville is about 80 feet per mile in the Nueces Basin and about 85 feet per mile in the San Antonio and Guadalupe Basins. The dip of the Lagarto is about 30 feet per mile and the dips of the Goliad, Lissie, and Beaumont are somewhat less.

Recharge, Movement, and Discharge of Ground Water

Recharge to the Gulf Coast aquifer is derived principally from the precipitation that falls on the loose sandy soil in the outcrops and, to some extent, by the seepage from streams that cross the outcrops. The movement of ground water is southeastward in the direction of the dip. The principal discharge is by seepage upward to the surface where the water is lost by evapotranspiration and, to a lesser extent, by seepage into streams and discharge through wells.

Chemical Quality of Ground Water

The Gulf Coast aquifer yields small to large quantities of fresh to moderately saline water. The water ranges widely in chemical content; however, water suitable in quality for public supply, irrigation, and most industrial uses can be found in most places underlain by the aquifer. The maximum depth to the base of the fresh to slightly saline water in the Nueces Basin is about 1,600 feet below sea level (Plate 13), and in the San Antonio and Guadalupe Basins, it is about 1,800 feet below sea level (Plate 14).

The chemical analyses of water from 18 wells that tap the Gulf Coast aquifer in the Nueces Basin are included in Table 7. The dissolved-solids content ranged from 482 to 5,180 ppm. The hardness ranged from soft to very hard--from 55 to 1,430 ppm.

The chemical analyses of water from 29 wells that tap the Gulf Coast aquifer in the San Antonio and Guadalupe Basins are included in Table 8. The dissolved-solids content in these samples ranged from 411 to 2,380 ppm. The hardness ranged from 16 to 936 ppm.

Utilization and Present Development

The total pumpage during 1961 from major wells tapping the Gulf Coast aquifer in the report area was about 18,000 acre-feet, or an average of about 16 mgd (Table 11). Pumpage for irrigation was 8,700 acre-feet (7.8 mgd), for public supply 6,900 acre-feet (6.2 mgd), and for industrial use 2,200 acre-feet (1.9 mgd).

Nueces River Basin

The total pumpage during 1961 from the Gulf Coast aquifer in the Nueces Basin was about 9,100 acre-feet, or an average of about 8.1 mgd (Table 11). Pumpage for irrigation was 7,600 acre-feet (6.8 mgd), for public supply 1,100 acre-feet (1.0 mgd), and for industrial use 340 acre-feet (0.3 mgd). The public supplies for Mathis, Freer, and George West are obtained from the Gulf Coast aquifer. Most of the ground water used for irrigation is pumped in Nueces and San Patricio Counties.

San Antonio River Basin

The total pumpage during 1961 from the Gulf Coast aquifer in the San Antonio Basin was about 2,100 acre-feet, or an average of about 1.9 mgd (Table 11). Pumpage for public supply was 1,100 acre-feet (1.0 mgd), for irrigation 780 acre-feet (0.7 mgd), and for industrial use 220 acre-feet (0.2 mgd). The public supplies for Kenedy, Karnes City, Goliad, and Runge are obtained from the Gulf Coast aquifer.

Guadalupe River Basin

The total pumpage during 1961 from the Gulf Coast aquifer in the Guadalupe Basin was about 6,600 acre-feet, or an average of about 5.9 mgd (Table 11). Pumpage for public supply was 4,700 acre-feet (4.2 mgd), for industrial use 1,600 acre-feet (1.4 mgd), and for irrigation 340 acre-feet (0.3 mgd). The public supplies for Victoria, Cuero, and Yorktown are obtained from the Gulf Coast aquifer. The city of Victoria is the largest user of ground water in the Guadalupe Basin, using about 3,600 acre-feet in 1961.

Availability and Potential Development

The potential development of water from the Gulf Coast aquifer depends chiefly on the ability of the aquifer to transmit water, the amount of water in storage, and the rate of recharge. Comparative estimates of the availability of fresh to slightly saline water in the aquifer in the Guadalupe, San Antonio, and Nueces River Basins are given in Table 12. The estimates were computed

Table 11.--Discharge of ground water by major wells in the Gulf Coast aquifer, 1961

Major subdivision	Public supply		Industrial		Irrigation		Total	
	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.	mgd	acre-ft./yr.
GU- 8	--	--	--	--	--	10	--	--
GU- 9	--	--	--	--	--	20	--	--
GU-10	0.1	112	0	0	0.1	112	0.2	220
GU-11	4.1	4,592	1.4	1,568	.2	224	5.7	6,400
Subtotal	4.2	4,700	1.4	1,600	.3	340	5.9	6,600
SA- 5	.8	896	.2	224	.6	672	1.6	1,800
SA- 7	.2	224	0	0	.1	112	.8	340
Subtotal	1.0	1,100	.2	220	.7	780	1.9	2,100
NU-27	.2	224	.3	336	.5	560	1.0	1,100
NU-30	.8	896	0	0	6.3	7,056	7.1	8,000
Subtotal	1.0	1,100	.3	340	6.8	7,600	8.1	9,100
Total	6.2	6,900	1.9	2,200	7.8	8,700	16.0	18,000

Figures are approximate because some of the pumpage is estimated. Figures are shown to nearest 0.1 mgd and to the nearest acre-foot. Totals are rounded to two significant figures.

Table 12.--Comparative estimates of the availability of ground water in the Gulf Coast aquifer in the Guadalupe, San Antonio, and Nueces River Basins

River basin	Estimated fresh to slightly saline water in storage (million acre-feet)		Assumed coefficient of transmissibility	Transmission capacity at average gradient	Transmission capacity at maximum gradient	Rate of withdrawal		Time, in years, to lower water levels to 400 feet below land surface			Recharge[a]	
	Per linear mile of aquifer	Total	(gpd/ft.)	(acre-ft./yr.)	(acre-ft./yr.)	(mgd)	(acre-ft./yr.)	With no recharge	With recharge equal to transmission capacity at average gradient	With recharge equal to transmission capacity at maximum gradient	At average gradient (in./yr.)	At maximum gradient (in./yr.)
						5.9[b]	6,600	1,730	[c]	[c]		
Guadalupe	0.72	11.6	40,000	8,020	10,000	100	112,000	103	112	114	0.37	0.46
						200	224,000	52	56	56		
						1.9[b]	2,100	4,150	5,910	6,510		
San Antonio	.92	8.34	8,250	582	723	50	56,000	151	152	153	.05	.08
						100	112,000	74	76	76		
						8.1[b]	9,100	1,270	4,150	[c]		
Nueces	.53	11.6	26,700	6,300	10,500	100	112,000	103	110	114	.22	.36
						200	224,000	52	54	54		

a/ Recharge equal to the transmission capacity.
b/ Estimated 1961 rate of withdrawal.
c/ Average transmission capacity is greater than withdrawals.

using the same assumptions as those for the Carrizo Sand and Wilcox Group, undifferentiated, (p. 148 to 151) shown in Table 10, except that the coefficients of transmissibility were 40,000 gpd per foot for the Guadalupe Basin, 8,250 gpd per foot for the San Antonio Basin, and 26,700 gpd per foot for the Nueces Basin. The quantities of available water given in Table 12 are conservative estimates because the assumptions do not include water contributed by compaction.

Nueces River Basin

The maximum depth to the base of the fresh to slightly saline water in the Gulf Coast aquifer in the Nueces River Basin is about 1,600 feet below sea level (Plate 13). The maximum thickness of sand containing fresh to slightly saline water is about 400 feet (Plate 11). The coefficients of transmissibility, determined from pumping tests of 5 wells, ranged from 11,000 to 28,000 gpd per foot, and averaged 26,700 gpd per foot; coefficients of storage ranged from 0.00042 to 0.0012, and averaged 0.00073.

The lowering of the water levels to 400 feet below the land surface along an assumed line of discharge across the Nueces Basin would make available from storage in the Gulf Coast aquifer an estimated 11,600,000 acre-feet of fresh to slightly saline water (Table 12). If recharge is considered and the withdrawal in the Nueces Basin was increased to 100 mgd, the water levels along the assumed line of discharge would be lowered to 400 feet below the land surface in about 114 years (Table 12). This rate of withdrawal would require recharge at the rate of only 0.36 inch per year, which probably is less than the actual rate.

San Antonio River Basin

The maximum depth to the base of the fresh to slightly saline water in the Gulf Coast aquifer in the San Antonio River Basin is about 1,800 feet below sea level (Plate 14). The maximum thickness of sand containing fresh to slightly saline water is about 600 feet (Plate 12). The coefficients of transmissibility, determined from pumping tests of 10 wells, ranged from 1,400 to 17,000 gpd per foot, and averaged 8,250 gpd per foot; coefficients of storage ranged from 0.00004 to 0.00063 and averaged 0.00019.

The lowering of the water levels to 400 feet below the land surface along the assumed line of discharge across the San Antonio Basin would make available from storage in the Gulf Coast aquifer an estimated 8,340,000 acre-feet of fresh to slightly saline water (Table 12). If recharge is considered and the withdrawal in the San Antonio Basin was increased to 100 mgd, the water levels along the assumed line of discharge would be lowered to 400 feet below the land surface in about 76 years (Table 12). This rate of withdrawal would require recharge at the rate of only 0.08 inch per year, which probably is considerably less than the actual rate.

Guadalupe River Basin

The maximum depth to the base of the fresh to slightly saline water in the Gulf Coast aquifer in the Guadalupe River Basin is about 1,800 feet below sea level (Plate 14). The maximum thickness of sand containing fresh to slightly saline water is about 600 feet (Plate 12). The coefficients of transmissibility, determined from pumping tests of 9 wells, ranged from 8,300 to 83,000 gpd per foot, and averaged 40,000 gpd per foot; coefficeints of storage ranged from 0.00048 to 0.01, and averaged .0045.

The lowering of the water levels to 400 feet below the land surface along the assumed line of discharge across the Guadalupe Basin would make available from storage in the Gulf Coast aquifer an estimated 11,600,000 acre-feet of fresh to slightly saline water (Table 12). If recharge is considered and the withdrawal in the Guadalupe Basin was increased to 100 mgd, the water levels along the assumed line of discharge would be lowered to 400 feet below the land surface in about 114 years (Table 12). This rate of discharge would require recharge at the rate of 0.46 inch per year, which probably is less than the actual rate.

Problems

The contamination of the fresh to slightly saline water by salt-water invasion is a potentially serious problem in the Guadalupe, San Antonio, and Nueces River Basins. A lowering of artesian pressure by additional large-scale development enhances the possibility of salt-water contamination either by updip movement or by the movement of overlying salt water into the fresh to slightly saline zone through corroded casings or through improperly constructed wells.

In those areas where only small supplies of fresh to slightly saline water are available, it is especially important that wells be adequately spaced so as to minimize interference effects and the resultant decrease of artesian pressure.

Secondary Aquifers

Queen City Sand Member of the Mount Selman Formation

The Queen City Sand Member of the Mount Selman Formation crops out in a southwesterly-trending belt 1 to 6 miles wide across the Guadalupe and San Antonio Basins (Plate 1); in the Nueces Basin, it is mapped only in the western part of Wilson County (Plate 2). Westward from Wilson County, the Queen City is mapped as a part of the Mount Selman Formation, undifferentiated (Plate 2). The Queen City consists of medium to fine sand, clay, and shale. The thickness of the aquifer ranges from 500 to 1,000 feet. The dip of the Queen City is predominatly southeastward toward the Gulf at about 125 feet per mile.

The principal sources of recharge to the Queen City are precipitation on the outcrop and seepage from streams crossing the outcrop. In general, the water moves downward to the water table in the outcrop, thence southeastward downdip except in areas where ground-water pumping has formed cones of depression in the water table or piezometric surface.

Water is discharged from the Queen City by wells and natural means. Pumpage from major wells was 1,500 acre-feet in 1961, 780 acre-feet of which was pumped for public supply in the Nueces Basin. The rest of the pumpage was for irrigation in the San Antonio River Basin. The natural discharge of ground water from the Queen City is by seepage into other formations in the subsurface and probably by evapotranspiration in the outcrop.

The Queen City Sand Member yields small to moderate quantities of fresh to slightly saline water. Chemical analyses of water from selected wells in the Queen City are shown in Tables 7 and 8. In and near the outcrop, the water is fresh, hard to very hard, and generally is suitable for irrigation or municipal supply. Farther downdip, the water becomes progressively more saline. In McMullen County, well SU-78-28-601, depth 2,765 feet, yielded water that was soft, high in bicarbonate and sulfate, and had a SAR of 151.

Because of the small volume of water pumped from the Queen City, water levels probably have not changed significantly; however, records are not available to document this.

Insufficient data preclude an appraisal of the ground-water potential of the Queen City Sand Member in the report area. Ground water in the Queen City is developed only on a small scale, and it is probable that the withdrawals in 1961 could be increased several times, assuming that wells are properly spaced. However, large-scale development may result in excessive declines in water levels and contamination of the fresh water by saline water from the overlying or underlying formations.

Sparta Sand

The Sparta Sand consists chiefly of medium to fine sand and some clay; most of the sand is in the upper two-thirds of the formation. The Sparta Sand maintains a uniform thickness of about 110 feet where the complete section is present in the report area. In the Guadalupe and San Antonio Basins, the Sparta crops out in a belt about one mile wide across southern Wilson, northern Gonzales, and southern Bastrop Counties (Plate 1). In the Nueces Basin west of Wilson County, the Sparta Sand and the overlying Cook Mountain Formation are mapped as a unit (Plate 2). They crop out in a belt that extends across central Atascosa, southern Frio, southeastern Zavala, western LaSalle, the northeastern and southeastern corners of Dimmit, and central Webb Counties. Downdip, however, electric logs of wells indicate that the unit can be differentiated, the Sparta Sand being represented by a prominant sand body 80 to 100 feet thick. The dip of the Sparta is predominantly southeastward at about 125 feet per mile, except in the central and western parts of the Nueces Basin where the direction of dip ranges between northeast and south due to geologic structure and the dip of the beds is about 70 feet per mile.

Most of the recharge to the Sparta Sand is from precipitation on the outcrop, but some is seepage from streams that flow across the outcrop. Water moves from the outcrop southeastward and becomes confined a short distance downdip; consequently, most of the water in the Sparta is under artesian pressure. The water in the Sparta is discharged through wells, by seepage into other formations in the subsurface, and by evapotranspiration. The discharge by major wells in 1961 was about 1,500 acre-feet, of which 1,400 acre-feet was for irrigation in the Nueces Basin and only 69 acre-feet for public supply, all of which was in the Guadalupe Basin. In the San Antonio River Basin, the Sparta Sand is tapped by only a few wells, principally for domestic and livestock supplies.

The Sparta Sand yields small to moderate quantities of fresh to slightly saline water in the area of outcrop and for a short distance downdip. Where more deeply buried, the water in the Sparta increases in salinity and becomes unfit for most purposes. Chemical analyses of water from selected wells in the Sparta Sand in the Guadalupe, San Antonio, and Nueces River Basins and the Cook Mountain and Sparta Sand, undifferentiated, in the western part of the Nueces River Basin are shown in Table 7 and 8.

The ground-water supplies in the Sparta Sand have been developed only to a very small extent, and in many areas, it seems likely that additional moderate supplies could be developed from the formation, principally for irrigation. However, a large increase in the development of the available fresh to slightly saline water might result in the encroachment of the more mineralized water into the sands containing water of good quality. Additional data on the hydraulic characteristics are needed to determine more accurately the ability of the sands to transmit and yield water to wells. Also, additional chemical analyses are necessary to locate accurately the extent of the sands containing fresh to slightly saline water.

Leona Formation and Alluvium

The Leona Formation and Recent alluvium are mapped together in the report area and may be considered a single hydrologic unit or aquifer. The formations consist of clay, silt, sand, and gravel; the Leona forms alluvial terraces along the major streams, whereas the alluvium forms the flood-plain and channel deposits of the present streams. The Leona Formation has a maximum thickness of about 80 feet compared to about 30 feet for the Recent alluvium.

In general, the principal source of recharge to the aquifer is from the infiltration of precipitation on the outcrop. During periods of high streamflow, some recharge is temporarily added to the alluvium as bank storage. Southeast of Uvalde, the Leona Formation is in hydraulic connection with the underlying Edwards and associated limestones, and in this area, the Leona is recharged mainly by the upward flow of water from the limestones along faults.

The water occurs under water-table conditions, except in part of the Leona River Valley where a layer of silty clay overlies the gravel and acts as a confining layer at least during periods of high water levels. In general, water in the Leona moves toward the streams and is discharged naturally through springs and seeps; it is discharged also through wells, principally for domestic and livestock uses, and locally for irrigation.

The chemical analyses of water from selected wells in the Leona Formation and the Recent alluvium are included in Table 3, 7, and 8. The water is very hard but relatively low in dissolved solids except in DeWitt County, where water from two wells contained more than 1,000 ppm dissolved solids and more than 250 ppm chloride. The nitrate content in several wells exceeded the recommended limits for drinking-water standards and in one sample from a well in the Leona Formation in Medina County, the nitrate content was 387 ppm.

In 1961, about 2,900 acre-feet of water was pumped from the Leona Formation and Recent alluvium, of which 800 was from wells in the Guadalupe River Basin and 2,100 acre-feet in the Nueces River Basin. Most of the pumpage was for irrigation, only a small part being for public supply.

The data are insufficient to permit a complete evaluation of the potential ground-water development from the Leona Formation and Recent alluvium. For the most part, the aquifer is heavily pumped in a few areas in the Nueces River Basin, especially in Uvalde County; however, in many areas small to moderate additional supplies probably can be developed.

SUMMARY OF GROUND-WATER WITHDRAWALS IN THE GUADALUPE, SAN ANTONIO, AND NUECES RIVER BASINS

The summaries of the ground-water discharge by major wells and springs in the Guadalupe, San Antonio, and Nueces River Basins in 1961 are given in Tables 13, 14, and 15; the withdrawals have been tabulated by principal use, aquifer, and major subdivisions of the basins. Table 16 shows that the total discharge was 910,000 acre-feet in the three basins, including 20,000 acre-feet pumped for domestic and livestock purposes. The major pumpage was for irrigation, 240,000 acre-feet, although springs in the Balcones fault zone area in the Guadalupe River Basin discharged about 380,000 acre-feet and the total spring flow was 450,000 acre-feet. More than 85 percent of the water pumped for irrigation was from wells in the Nueces River Basin, most of which was from the Carrizo Sand and Wilcox Group, undifferentiated. The largest amount of ground water used by industry and public supply was from the Balcones aquifer in the San Antonio River Basin, reflecting the large withdrawals in the metropolitan San Antonio area.

Table 13.--Summary of ground-water discharge by major wells and springs in the Guadalupe River Basin, 1961, in acre-feet

Major subdivision	Well discharge						Springs		Carrizo Sand and Wilcox Group, undifferentiated	Edwards and associated limestones and Balcones aquifer	Trinity Group	Gulf Coast aquifer	Leona Formation and Recent alluvium	Sparta Sand	Total
	Public supply		Industrial		Irrigation										
	mgd	acre-ft.	mgd	acre-ft.	mgd	acre-ft.	mgd	acre-ft.							
GU- 1	1.7	1,900	--	0	0.2	210	--	--	--	--	2,100	--	--	--	2,100
2	.1	89	--	0	.1	60	--	--	--	--	150	--	--	--	150
3	--	0	--	0	--	0	--	--	--	--	--	--	--	--	0
4	3.7	4,200	0.6	670	.3	320	218	240,000	--	250,000	--	--	160	--	250,000
5	--	0	--	0	--	0	--	--	--	--	--	--	--	--	0
6	.5	520	--	0	--	30	--	--	--	220	--	--	550	--	770
7	2.7	3,000	--	0	.1	110	124	140,000	840	140,000	--	--	83	69	140,000
8	--	--	--	0	--	10	--	--	3	--	--	10	--	--	10
9	.4	450	--	0	--	20	--	--	450	--	--	20	--	--	500
10	.1	150	--	0	.1	110	--	--	--	--	--	220	--	--	220
11	4.1	4,600	1.4	1,600	.2	220	--	--	--		--	6,400	--	--	6,400
Total	13.5	15,000	2.0	2,300	1.1	1,100	340	380,000	1,300	390,000	2,200	6,600	800	69	400,000

Total pumpage for domestic and livestock uses, 4,200 acre-feet.
Totals are approximate because most figures in the table have been rounded to two significant figures and totals are further rounded to two significant figures.

Table 14.--Summary of ground-water discharge by major wells and springs in the San Antonio River Basin, 1961, in acre-feet

Major subdivision	Well discharge						Springs		Carrizo Sand and Wilcox Group, undifferentiated	Edwards and associated limestones and Balcones aquifer	Hosston and Sligo Formations and Trinity Group	Gulf Coast aquifer	Queen City Sand Member of the Mount Selman Formation	Total
	Public supply		Industrial		Irrigation									
	mgd	acre-ft.	mgd	acre-ft.	mgd	acre-ft.	mgd	acre-ft.						
SA-1	0.5	540	--	0	11.9	13,000	--	--	--	14,000	210	--	--	14,000
3	100.5	110,000	23.4	26,000	14.0	16,000	37.4	42,000	340	200,000	340	--	--	200,000
4	2.7	3,000	--	0	.5	540	--	--	110	2,800	330	--	320	3,600
5	1.5	1,700	.2	220	2.1	2,300	--	--	2,000	--	--	1,800	440	4,200
7	.2	220	--	0	.1	110	--	--	--	--	--	340	--	340
Total	105.4	120,000	23.6	26,000	28.6	32,000	37.4	42,000	2,500	220,000	880	2,100	760	230,000

Total pumpage for domestic and livestock uses, 6,500 acre-feet.
Totals are approximate because most figures in the table have been rounded to two significant figures and totals are further rounded to two significant figures.

Table 15.--Summary of ground-water discharge by major wells and springs in the Nueces River Basin, 1961, in acre-feet

Major subdivision	Well discharge						Springs		Carrizo Sand and Wilcox Group, undifferentiated	Edwards and associated limestones and Balcones aquifer	Gulf Coast aquifer	Leona Formation and Recent alluvium	Trinity Group	Queen City Sand Member of the Mount Selman Formation	Sparta Sand	Total
	Public supply		Industrial		Irrigation											
	mgd	acre-ft.	mgd	acre-ft.	mgd	acre-ft.	mgd	acre-ft.								
NU- 1	--	15	--	0	--	0	--	--	--	--	--	--	--	--	--	15
2	--	0	--	0	--	0	--	--	--	--	--	--	--	--	--	0
3	--	0	--	0	8.0	9,000	--	--	--	9,000	--	--	--	--	--	9,100
4	--	0	--	0	7.6	8,500	--	--	8,400	110	--	--	--	--	--	8,500
6	1.6	1,800	0.5	510	34.8	39,000	--	--	41,000	--	--	--	--	--	--	41,000
9	.5	560	--	0	3.7	4,200	--	--	4,000	--	--	--	--	--	770	4,800
11	--	0	--	0	--	10	--	--	--	--	--	--	--	--	10	10
12	--	0	--	0	.1	140	--	--	--	--	--	--	--	--	140	140
14	--	44	--	0	--	0	--	--	--	--	--	44	--	--	--	44
15	.4	420	--	0	4.6	5,200	--	--	--	5,400	--	110	110	--	--	5,600
17	.5	560	--	0	4.4	4,900	--	--	3,200	2,000	--	220	--	--	--	5,400
19	2.9	3,200	1.4	1,600	29.5	33,000	27.6	31,000	18,000	49,000	--	1,600	--	--	--	69,000
20	1.0	1,100	.2	220	25.8	29,000	--	--	30,000	--	--	--	--	--	--	30,000
21	.4	450	.2	220	19.6	22,000	--	--	21,000	1,300	--	--	--	--	--	22,000
23	--	43	.1	110	3.0	3,300	--	--	3,000	--	--	--	--	--	470	3,500
25	2.3	2,600	.3	320	43.6	49,000	--	--	50,000	1,200	--	--	--	780	--	52,000
27	.2	220	.3	340	.6	700	--	--	110	--	1,100	--	--	--	--	1,200
30	.8	900	--	0	6.2	7,000	--	--	--	--	8,000	--	--	--	--	8,000
Total	10.6	12,000	3.0	3,300	191.5	210,000	27.6	31,000	180,000	68,000	9,100	2,100	110	780	1,400	260,000

Total pumpage for domestic and livestock uses, 10,000 acre-feet.
Totals are approximate because most figures in the table have been rounded to two significant figures and totals are further rounded to two significant figures.

Table 16.--Summary of ground-water discharge by major wells and springs in the Guadalupe, San Antonio, and Nueces River Basins, 1961, in acre-feet

Basin	Well discharge						Springs		Primary and Secondary Aquifers							Total
	Public supply		Industrial		Irrigation				Hosston and Sligo Formations and Trinity Group	Edwards and associated limestones and Balcones aquifer	Carrizo Sand and Wilcox Group undifferentiated	Queen City Sand Member of the Mount Selman Formation	Sparta Sand	Gulf Coast aquifer	Leona Formation and Recent alluvium	
	mgd	acre-ft.	mgd	acre-ft.	mgd	acre-ft.	mgd	acre-ft.								
Guadalupe	13.5	15,000	2.0	2,300	0.9	1,200	340.0	380,000	2,200	390,000	1,300	--	69	6,600	800	400,000
San Antonio	105.4	120,000	23.6	26,000	28.6	32,000	37.4	42,000	880	220,000	2,500	760	--	2,100	--	230,000
Nueces	10.6	12,000	3.0	3,300	191.5	210,000	27.6	31,000	110	68,000	180,000	780	1,400	9,100	2,100	260,000
Total	130	150,000	29	32,000	220	240,000	410	450,000	3,200	680,000	180,000	1,500	1,500	18,000	2,900	890,000

Total pumpage for domestic and livestock uses, 20,000 acre-feet, not included in total.
Totals are approximate because most figures in the table have been rounded to two significant figures and totals are further rounded to two significant figures.

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Records of water levels and artesian pressure in observation wells in the Guadalupe River, San Antonio River, and Nueces River Basins are published in the following U. S. Geol. Survey Water-Supply Papers:

Year	Water-Supply Paper no.	Year	Water-Supply Paper no.	Year	Water-Supply Paper no.
1935	777	1942	947	1949	1159
1936	817	1943	989	1950	1168
1937	840	1944	1019	1951	1194
1938	845	1945	1026	1952	1224
1939	886	1946	1074	1953	1268
1940	909	1947	1099	1954	1324
1941	939	1948	1129	1955	1407

Table 1.--Geologic units and their water-bearing properties, Guadalupe, San Antonio, and Nueces River Basins--Continued

Era	System	Series	Group	Geologic unit	Approximate thickness (ft.)	Lithologic character	Water-bearing properties
Cenozoic	Tertiary	Eocene	Claiborne	Cook Mountain Formation and Sparta Sand, undifferentiated (Nueces River Basin)	600- 900	Gypsiferous clay, sandstone, impure limestone, and lignite. Much of the sandstone is glauconitic.	Yields small to moderate quantities of slightly to moderately saline water for domestic uses and irrigation from sands in lower part of Cook Mountain and Sparta, undifferentiated.
				Sparta Sand (San Antonio and Guadalupe River Basins)	110	Chiefly medium to fine sand, and some clay.	Yields small to moderate quantities of fresh to slightly saline water in outcrop area; water is slightly to moderately saline downdip.
				Mount Selman Formation (Nueces River Basin): Post-Bigford beds	700- 900	Chiefly dark clay, a few beds of sandstone and limestone, and thin beds of coal. Clay beds contain large quantities of gypsum.	Generally yields small quantities of slightly to moderately saline water. Yields small to moderate quantities of fresh to slightly saline water near outcrop in Atascosa and Frio Counties.
				Mount Selman Formation (Nueces River Basin): Bigford Member	400- 800	Chiefly gypsiferous sandy clay; contains many lenses of sandstone ne near the base; also contains a few thin layers of limestone and many thin beds of lignite. Plant remains are abundant.	Yields small quantities of fresh water in and near the outcrop in northern Zavala County. Elsewhere in the Winter Garden district it yields small quantities of slightly to very saline water.
				Mount Selman Formation (San Antonio and Guadalupe River Basins): Wechws Greensand Member	100- 200	Fossiliferous glauconitic shale and sand. Weathers to reddish-brown ferruginous soil.	Not known to yield water to wells.
				Mount Selman Formation (San Antonio and Guadalupe River Basins): Queen City Sand Member	500-1,000	Medium to fine sand, clay, and shale.	Generally yields small to moderate quantities of fresh to slightly saline water.
				Mount Selman Formation (San Antonio and Guadalupe River Basins): Reklaw Member	200- 400	Clay with some glauconitic sand in basal part.	Yields small quantities of fresh to slightly saline water to wells in and near outcrop.
				Carrizo Sand	200-1,000	Coarse to fine sand, sandstone, silt, shale, and clay.	A primary aquifer in the report area. Yields moderate to large quantities of fresh to slightly saline water.
			Wilcox		150-2,300	Sandy clay, sand, clay, silt, and thin beds of lignite.	Yields small to moderate quantities of fresh to very saline water.
		Paleocene	Midway	Wills Point Formation	250- 490	Clay with sandy and limy concretions.	Not known to yield water to wells in the report area.
				Kincaid Formation	30- 550	Dark marine shale, sandy shale, sandstone, and sandy limestone.	Do.
Mesozoic	Cretaceous	Gulf	Navarro	Escondido Formation	450-1,300	Shale and sandstone, in places impregnated with asphalt. Thin beds of limestone in Medina County.	Yields small quantities of fresh to slightly saline water to wells in Maverick, Kinney, and Medina Counties. Elsewhere, it is not known to yield water to wells.
				Olmos Formation	400- 920	Clay, sand, sandy clay, coal, and thin beds of sandstone.	Yields no water to wells in the report area.
				Kemp Clay and Corsicana Marl	300- 600	Marl, clay, shale, lenticular sandstone, and limestone.	Not known to yield water to wells in the report area.
				(Nueces River Basin): San Miguel Formation	300- 800	Calcareous sandstone and sandy limestone interbedded with clay.	Not known to yield water to wells in report area except in Kinney County where the sandstone beds yield small quantities of very saline water.
				(Nueces River Basin): Upson Clay	750±	Clay, marl, chalky limestone, thin lenticular beds of sandstone, and some layers of gypsum.	Small quantities of very saline water obtained from sandstone beds.
				(Nueces River Basin): Anacacho Limestone (equivalent in age to San Miguel and Upson Formations and to Taylor Marl)	240- 500	Limestone, chalk, marl, and sandy clay; some limestone asphaltic.	Yields small quantities of water for domestic and livestock uses in parts of Kinney County; elsewhere it is not known to yield fresh water.
				(San Antonio and Guadalupe Basins): Taylor Marl	230- 550	Nodular marl, locally chalky, and calcareous clay.	Supplies small quantities of water to a few shallow wells.
				Austin Chalk	135-1,030+	White to buff chalk, marl, limestone, and some pyrite.	Yields small to moderate quantities of fresh to slightly saline water to wells.
				Eagle Ford Shale	20- 300	Black shale and gray sandy limestone weathering to yellow clay and brown flagstone.	Yields small quantities of water to wells west of Bexar County.
		Comanche	Washita	Buda Limestone	30- 180	Fine-textured, brittle limestone with minute calcite veins and red and black specks.	Not known to yield water to wells in the report area.
				Grayson Shale	30- 220	Blue clay, thin beds of fossiliferous limestone, pyrite and gypsum.	Do.
				Georgetown Limestone	20- 500	Chiefly hard massive limestone with some thin beds of marl; contains chert nodules in Uvalde and Kinney Counties.	Yields large quantities of fresh water in Bexar County and westward.
			Fredericksburg	Kiamichi Formation	155- 210	Black shale, black and brown limestone, and anhydrite.	Not known to yield fresh water to wells in the report area.
				Edwards Limestone	350- 600	Hard massive limestone and dolomitic limestone; contains flint nodules. Cavernous in places.	Principal water-bearing formation in Balcones fault zone. Yields moderate to large quantities of fresh water.
				Comanche Peak Limestone	30- 70	Nodular, marly limestone.	Water-bearing properties similar to the Edwards Limestone.
				Walnut Clay	1- 20	Sandy clay, marl, and limestone.	Yields small quantities of water to a few wells in Comal County, but generally is non-productive.
			Trinity	Glen Rose Limestone: Upper member	400- ?	Shale and marl alternating with thin layers of impure limestone; also contains two thin layers of anhydrite.	Yields are generally small, and much of the water is saline.
				Glen Rose Limestone: Lower member	50- 380	Massive fossiliferous limestone basal part, thin beds of marl and limestone in upper part.	Yields small to moderate supplies of fresh water.
				Travis Peak Formation; Pearsall Formation in subsurface: Hensell Sand Member of Travis Peak Formation or Hensell Shale Member of Pearsall Formation	20- 150	Sandstone, conglomerate, shale, ferruginous clay, limestone, and dolomite.	Yields small to moderate quantities of fresh to slightly saline water.
				Travis Peak Formation; Pearsall Formation in subsurface: Cow Creek Limestone Member of Travis Peak and Pearsall Formations	50- 75	Massive, detrital limestone, sandy limestone, and dolomite.	Yields small quantities of fresh water.
				Travis Peak Formation; Pearsall Formation in subsurface: Pine Island Shale Member of Pearsall Formation	45- 75	Sandy, fossiliferous, dark-blue to gray shale containing thin interbedded layers of dolomitic limestone (in Bandera County).	Yields no water to wells.
		Coahuila (Mexico)	Nuevo Leon and Durango (Mexico)	Sligo Formation	0- 200	Limestone, in places dolomitic, sandy dolomite, shale, and sandstone.	Yields small to moderate quantities of fresh water in Bandera County.
				Hosston Formation	0- 900	Conglomerate, sandstone, shale, dolomite, red and green clay, and limestone.	Yields small to moderate quantities of fresh water in Bandera County and northwestern Bexar County.
Paleozoic		?	?	?	?	Hard black, red and green noncalcareous shale, sandstone, limestone, schist and slate.	Not known to yield water to wells in report area.
Cenozoic or Mesozoic	Tertiary or Cretaceous	?	?	Igneous rocks	?	Intrusive igneous rocks.	Not known to yield water to wells.

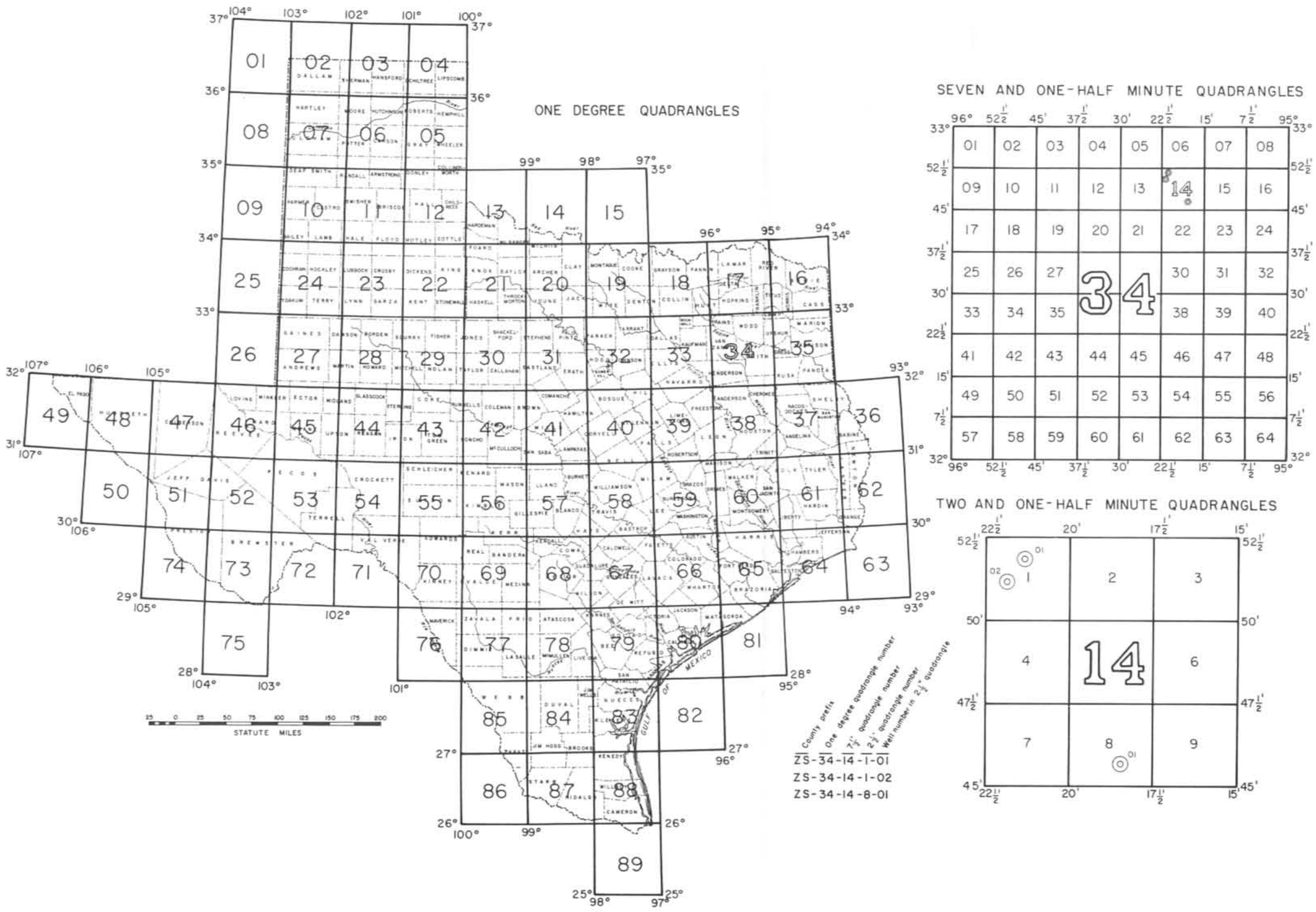

Figure 2

Map of Texas Showing the Well-Numbering System Used by the Texas Water Commission

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